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Foreword

The papers in this Record are the reports on topics of research chosen by graduate students who were selected for awards from a nationwide competition under the second (1987–88) Graduate Research Award Program on Public-Sector Aviation Issues. The papers were presented at the Annual Meeting of the Transportation Research Board (TRB) in Washington, D.C., on January 25, 1989. The authors are John B. Fisher, a Ph. D. candidate at Ohio State University; Kimberly J. Johnson, a master's degree candidate at Harvard University; Jan E. Monroe, a candidate for a master's degree at Portland State University (Oregon); and Roger L. Wayson, a Ph. D. candidate at Vanderbilt University.

The Graduate Research Award Program is sponsored by the Federal Aviation Administration and administered by TRB. It was created to stimulate thought, discussion, and research by graduate students who may become future managers and policymakers in civil aviation.

The research reported in this Record deals with managing demand to reduce airport congestion and delays, practical methods for shifting general aviation from commercial service airports to reliever airports, consensus-building techniques applied to the aircraft noise and airport access dilemma, and the use of a computerized knowledge-based expert system to maximize airport capacity in harmony with noise mitigation plans.

Managing Demand To Reduce Airport Congestion and Delays

JOHN B. FISHER

Delays caused by airport and airway congestion are spreading throughout the national air transportation system, and the FAA's estimates of passenger growth indicate that the situation will continue to deteriorate unless prompt actions are taken. The most often mentioned solution to the imbalance between the demand for airport services and the available supply is to build new airports, but airport construction is an expensive and lengthy process. Therefore, the government's Airport Capacity Enhancement Plan and an Industry Task Force have recommended several system enhancements to boost capacity. However, the recommended enhancements will not provide enough capacity to accommodate the forecast growth in traffic. Consequently, it appears that airport congestion and delays will continue unless efforts are undertaken to manage demand. To that end, peak/off-peak landing fees are suggested, combined with passenger surcharges to moderate the demand for services during peak periods at severely congested airports.

The Federal Aviation Administration (FAA) estimates that over the next 12 yr, passenger enplanements in this country will grow about 4.5 percent annually (*1*, p. 46), and that the number of air carrier operations will increase about 2.3 percent annually through 1999 (*1*, p. 5). However, Federal Aviation Administrator Allan McArtor has stated that there already are "more aircraft in the system than the country's runways can handle" (*2*). Consequently, delays have become frequent and persistent occurrences. In June 1987, the Air Transport Association (ATA) estimated that U.S. airlines were incurring total delays averaging 2,000 hr per day, which is equivalent to grounding an airline with 250 jets (*3*). The overcrowding has become so severe that future demand at most major airports will be satisfied only at the cost of even greater delays (*4*, pp. 2–19).

Forecasts of demand at Boston's Logan Airport indicate that, in the absence of supply enhancements, the average delay during instrument meteorological conditions could rise from 60 min/passenger in 1988 to 100 min/passenger by 1990 and to almost 3 hr/passenger by the turn of the century (*5*, p. 15). Moreover, the congestion-delay problem, which has been concentrated at a relatively small number of airports, is expected to spread throughout the system. Based on FAA estimates, all but seven large hubs and almost half of all large and medium hubs will be suffering from severe airside congestion by the turn of the century (*6*, p. 2).

Because of the severity of the problem, airport congestion and delays have received a great deal of consideration, and this paper presents yet another perspective. The first part of the paper focuses on the factors that have contributed to the worsening of congestion and delays, the second briefly reviews the potential for and limits to enhancing system capacity, and the third discusses techniques for bringing demand in line with the available supply. In the final section of the paper, a combination of economic techniques for managing demand is recommended as a remedy to airport and airway congestion and delays.

THE SPREAD OF CONGESTION AND DELAYS

The search for remedies logically begins with an identification of the forces behind the problem of airport congestion and delays. Over the past 5 yr, increasing numbers of passengers and airplanes have been funneled into fewer and fewer airports. Between 1983 and 1987, annual passenger enplanements rose 40 percent to 447 million, and the number of scheduled aircraft departures increased by 31 percent to 6.5 million, but the number of airports receiving scheduled commercial air service declined 2.5 percent, from 854 to 834 (*7*, *8*). The decline in the number of airports receiving scheduled service has contributed to congestion and delays, but the problem is much more complex than is implied by these figures.

Congestion and delays occur whenever airport demand exceeds the system's capacity. However, the relationship between the demand for and the supply of airport capacity can change drastically in a very short period of time because of weather changes, equipment outages, or air traffic control procedures. Table 1 shows the peak scheduled demand and maximum hourly capacity under instrument flight rules (IFR) and visual flight rules (VFR) conditions at 18 primary commercial airports. At 14 of the 18 airports, the peak level of scheduled demand equals or exceeds 75 percent of maximum capacity under instrument meteorological conditions. At seven of the airports, the peak level of scheduled demand actually exceeds maximum capacity under IFR conditions. Experience has shown that an airport becomes congested and delays start accumulating whenever demand exceeds 75 to 80 percent of the available supply (*9*, p. 8) and that the length of the average delay grows at an increasing rate as the ratio of demand to supply approaches 100 percent (see Figure 1). Therefore, the

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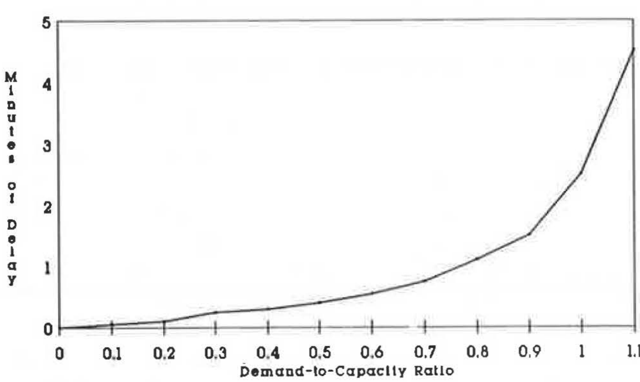
TABLE 1 MAXIMUM HOURLY CAPACITY AND PEAK NUMBER OF SCHEDULED AIRLINE OPERATIONS PER HOUR AT SELECTED AIRPORTS

	Maximum Hourly Capacity			
Airport	IFR Conditions	VFR Conditions	Peak Number of Scheduled Airline Operations	Ratio (%)
Boston Logan	100	110	89	89
Cleveland	51	72	36	71
Washington National	65	85	51	79
Denver Stapleton	66	140	108	164
Detroit Metro	120	120	98	82
Newark	102	111	78	77
Houston International	92	116	53	58
New York Kennedy	68	90	85	125
Los Angeles International	124	131	137	110
New York La Guardia	66	78	68	103
Miami	110	128	95	86
Minneapolis/St. Paul	80	104	84	105
Chicago O'Hare	212	212	153	72
Philadelphia	76	110	82	108
Pittsburgh	110	120	91	83
San Francisco	65	85	51	79
St. Louis	73	90	95	130
Tampa	105	120	35	33

NOTE: Maximum hourly capacity is total number of operations/hr based on a 50-50 arrival and departure mix, 1984 data.
IFR conditions: instrument flight rules apply.
VFR conditions: visual flight rules apply.
Peak number of scheduled airline operations/hr based on November 1987 weekday service, as published in the *Official Airline Guide*.
Ratio is peak number of scheduled airline operations divided by maximum hourly capacity in IFR conditions.
Source: FAA.



SOURCE: *Airport Capacity and Delays.* Advisory Circular AC150/5060-5, FAA, U.S. Department of Transportation, Sept. 23, 1983.

FIGURE 1 Nonlinear relationship between average delay per aircraft and demand-to-capacity ratio.

solution to the congestion-delay problem is to minimize the ratio of demand to capacity, but there is much controversy over which part of the ratio should receive the higher priority.

Many economists have focused on the need to reduce demand because congestion and delays affect both long-haul passengers, who have few substitutes for air travel, and short-haul passengers, who have many (*10*, p. 92). This conflict between the travel needs and options of short-haul versus long-haul travelers is nowhere more apparent than at Boston's Logan Airport. According to the August 1, 1988 *Official Airline Guide*, there were 11 daily scheduled arrivals into Logan from airports within the Boston metropolitan statistical area. In addition, there were a total of 44 scheduled daily arrivals from four resort areas within the state of Massachusetts, and 16 scheduled daily arrivals from one out-of-state city just 55 mi away. These 71 flights represent only about 13 percent of Logan's scheduled daily arrivals, but they contribute to congestion and delays by competing with long-distance flights for limited airport access. Some experts have argued that existing runway capacity would be better used if some of the demand from short-haul users could be reduced.

Other observers blame the frequent imbalances between airport supply and demand on the fact that no new airports have been built in the past 15 years. Cries to build more airports make good headlines, but they ignore the complexities of new-airport development. For example, aviation demand is generally concentrated around large urban areas. The 20 largest metropolitan statistical areas in the United States account for approximately 60 percent of the domestic-origin and domestic-destination passenger traffic, even though the 20 most populous cities represent only 40 percent of the total U.S. population (*11*). If new airports are to be built near the major metropolitan areas that generate passenger demand, the challenge will be to find large sections of affordable and environmentally acceptable land.

Even when suitable sites can be identified, mustering support for new-airport development has proved to be difficult. Air carriers have been among the most outspoken advocates of airport construction, yet some airlines are opposing proposals for new airports in Chicago and Denver. The city of Denver has had to seek help from a federal court to enlist United and Continental airlines as backers of a proposed airport (*12*), and *Airline Business* has reported that United is opposing efforts to build a new airport in Chicago (*13*).

Not only have some airlines been slow to support new-

TABLE 2 SCHEDULED DAILY DEPARTURES AT SELECTED HUB AIRPORTS (*15*)

		Number of Scheduled Daily Departures		
Airport[a]	Carriers[b]	January 1983	January 1988	Percent Increase
STL	TW and OZ	250	312	25
ATL	DL and EA	546	724	33
DEN	CO, FL and UA	314	453	44
LAX[c]	AL, DL, UA, and AA	237	380	60
DFW	AA, DL and WA	331	537	62
SFO	UA, PS and AL	122	239	96
ORD	UA and AA	331	658	99

NOTE:
[a]Airport identifier codes: STL = St. Louis, ATL = Atlanta, DEN = Denver, LAX = Los Angeles International, DFW = Dallas/Ft. Worth, SFO = San Francisco, and ORD = Chicago O'Hare.
[b]Carrier identifier codes: TW = TWA, OZ = Ozark, DL = Delta, EA = Eastern, CO = Continental, FL = Frontier, UA = United, AL = USAir, AA = American, WA = Western Airlines, and PS = Pacific Southwest.
[c]1983 data include scheduled departures of airlines later acquired by major carrier.

TABLE 3 TOTAL OPERATIONS AT SELECTED AIRPORTS

	Total Takeoffs and Landings		Percent of Operations at All Tower Airports	
Airport	Fiscal 1978	Fiscal 1987	Fiscal 1978	Fiscal 1987
ORD	754,986	796,609	1.12	1.31
ATL	543,951	801,833	0.81	1.31
LAX	528,540	655,189	0.79	1.07
DEN	468,575	521,608	0.70	0.86
DFW	398,644	609,300	0.59	1.00
Totals	2,694,696	3,384,539	4.01	5.55

NOTE: Airport Identifier Codes: ORD = Chicago O'Hare, ATL = Atlanta, LAX = Los Angeles International, DEN = Denver Stapleton, and DFW = Dallas/Ft. Worth.
Source: FAA.

airport development, but some deregulated carriers have adopted operating practices that actually contribute to congestion and delays. Eleven times per day in the spring of 1986 American Airlines scheduled 30 flights into its Dallas hub within a 15-min period (*14*). The tight scheduling of connecting complexes at airline hubs makes for efficient use of equipment and minimizes passengers' scheduled travel time, but it also fosters congestion whenever delays in one connecting bank spill into the next complex, thereby creating a chain reaction that can have a long-lasting impact.

The airlines continue to add flights into and out of their hub airports because each additional spoke results in a geometric increase in the number of potential passengers. In 1983, there were only 11 cities where a single carrier had more than 100 daily departures. By February 1988, there were more than 24 cities with a single carrier offering at least 100 daily departures (*15*). The extent to which some airlines have increased their scheduled daily departures at their hub airports is shown in Table 2. The flights have been added at airports that have been classified as severely constrained, and there have not been increases in airport capacity comparable to the increases in the number of scheduled departures by the hub carriers.

The growth of hub-and-spoke route networks has resulted in a significant concentration of airline operations at a relatively small number of commercial airports. Table 3 shows that in fiscal 1978 the combined number of operations at Chicago O'Hare, Atlanta, Los Angeles International, Denver Stapleton, and Dallas/Ft. Worth accounted for 4.0 percent of the total operations at all tower-controlled airports. In fiscal 1987, the number of operations at the same five airports, which are major airline hubs, had increased by 25.6 percent and accounted for 5.6 percent of total operations at tower-controlled airports.

Growth in the number of hub carrier operations adds to congestion and typically increases the carrier's market share, both of which impose costs on society. According to a report released by the Congressional Budget Office, "There is ample statistical evidence that, other things being equal, passengers in more concentrated markets pay higher fares, and that the greater a carrier's share of total traffic at an airport the higher the fare it is able to charge" (*16*, p. 34). Market concentration also raises the possibility that the hub airline can exert undue influence on airport authorities. Senator John C. Danforth (R-Mo.) has said that "Trans World Airlines dominate[s] enplanements [at St. Louis] . . . and ha[s] a strong voice in determining whether the airport should expand" (*17*).

The post-deregulation business practices of the major airlines have contributed to congestion and delays. On the other hand, some of the major airlines have realigned their schedules in attempts to reduce congestion and delays. For instance, in July 1987 American Airlines claimed it had rescheduled 1,537 of its 1,600 daily departures. Moreover, one airline executive confided that he felt the airlines had gone just about as far as they could to reduce congestion and delays (personal communication). Nevertheless, the number of scheduled operations at many congested airports still exceeds capacity limits under certain conditions, and the FAA's forecasts indicate that even more passengers and airplanes will be demanding access to the overcrowded system.

TECHNIQUES FOR BUILDING SUPPLY TO MEET DEMAND

All potential remedies to the congestion and delay problem seek to equate the supply of airway and airport services with their demand. To that end, the FAA's Airport Capacity Enhancement Plan has identified three approaches to expanding system capacity: airport improvements, airspace procedure improvements, and aircraft improvements (*4*, p. xii).

Airport improvements are appealing long-term solutions to the problem of congestion and delays because of the nonlinear relationship between the length of delays and the demand-to-capacity ratio. It was stated earlier that as airport demand approaches capacity, the length of the average delay grows at an increasing rate. Conversely, according to the plan, "each one percent increase in capacity lowers the costs of delay by [about] five percent" (*4*, pp. 4–11), and the Industry Task Force on Airport Capacity Improvement and Delay Reduction noted that "the construction of new airports and runways is still the best way to increase airport capacity" (*18*). However, the five new airports and 32 new runways called for in the report will cost an estimated $34 billion, will take years to construct, and must overcome many political and environmental hindrances. Therefore, until new airports and runways can be added, other capacity enhancements are needed, and the Airport Capacity Office has funded the development of airspace procedure and aircraft improvements.

The proposed operational improvements to increase system capacity are relatively inexpensive and fairly easy to implement. On the other hand, operational improvements to system capacity are frequently site specific, and until the numbers and experience levels of air traffic controllers are restored to pre-strike levels, operational techniques such as "simultaneous operations on converging runways," "reduced spacing," and "simultaneous operations on intersecting wet runways" must be meticulously tested and selectively implemented. In addition, the Industry Task Force estimated that all such procedures combined will increase system capacity by a total of about 20 percent (*6*, Attachment 16), and the benefits of the added capacity probably will be short-lived.

Domestic enplanements are forecast to grow about 4.5 percent annually through the remainder of this century (*19*), and according to the Industry Task Force, the implementation of operational improvements will not significantly relieve severe congestion at a number of hard-core problem airports, which will continue to inconvenience up to 50 percent of the traveling public and impose large delay costs (*6*, Attachment 6). Therefore, it appears that if congestion and delays are to be reduced, user demand must be moderated.

TECHNIQUES FOR BRINGING DEMAND IN LINE WITH CAPACITY

Some industry observers have commented that demand management techniques are admissions that the air traffic control system has failed to handle the demand placed upon it. It is true that an air traffic control system that handled a then-record 240 million scheduled enplanements and 4.9 million scheduled departures in 1978 is probably feeling the strains of 447 million scheduled enplanements and 6.6 million departures 10 yr later (*7*). It also is true that some demand management techniques are arbitrarily imposed caps limiting access to severely overcrowded airports, but other types of market-based demand management techniques may provide long-term remedies that are consistent with existing government policy, efficient, nondiscriminatory, and cost-effective.

Demand management techniques do not attempt to expand airport capacity, but they can postpone the need for expansion by promoting more intensive and more economically efficient use of the existing capacity (*9*, p. 1). Techniques for managing demand are generally classified in two groups, administrative techniques and economic techniques, both of which attempt to equate demand with supply by limiting the number of operations that will be permitted access to the airport. The techniques are distinguished by their approaches to allocating access to scarce airport and airway services.

Administrative Techniques for Managing Demand

Administrative techniques for managing demand traditionally have involved the imposition of slot quotas. Determining an airport's hourly slot quota (defined as the number of scheduled takeoffs and landings that the airport will handle during any given hour) is the sole prerogative of the federal government and is based on the capacity of the airport. Fluctuations in supply and demand make it difficult to ascertain a desirable quota level, as evidenced by the FAA's recent decision to reduce the hourly capacity limits at Chicago O'Hare (*20*). It is even more challenging to allocate the slots equitably among the many competing users.

To promote equity at airports where slot quotas have been instituted, the government traditionally has relied on the administrative technique of designating a portion of an airport's slot quota for each of the different categories of users, such as incumbent carriers, new entrants, and general aviation. The allocation of the slots to each user within a category is then determined by another set of administrative techniques. For instance, the government has granted antitrust immunity for airline scheduling committees to negotiate among themselves the allocation of slots set aside for incumbent carriers, and the government frequently relies on a first-come-first-served reservations system to allocate the slots set aside for general aviation users.

Administrative techniques ensure that the number of scheduled operations does not exceed a predetermined level, creating an artificial equilibrium that can be used, in the short term, to alleviate congestion and delays. The Massachusetts Port Authority (Massport) has estimated that "if the number of peak period operations at Logan were reduced 20 percent, the duration of the average delay would decrease by 80 percent, thereby reducing delay by 50 minutes for each of 7,000 passengers" (*5*, p. 20).

Administrative techniques limit overcrowding, but they have several serious shortcomings. First, they are short-term solutions that ignore the reality of inadequate supply. The imposition of quotas masks changes in the actual market demand for access to a slot-controlled airport, and the lack of information on true market demand makes planning for future capacity enhancements more difficult.

Second, airport congestion and delay is a local phenomenon, albeit with nationwide consequences, and the federal government has taken the position that the initiative for airport policies equating capacity and demand is vested in the communities that own and operate the airports (*4*, p. xiii). However, the federal government specifically prohibits local airport authorities from independently imposing a ceiling on the number of operations for the purpose of reducing or eliminating congestion, and local authorities are prohibited from distributing landing and takeoff rights (*21*).

Third, the quotas are arbitrarily determined. There is no mechanism, other than administrative trial and error, to ensure an efficient allocation of the slot quota. Even the most ingenious allocation of slots cannot anticipate all of the changes in demand that will occur among the different categories of users and among the users within each category.

Fourth, administrative techniques tend to preserve the status quo of airline market shares. Quotas can limit the potential for new entry and can result in anticompetitive agreements among the incumbents. The lack of competition in some administratively constrained markets has resulted in average fares 20 percent higher than fares in other markets (*22*), which is a compelling reason to regularly consider "a change in slot allocations" (*17*). However, reallocating slots is a perplexing task. Efforts to reduce congestion at one airport cannot be considered in isolation but must be analyzed with due consideration of the impact on operations at other airports with which the airport is linked (*9*, p. 31).

Finally, the allocation of slots is complicated by the increasing use of feeder agreements at hub airports. In many smaller communities, a commuter carrier operating under a feed agreement with a major carrier has replaced the major carrier's jet service with high-frequency service in smaller equipment. This arrangement has benefited the commuter carrier, the communities receiving higher-frequency service, and the major carrier who relies on the commuter's feed traffic. However, it has also resulted in a surge in the number of operations at many hub airports. Nationwide in 1987, commuter carriers accounted for approximately 6.5 percent of total domestic enplanements but 55.7 percent of all air carrier operations (*23*).

It has been argued that because it takes so many commuter flights to equal the passenger load of one large commercial jet airplane, the number of passengers that an airport could serve would be increased if slots were reallocated from the commuter carriers to the major carriers. Moreover, reallocating slots from commuter carriers to major carriers probably would reduce the amount of feed traffic for the hub airline, which in turn would conceivably weaken the hub airline's competitive position relative to the other airlines at that airport. However, reallocating commuter slots also means a reduction in service to small communities and an economic hardship for the commuter carrier whose livelihood is tied to the amount of feed traffic carried to the major's hub.

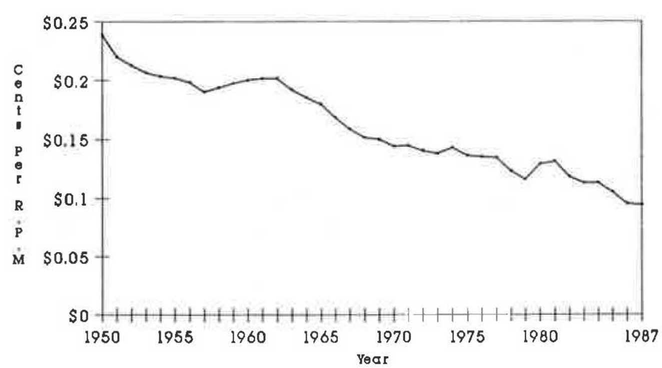
It is worth noting that small-community air service is not a purely economic issue. It has been, and continues to be, primarily a social issue. Congress closely monitors air service to small communities and has been forthcoming with money to ensure its continuance. Reducing commuter slot allocations, which reduces small-community access to the national aviation system, seems to run counter to the desires of Congress.

Administrative techniques will always be vulnerable to attack on the equity issue because the allocations are arbitrary. There is no opportunity for the haves and the have-nots to express the relative value of slots. In addition, administrative techniques are stopgap measures that neither increase supply nor reduce the true underlying demand. They are not long-term solutions to airport congestion and delays. A better, long-term approach is to adopt pricing mechanisms that automatically bring demand in line with the available capacity.

Economic Techniques for Managing Demand

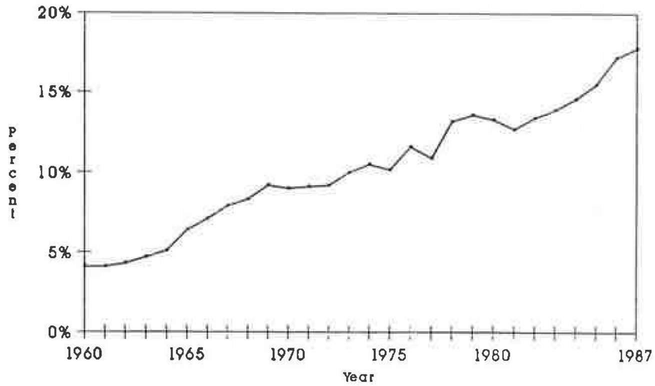
The boom in air travel and the resultant congestion and delays can be attributed, in part, to two divergent trends in the pricing of air transportation services. Airline fares, expressed in constant dollars, have been on a downward trend for the past 30 yr (see Figure 2). The steady decline in fares has fostered rapid growth in air travel, which in turn has stimulated demand for airport and airway services.

A Gallup survey conducted for the ATA indicates that the percentage of the adult population that had flown during a given year increased from 25 percent in 1977 to 30 percent in 1987 (*24*). Figure 3 shows that as fares have declined, the percentage of intercity passenger miles traveled by air has increased from 10.9 percent in 1977 to 17.8 percent in 1987. The rate at which intercity travelers are abandoning their automobiles and other modes of travel is increasing (*25*).



SOURCE: Air Transport Association

FIGURE 2 Revenue per revenue passenger mile for scheduled U.S. operations stated in constant dollars.



SOURCE: Air Transport Association

FIGURE 3 Percent of all intercity passenger miles traveled by air.

Between 1981 and 1987, air's share of intercity passenger miles rose 6 percentage points. In recognition of this trend, American Airlines Chairman Robert Crandall has noted that although flying has become commonplace and affordable, "unfortunately the air traffic control system simply was not built to handle the resulting volumes of traffic" (*26*).

Air travel has become affordable because the monetary price of airport and airway access has not been adjusted upward in proportion to the increased demand for services. In economic parlance, higher traffic volumes resulting from lower real airline fares have shifted the demand curve for airport services upward along a fixed supply curve. In an open market, each upward shift in the demand curve would result in a new and higher equilibrium price, equating airport supply with demand. However, increases in the monetary price for airport access apparently have lagged behind the upward shifts in the true equilibrium prices, resulting in artificially low prices and demand in excess of supply.

At least one observer has noted that the major reason for the disparity between the industry's needs and the industry's ability to provide for them is the failure of present arrangements to perform the major function of a properly working price system (*10*, p. 95). Some airports are attempting to reduce congestion and delays with pricing mechanisms. The techniques used and their long-term prospects for easing congestion and delay are analyzed in the following sections.

Slot Sales

Slot sales/auctions is a hybrid approach to allocation that combines features of both administrative and economic techniques for allocating airport demand. An airport's quota of slots is administratively determined, but instead of relying on administrative techniques to allocate the quota among user groups, the slots are exchanged in an open-market system whereby any person can buy, sell, lease, or trade the airport operating rights granted by the government, with prices to be determined by the forces of supply and demand (*27*). Michael E. Levine Associates has noted that a "properly designed and operated [auction process] is clearly superior to the present system for allocating scarce airport capacity" and has a number of advantages, including user determination of each slot's worth and long-term local control. The local airport authority would be able to maintain some measure of control by buying, selling, and trading slots for its own account; and the open-market exchange of slots would provide planners with information on the level of demand for airport services and revenues for airport expansion (*28*). Despite the advantages of slot sales over administrative techniques of allocation, there are problems with slot sales that limit their appeal.

Arbitrary administrative decisions have to be made on a variety of complex economic issues, including the number of slots to allocate per time period per day; the length of time each operating right is valid; the takeoff, landing, and taxiway rights associated with each slot; and the process for distributing the initial allocation of slots. In addition, a decision has to be made on the use-or-lose requirements for each slot, the procedures for recalling an underused slot, and the use of proceeds that accrue to the airport authority as a result of its slot market activities. It was stated earlier that administrative techniques lack a mechanism that ensures an efficient allocation of slots. Similarly, there is no assurance that the number and nature of the slots made available for sale are the most desirable or the most effective.

A second shortcoming of slot sales is that access to the airport is controlled by a potential user's ability to identify persons holding an operating right at the desired time and by the buyer's ability to then offer a price that induces the seller to part with the operating right. There is concern that the allocated operating rights, which are valuable assets, might be hoarded by financially strong buyers, thereby blocking airport access to potential users. A dominant carrier would be tempted to accumulate a large proportion of the available operating rights and redistribute them according to its own needs and those of its feeder carriers. Carriers who might otherwise offer competing service may have trouble garnering sufficient slots, particularly if the service involves more than one slot-controlled airport. In general, "the difficulties in using slot [sales] to ration capacity grow exponentially as the number of slot-restricted airports increases" (*16*, p. 67). The problems arising from an arbitrary determination of the number of slots to offer for sale and the potential for abuse in the slot market suggest that slot sales are not the most efficient or effective technique for allocating scarce airport resources.

Peak/Off-Peak Pricing

An economic technique that has received considerable attention by economists and that some airports have instituted is peak/off-peak pricing. The appeal of peak-hour pricing is its simplicity. A surcharge is imposed on peak-hour operations to induce some users to go elsewhere during the peak period or to use the airport at a less congested time.

Peak/off-peak pricing is not inconsistent with the government's free-market philosophy of deregulation. Moreover, peak/off-peak pricing can satisfy each of the following requirements for an efficient and effective remedy to congestion and delay:

- It does not compromise safety;
- It is not inherently discriminatory against any user group;

- It is not incompatible with other approaches for reducing congestion and delays;
- It does not conflict with other airport objectives, such as noise control;
- It does not favor any political constituency;
- It is fiscally sound;
- It is effective as both a short-term and a long-term approach; and
- It is well-grounded in theory and backed by actual experience.

Nevertheless, actual adoption of peak/off-peak pricing has been limited.

Much of the economic literature on peak-period pricing theory does not recognize the unique operational considerations of the aviation industry. For instance, some airports have unique congestion and delay problems that cannot be addressed by pricing. New York's Kennedy Airport suffers from peak congestion between 3:00 p.m. and 10:00 p.m., which is a function of the rigid curfews at foreign airports in different time zones. Pricing techniques will not have much effect on congestion and delays arising solely from the operational constraints associated with foreign flights.

Furthermore, in cases where peak-hour surcharges have been imposed, the airlines have demonstrated low cross-elasticities of demand between peak and off-peak periods (*29*). The airlines' unresponsiveness is not surprising because the peak-hour surcharges have been relatively small compared with the total costs of operating a flight. Landing fees usually account for less than 5 percent of an airline's total operating expenses, and changes in other costs can either offset or dilute the effect of higher landing fees. The optimum fare schedule needed to shift commercial airline operations away from peak periods to off-peak periods is not known (*30*) and is difficult to calculate.

Most applications of peak-hour pricing have been designed to encourage certain types of users to relinquish airport access in favor of other types of users. In such cases, the peak-hour surcharge is set high enough to discourage flights by the targeted user groups but not so high as to impose a significant financial burden on high-value users (typically defined as flights with large payloads). However, economic theory suggests that unless the peak-hour surcharge reflects the true value of airport access during the peak period, long-term airport demand will not be reduced. Users who place a relatively low value on access to the airport will go elsewhere or use the airport at other times to avoid the surcharge. However, if the surcharge is below the true market value of airport access during the peak period, users who place a higher value on airport access will continue to increase their demand during peak periods, and the problem of congestion and delays will not have been alleviated.

Peak-hour surcharges that are not equal to the true market value of airport access are discriminatory because there is no rationale for the price chosen other than to exclude a particular user group. At equilibrium, the true market value of airport access equals the marginal cost of providing that access. The marginal cost of airport access is the sum of the incremental cost of each operation plus a provision for the social costs each operation imposes on others (*31*). The latter set of costs includes the cost of noise pollution suffered by airport neighbors and delay costs incurred by others waiting to use the airport at the same time. Of course, it is extremely difficult to identify the incremental cost of each airfield operation or to impute a dollar figure of the intangible costs arising from each user's access. Fortunately, the theoretical value of marginal cost pricing is not compromised by an iterative series of administrative "best-guesses" to find the optimal price.

Peak/off-peak pricing based on marginal costs allows a local airport authority to establish an equitable price for airport access that all potential users can choose to accept or not at any time during the day. Unlike slot sales, there is no separate operating right that must be acquired, and a potential user does not have to find a seller with a slot at the desired time. The airport is a willing seller to all potential users at the equilibrium price.

Those who object to the theory behind peak-hour pricing often do so on the grounds that the price for airport access should only reflect the tangible costs of providing the service. This attitude presumably stems from the long-standing practice of granting open and equal access to all potential users on a first-come-first-served basis. Unfortunately, whenever demand is rising and capacity is fixed, allocation is inevitable if the price, including social costs, is not allowed to rise in response to higher demand.

Direct Passenger Surcharges

Demand for airport access ultimately is derived from a traveler's decision to use air transportation to reach a desired destination. Obviously, there would be no demand for airport and airway services from the airlines if potential travelers chose not to fly. Yet nearly all of the literature on reducing airport congestion and delays focuses on methods of altering demand by the airlines.

Economic techniques, such as peak/off-peak pricing, indirectly attempt to alter a passenger's travel behavior by imposing costs on the airline. The airline then is supposed to pass the costs on to the passenger, thereby causing the desired change in travel behavior. However, the airline decides to what extent it will pass along to the passenger the price of access to the airport at peak periods. There is no direct link between the airport authority that is trying to control congestion and the passenger who is the true source of that congestion. Consequently, an airport authority has to rely on the airline to communicate to the passenger in the form of higher fares the cost of congestion. The possibility that the airline may choose not to pass along all of those costs indicates the inherent inefficiency of indirect methods of controlling travel behavior.

Moreover, airside congestion is just one facet of the congestion and delay problem. Landside and terminal congestion are quite severe at some airports. Of 33 airports surveyed by the Industry Task Force in 1982, 36 percent cited runway capacity problems, 39 percent cited taxiway capacity problems, 48 percent cited terminal capacity problems, 58 percent cited airport gate problems, and 58 percent cited terminal curbside problems (*6*, Table 1). Shortages of terminal capacity and airport gate and terminal curbside problems are caused by too many people seeking access to the air transportation system, not too many airplanes seeking such access.

The airlines have done a commendable job of making air travel commonplace and affordable. However, as American Airlines' Crandall has noted, at the present time the national airspace system cannot accommodate all of the passengers who want to take advantage of the services being offered by the airlines. Therefore, until the system's capacity can be expanded, congestion and delay could be reduced by controlling the level of underlying demand from potential travelers.

Controlling the demand for airport services could be achieved with passenger surcharges that encourage travel by alternative modes, provide incentives to travel by air at off-peak times, and promote the choice of flights connecting at less congested airports. For example, all tickets for travel during peak periods would be subject to surcharges regardless of the routings. Passengers would have a clear choice, pay a surcharge to travel at peak periods or avoid the surcharge by scheduling trips during off-peak periods. Furthermore, any itinerary that included flights connecting at congested airports would incur additional surcharges for each connection. Again, passengers would have a clear choice; flights that involve a connection at a congested airport would be subject to a connecting surcharge. The connecting surcharge would apply only to flights involving a connection at a congested airport, and would be in addition to any peak-period surcharge that might apply. Travelers living in a city with a congested airport would not be subject to the connecting surcharge unless their travel plans involved connections at other congested airports.

Of course, not all travelers will have access to flights that do not involve a connection at a congested airport. For example, travelers from small communities whose only air service is provided by a commuter airline tied to a major carrier's hub operation could be exempted from the connecting surcharge at the hub airport. Travelers in larger markets who currently do not have a choice of flights that would allow them to avoid the connecting surcharge might see the situation change after imposition of the surcharge. Theoretically, airlines would have an incentive to begin offering nonstop flights or flights connecting at uncongested airports, because neither type of flight would be subject to the connecting surcharge. Other things being equal, airlines offering flights exempt from the connecting surcharge would have a competitive advantage over airlines whose flights would be subject to connecting surcharges.

The proposed passenger surcharges would be levied on the true source of air service demand, which could affect the demand for airport services by reducing the overall level of air travel demand, shift demand from peak to off-peak periods, and offer connecting passengers an incentive to travel through less congested hub airports. There are other advantages to passenger surcharges: they can be quickly adjusted in response to long-term or short-term changes in capacity and demand, they do not compromise safety, and they are compatible with other techniques for reducing congestion and delay. The surcharges could be adjusted to reflect differences in congestion at various hub airports and by time of day. A connecting surcharge may also provide an incentive for the hub airlines to shift some of their connecting flights to less congested airports, such as Omaha, Columbus, Indianapolis, and Birmingham.

The degree to which passenger surcharges would achieve the desired results is a function of two factors. First, potential passengers must be informed of the existence and nature of the surcharges. Second, methods must be developed so that passengers pay the surcharge when purchasing their tickets or confirming their reservations (*32*). Fortunately, the availability of computerized reservation systems and established procedures for collecting the government's 8 percent tax on airline tickets provide many of the necessary apparatuses by which the passenger surcharges could be implemented. Moreover, the growing importance of travel agents for preparing itineraries and distributing tickets would facilitate the dissemination of information about the surcharges. In particular, the surcharges could be programmed into the airlines' computerized reservation systems so that the surcharges would be displayed on a travel agent's computer terminal whenever a potential passenger inquired about travel alternatives.

Passengers who have grown accustomed to traveling on attractive discount fares may resent the imposition of user surcharges, but there is a compelling economic argument for the surcharge. Under the present allocation system, passengers randomly "pay" for the imbalance between supply and demand by being subjected to delays of indeterminate frequency and duration. A monetary surcharge theoretically would reflect the cost that the user is imposing on the overcrowded system. Travelers who value the speed and convenience of undelayed air travel would be offered the opportunity to express monetarily the worth of less congested travel. Of course, the peak-period surcharge could be avoided by the choice of travel during less congested off-peak periods, and the connecting surcharge could be avoided by the choice of flights that connect at less congested airports. Moreover, passengers would benefit with the introduction by airlines of competing service that would not be subject to the additional surcharge, such as nonstop service or flights connecting at uncongested airports.

The airlines that have lowered fares to attract customers are bound to object to the imposition of a passenger surcharge that raises the cost of air travel. Indeed, a stated intention of the passenger surcharge is to reduce passenger demand for air travel because the airlines' low fares have attracted more passengers than the system, whose capacity is temporarily fixed, can handle. Furthermore, some carriers have invested millions of dollars to develop their hub operations at what are now congested airports. However, the proposed surcharges are designed to offer lucrative incentives for passengers to choose competing flights that do not involve a connection at those congested hub airports.

Not only will the surcharge affect demand for some airlines' services, but the major airlines will be asked to bear a large portion of the costs of implementing the surcharges. For example, their computerized reservation systems will have to be programmed to calculate and display the proposed surcharges, and the airlines will be responsible for collecting the surcharges. Clearly, the airlines have legitimate reasons to oppose the surcharges.

On the other hand, there are undesirable social costs (i.e., higher fares and undue influence over airport authorities) associated with the preeminent market positions of some airlines at their major hubs. Therefore, it is reasonable to question who will benefit if major hub airports are enlarged. At a time when many commercial airports are underused, is there any justification for enlarging congested hub airports just to handle the peak demands from airlines that continue to expand their hub operations? A passenger surcharge, designed to reduce the total amount of air travel and to divert some of the remaining traffic through less congested airports at off-peak times, might lessen the need to expand the major hub airports.

Some industry analysts believe economic incentives will not be effective because airline schedules are based on the needs of business travelers, whose travel behavior is relatively insensitive to changes in price. However, price-sensitive discretionary travelers will alter their travel patterns if confronted with out-of-pocket surcharges, and airline loads will be affected by the loss of those discretionary travelers. Inasmuch as the industry depends on attracting a profitable mix of passengers, the displacement of some discretionary travelers would force the airlines to reschedule some of their flights. Based on the nonlinear relationship between the length of average delays and the demand-to-capacity ratio, any rescheduling that results in a decrease in the number of airline operations during peak periods at congested airports would produce a proportionately greater reduction in delays. Properly implemented passenger surcharges could yield desirable reductions in congestion and delays.

Overcoming opposition from travelers and the airlines will be a major hurdle blocking the adoption of passenger surcharges. Nonetheless, many of the same arguments used to support airline deregulation now apply to the market for airport and airway services. Namely, the aviation system is becoming inefficient and inequitable because of congestion and delays. Passenger surcharges could ease some of those problems by reducing the amount of travel at peak periods and diverting some of the remaining demand to less congested airports.

SUMMARY AND CONCLUSIONS

The growing severity of airside, landside, and terminal congestion threatens to clog the aviation network, but political, environmental, operational, and financial considerations limit the number of feasible remedies. Building new airports and expanding existing facilities would provide much-needed additions to capacity, but new-airport development is hampered by high costs, opposition from hubbing airlines, and scarcity of acceptable sites near major metropolitan areas. Various operational enhancements will boost system capacity in the short term but will not increase supply enough to provide lasting relief in the face of rapidly growing demand.

Efforts to reduce congestion and delays by establishing slot quotas are also short-term approaches to the long-term problem. Equitably and efficiently allocating operating rights by means of administrative techniques is difficult if not impossible, and administrative techniques will not resolve the underlying issue of excess demand and insufficient supply. Economic techniques for managing demand do attempt to bring demand in line with existing capacity, and a combination of peak/off-peak landing fees and passenger surcharges might significantly reduce congestion and delays at some airports.

An equitable airport pricing policy would set landing fees equal to marginal costs. Users who demanded access during peak periods would be allowed to do so if they were willing to pay a premium for that privilege. Other users who did not value peak-period access as highly would have the choice of going elsewhere or waiting until a lower off-peak price was in effect. Managing passenger demand also should be part of any plan to reduce congestion and delays. Passenger surcharges could be used to motivate short-haul passengers to consider alternative means of transportation, as an incentive for connecting passengers to use less congested hub airports, and as an inducement for all passengers to travel at less congested times. Moreover, the connecting surcharge would provide an incentive for carriers to introduce competing nonstop service or flights that connect at less congested airports.

Although either technique alone would reduce congestion and delays, it is worth noting how well passenger surcharges and peak/off-peak landing fees complement each other. In the case of peak/off-peak pricing, airside access is allocated according to a user's willingness to pay a peak-period premium. Users who cannot justify the premium will not demand access during peak periods, which allows access by greater numbers of users who place a higher value on airside access. However, in order to recover the higher cost of airside access during peak periods, the airlines might use bigger airplanes carrying larger numbers of passengers, which would increase congestion in other parts of the airport.

On the other hand, passenger surcharges would reduce the number of travelers using the entire airport, which in turn would reduce the airlines' demand for airside access. Consequently, there would be an increase in the number of available takeoff and landing slots that might be taken by users who place a relatively low value on airfield access. An influx of low-value users would increase airfield congestion, which would delay the remaining commercial users. Therefore, in order to obtain efficient use of all airport resources, it appears that a combination of passenger surcharges and peak/off-peak landing fees is desirable.

Many critics argue that economic techniques merely postpone the inevitable need for expansion. They are right. If the national transportation system is to grow, it must have new and better facilities. In the meantime, the combination of peak/off-peak landing fees to control airside access and passenger surcharges to manage travel demand could produce a more equitable and efficient allocation of scarce airport capacity than now exists.

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Practical Methods for Shifting General Aviation Traffic from Commercial Service Airports to Reliever Airports

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This report is intended to provide assistance to local governments managing the nation's busiest airports in the development of policies to respond to actual or imminent congestion. It reviews the causes of congestion at commercial-service airports. Legal principles limiting regulation by the airport owner and governing the setting of fees are reviewed. Regulatory and economic methods that local airport officials could use to shift general aviation (GA) traffic to other airports are reviewed and discussed. Three examples of commercial-service airports with a range of congestion problems (Portland International, Seattle-Tacoma International, and Boston Logan International) are analyzed and possible approaches to shifting GA traffic at each are theorized. Conclusions are then drawn as to actions that these and other commercial-service airport operators could use to shift GA traffic and to set appropriate fee levels.

THE PROBLEM

The nation's busiest airports are getting even busier. Between 1987 and 1999 total aircraft operations at towered airports are expected to increase by 33.5 percent, an annual growth rate of 2.4 percent (*1*). This increase in air traffic has been caused by rapid increases in the commercial-passenger, commuter, and air cargo segments of aviation. The increased air traffic has created overcrowding and delay both on the ground and in the air. The overcrowding is concentrated at hub airport locations, and 17 major air carrier airports were considered severely congested in 1985. The situation is expected to get worse; 41 more commercial-service airports are expected to become congested by the year 2000 (*2*).

The increase in passenger traffic is thought to have been the result of the decreasing relative cost of ticket prices. That the average actual cost has declined can be seen by examining the real yield [dividing the airline revenue per revenue passenger mile (R/RPM) by the consumer price index]. In 1977 the airline average yield was $0.0437 per revenue passenger mile. By 1987 the R/RPM yield had declined to $0.0330, a decline of 24.5 percent (*3*). The Airline Deregulation Act of 1978, changes in the aircraft fleet (caused by the introduction of more efficient new aircraft), and a healthy economy are commonly thought to have been the primary reasons for the airline ticket price decline (although on some routes with little competition or low traffic volumes ticket costs are higher than before deregulation). The era of lower prices may be at an end, however, because many airlines have merged or gone out of business and a number of the remaining airlines have indicated that price increases will occur in early 1989. Nonetheless, the 1988–1999 FAA forecast indicates that commercial air passenger traffic will continue to rise and that domestic revenue passenger miles will increase from 333 billion in 1988 to 566 billion in 1999 (*1*).

The hubbing concept and a desire for greater flight frequency have caused the airlines to use smaller aircraft, flying more often. This has increased the number of commercial operations at many primary commercial airports. In addition, the major airlines have also been developing feeder and commuter airline systems that have dramatically increased the number of commuter airline operations at many commercial-service airports (a 62 percent increase at Portland International Airport between 1986 and 1987, for example). These increased operations are forcing large commercial-service airports to adopt new policies to shift smaller aircraft elsewhere in order to make more efficient use of existing capacity. The purpose of these policies is to accommodate the increased passenger and air cargo demands and to generate more income. Capacity is usually measured in operations per hour. The airport operator, the FAA, and the airlines are all interested in increasing the number of operations per hour without compromising safety. From the air traffic controllers' standpoint, however, working at maximum capacity is undesirable. (Note the October 1988 reduction in maximum operations at O'Hare Airport in Chicago, for example.)

POSSIBLE SOLUTIONS

A variety of solutions have been suggested for the problem of overcrowding (or inadequate capacity) at congested airports. In economic terms these can be divided into three categories, those that (a) increase the supply (capacity), (b) reduce the demand, or (c) spread the demand more evenly over time, reducing peak demand.

In concrete terms the airport operator can adopt policies to limit or shift demand or increase capacity, or both. The FAA can attempt to increase capacity through improved equipment and procedures. The airlines can more realistically schedule flights, thus spreading flights over a wider range of

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hours. Ideally, the total traffic would be evenly distributed throughout the day to minimize peaking problems. Unfortunately, humans generally do not like to fly in the middle of the night.

Capacity improvements for the system can also be created through the construction of new airports, the addition of more runways to existing airports, and technological solutions. Technological solutions include sophisticated equipment that allows the addition of new independent arrival streams for aircraft, decreases in separation standards, improved air traffic routing of aircraft (such as the East Coast Plan), and improved operations in adverse weather.

The problem with the solutions aimed at increasing capacity has been succinctly summarized as follows: "The ultimate conclusion is inescapable: technology, new runways and new airports are all necessary to address the airport capacity issue; but if the demand grows in its historical manner and new construction/technology continue at their current pace, solutions will not be sufficient to address the capacity/delay issues" (*4*). The time it takes to implement technological solutions or to construct new facilities and the projected rapid growth of aviation traffic are all factors pointing to the need for alternative solutions.

There are other problems as well with technological solutions and new construction. The transport pilot's perception is that the skies are less safe today (*5, 6*). Pressure has been placed on the FAA to develop mechanisms to increase the number of operations per hour within given parts of the airspace, yet most of the technical solutions to capacity involve decreasing separations between aircraft, thus logically providing less of a safety margin between aircraft. Even though such new safety margins may be acceptable (for example, a 1-in-10-million accident risk), the reality is that there will be less margin for error, both on the part of the pilot and on the part of the air traffic controller.

One problem with new construction is the enormous financial cost (i.e., the competition for scarce public resources). A proposed new Denver airport, for example, is estimated to cost up to $3 billion when fully developed. Because of this cost, the airlines now operating at Denver are questioning the benefits of a new airport and are reluctant to financially support such an expensive project (*7*). (Other factors, such as concerns about increased room for competition and the rate of future growth of aviation, may also enter into this reluctance.) There is no doubt that new runways at most airports could accommodate growth in that area, and in some locations, such as Las Vegas McCarran International, Boise Air Terminal, and Cincinnati Lunken, such development can proceed without significant environmental problems. Notwithstanding these desirable circumstances, airports such as Los Angeles International, San Francisco International, Washington National, Seattle-Tacoma International, and Boston Logan International all face severe public opposition to expansion.

The environmental and political problems encountered in trying to expand a major airport in an urban area are well known. Noise problems, automobile congestion, and impacts on the environment (such as fills in rivers and estuaries) all contribute to vast political opposition, leading one to conclude that many major urban airports are unlikely to be able to expand in the foreseeable future.

THE NEED FOR REGULATION

As all users (GA, major air carriers, airfreight companies, military aviation, and commuter airlines) of the nation's primary commercial-service airports compete for increasingly limited capacity and technical improvements and new construction fail to keep pace, then administrative solutions become necessary. The only question is by whom and to what end. Kendall K. Hoyt, the Washington editor of *Airport Services Management*, says, "Unless capacity increases, 'first come first served' must give way to 'greatest good for the greatest number' " (*8*). The problem then becomes one of how to define the greatest good for the greatest number and how to achieve it. Although there can be instances in which the value of the cargo or the passengers may make a small airplane important to society (the organ being supplied for transplant or the government official arranging for the release of hostages), in general our democratic society views the value of one individual's time as being no more important than that of another. Therefore, the aircraft carrying the most passengers is considered to be more important, generally, than the aircraft carrying fewer passengers.

Administrative means can reduce aircraft operations during peak periods by shifting these operations to other times or reliever airports (airports that are nearby and act to relieve the pressure from the primary commercial-service airport). Several of these administrative options for decreasing or shifting demand have been described in *Airport System Development* (*9*) as follows:

> There are two basic approaches to managing demand, both with the same objective: to ease congestion by diverting some traffic to times and places where it can be managed more promptly and efficiently. This can [theoretically] be done through administrative means [although political and legal roadblocks may prevent actual implementation]; the airport authority or another governmental body may allocate airport access by setting quotas on passenger enplanements or on the number and type of aircraft operations that will be accommodated during a specific period [in theory, but only the FAA, under present law, may actually do so]. The alternative approach is economic—to structure the pricing system so that market forces allocate scarce airport facilities among competing users. Thus demand management does not add capacity; it promotes more effective or economically efficient use of existing resources (p. 109).

SHIFTING DEMAND

Although GA did not cause the present congestion problems, it is considered a good candidate to shift from primary commercial-service airports because GA aircraft

- Carry fewer passengers;
- Can usually operate at much smaller airports than can larger commercial aircraft;
- Are generally slower, lighter, and require greater separation from heavier commercial aircraft because of wake vortex; and
- Can take up to 10 min to take off and clear the airport and terminal area airspace.

Two or three commercial aircraft, accommodating hundreds of passengers, can take off within the same period of time as a single GA aircraft carrying a handful of people. Thus the opportunity cost to the airport system is the delay GA operations cause and is the reason for seeking to shift such aircraft away from congested commercial airports during peak operational periods. The remainder of this paper focuses on local regulatory efforts to accomplish such a shift.

FEDERAL POLICY ON REGULATION

The federal policy on regulation is mixed. Congress has stated that "artificial restrictions on airport capacity are not in the public interest and should not be imposed to alleviate air traffic delays unless other reasonably available and less burdensome alternatives have first been attempted" (*10*). Although such sentiments are commendable, they do not alter the reality of congested airport facilities. In some cases, the FAA has been forced to impose capacity regulation [14 (CFR) 93.121-93.133] at some of the nation's busiest airports (D.C. National, Kennedy, O'Hare, and La Guardia) where capacity has been reached.

Slot assignment and prioritization are not available to the airport operator as regulatory or economic measures because they are preempted by federal law [49 USC § 1305 (a)(1)]. In part, this law states that no public airport owner "shall enact or enforce any law, rule, regulation, standard, or other provision . . . relating to rates, routes, or services of any air carrier." The assignment of slots is a regulation of the times during which air carriers can land and therefore is a power reserved to the FAA. Notwithstanding the present law, there are other reasons why slot assignment, and slot auctions in particular, are undesirable. These include antitrust implications, the limiting of entry by new airlines that have fewer financial resources, and the two-part question of who the right actually belongs to and who should receive the revenues once they are collected.

ALLOWED REGULATION

Airport managers can, however, indirectly regulate demand through economic methods. The proprietary right to set rates for airport usage has been established by Congress [49 USC § 1305 (b)] and upheld by the courts [*Evansville-Vanderburgh A.A. Dist.* v. *Delta Airlines Inc.*, 92 S.Ct. 1349 (1972)], although Congress has since passed the Anti-Head Tax Act prohibiting outright state and local taxes on passengers. In fact, there is an obligation for airports receiving federal funds to charge reasonable fees for the use of the airport in order to provide revenue to maintain the facility (49 USC § 1701). Fees and charges for airport usage, in addition to the primary purpose of providing revenues to the airport, have the effect of regulating demand. As will be seen, however, the imposition of such fees has been restricted by both Congress and the courts.

Other economic and regulatory disincentives in addition to usage fees are available. Regulatory disincentives include limiting facilities, services, and areas available for GA. Economic disincentives can include increasing landing fees, tie-down fees, lease fees, fuel flowage fees, and peak-hour surcharges.

REGULATORY DISINCENTIVES

Although airport operators are required to provide *equal access* to all aviation users, they are not required to provide *equal facilities or services*. Thus, a service policy could be adopted merely to provide minimal services to GA.

Airport operators have the option of adopting policies limiting FBO (fixed base operator) services. The Airport Master Plan can be used to limit the area designated as available for GA use. The request-for-proposal process for FBO selection, in addition to its traditional purpose of specifying the minimum level of services that is acceptable, can also be used to limit those services allowed. Typical GA FBO services that are magnets for attracting GA traffic can be limited or prohibited at primary commercial airports and encouraged and supported at reliever airports. These include:

- T-hangers
- aircraft tie-downs
- aircraft maintenance service and facilities
- aircraft refurbishing and rebuilding
- aircraft sales
- aircraft painting
- avionics repair

LIMITS TO LOCAL REGULATION

Airport owners are prohibited from preventing GA from landing or taking off during the most congested periods. Federal law (49 USC § 2210) requires that public-use airports upon which federal funds have been expended must make the airport available "for public use on fair and reasonable terms without unjust discrimination." Numerous court cases have concluded that the airport operator may not impose limits by class of use.

The FAA preemption of authority to regulate the use of publicly funded airports is based on federal supremacy in the regulation of interstate commerce. Although such federal limitation on the regulatory powers of other levels of government is appropriate for airspace use, it is not necessarily appropriate for limiting entry into congested aviation facilities. In any event, the federal government is currently the only level of government that can restrict entry into the nation's busiest airports based on pure regulation (i.e., slot assignments and establishment of limits on hourly airport operations).

ECONOMIC DISINCENTIVES

The Logan Airport battle in Boston over fees has highlighted the use of economic disincentives. Alfred Kahn, former Civil Aeronautics Board (CAB) chairman, has said that access to major airports "should only be available to those who are willing to pay a premium price for what is a valuable commodity" (*11*). Airport operators are now beginning to act on this philosophy.

The Port Authority of New York and New Jersey implemented a peak-period surcharge of $100 for GA in 1986 and claims that this has resulted in 30 percent of GA flights moving

TABLE 1 RATES AND CHARGES (AS OF JULY 1, 1988)

	Portland	Sea-Tac	Logan
Landing Fees/1,000 lbs.	$0.95[a]	$1.05[b]	$0.50[c]
Minimum	None	$25.00	$91.78

[a]Portland International Airport fees are adjusted every 6 months and have averaged $0.92 since 1981.
[b]Seattle-Tacoma fees are adjusted quarterly and the $1.05 is for the July–Sept. 1988 quarter.
[c]Logan's fees from July 1, 1988.

to nonpeak hours (*12*). Chicago's Midway Airport was considering raising GA landing fees to $100 in 1987 (*13*). Logan Airport in Boston, Massachusetts, prevailed in a U.S. District Court ruling in June 1988 allowing it to go ahead with a fee increase raising its minimum fees for GA to $91.78 plus $0.50/1,000 lb landed weight (Table 1) (*14*). Other major airports, including Los Angeles International, Denver Stapleton, and Chicago's Midway and O'Hare airports, are "hinting at" following suit (*15*).

These major airports are apparently choosing to escalate their minimum fees for GA rather than waiting for (and perhaps in some cases wanting) other types of capacity expansion. Because federal policy prohibits airport owners from regulating or excluding certain classes of users, they do not have any other options that are within their control.

ARE FEES FAIR TO GENERAL AVIATION?

Although GA users of the airport system pay a fuel tax into the Aviation Trust Fund, GA generally is considered to be subsidized by other users of the National Airway System (ultimately commercial-airline passengers). A study by the FAA estimated that in 1988 air carrier taxes would account for 96 percent of all federal tax revenues on aviation and would reimburse 95.5 percent of FAA National Airport and Airway System costs (*16*). On the other hand, GA was projected to reimburse only 7 percent of the costs it imposes on the system. For GA piston aircraft the situation is even worse, with approximately 3 percent of costs being recovered (based on 1985 data). Naturally, GA interests debate the proper allocation of these fees and claim that it pays its fair share of federal costs. The arguments that GA has raised in its defense sound similar to eating in the most expensive restaurant in town and then claiming that one should only have to pay McDonald's prices.

The Office of Technology Assessment (OTA) has stated that "general aviation landing fees vary greatly from airport to airport, ranging from charges equal to those paid by the commercial airlines to none at all. Most landing fees are assessed on the basis of certified weight" (*9*). The practice of basing landing fees on aircraft weight tends to promote use of commercial airports by GA. Because most GA aircraft are relatively light (less than 10,000 lb), they pay very low landing fees at most commercial airports—typically $10 or less. According to the OTA report, "Residual-cost airports and compensatory airports alike have landing fees for general aviation that are so small as to be negligible, either as a source of revenue to the airport or as a deterrent to use of congested facilities" (*9*).

DEVELOPMENT OF FEES

The setting of fees for commercial-service airports can go a long way to relieve congestion. Such fees, however, must be rationally constructed and fair to all users. In *Hendrick* v. *Maryland*, 35 S.Ct. 142 (1915), the U.S. Supreme Court ruled that

> where a state *at its own expense* furnishes special facilities for the use of those engaged in commerce, interstate as well as domestic, it may exact compensation therefor. The amount of the charges and the method of collection are primarily for determination by the state itself; and so long as they are reasonable and fixed according to some uniform, fair, and practical standard, they constitute no burden on interstate commerce (emphasis added).

RESTRICTIONS ON USING FEDERAL FUNDS IN THE RATE BASE

It can certainly be argued that FAA grants for specific construction projects are not furnished at the airport's expense. In fact, the Airport and Airway Safety and Capacity Expansion Act of 1987 prohibits the use of certain FAA-funded improvements in the calculation of costs for the airport in setting rates. Section 511 (9) of the act states that

> the airport operator or owner will maintain a fee and rental structure for the facilities which will make the airport as self-sustaining as possible under the circumstances existing at that particular airport, taking into account such factors as the volume of traffic and economy of collection, except that no part of the Federal share of an airport development or airport planning project for which a grant is made under this title or under the Federal Airport Act or the Airport and Airway Development Act of 1970 shall be included in the rate base in establishing fees, rates, and charges for users of that airport.

The charging of depreciation of major assets is not appropriate if those improvements were funded through federal dollars or from local taxes, especially where no reserve fund is set up to accumulate those revenues. Unless the airport anticipates having to rebuild completely those assets from its user revenues, it should not charge the public twice (once through taxes and once through revenues), especially when it is anticipated that the federal government or the local taxpayer will pay for the replacement of the improvements when needed. It would behoove all airport users to ensure that they are not being charged for depreciation of tax-funded improvements. In terms of accounting procedure it is much more logical and consistent with public budgeting policy to depreciate the book value of the tax-funded assets than to charge the depreciation against the income.

FEES MUST BE REASONABLE

Court rulings have placed limits on airport operators' rights to raise fees: "In 1981, the Indianapolis Airport Authorities brought suit against six airlines for refusing to pay new landing fee rates. The court eventually decided in favor of the airlines, ruling that the rate increase was *unreasonable* [emphasis added]. In 1976, a court in North Carolina ruled that the Raleigh-

Durham Airport could only raise its landing fees to 22.3¢ per 1,000 lb instead of the proposed 33¢ to 35¢ per 1,000 lb" (*8*). In a U.S. District Court ruling, Logan's right to impose such fees has been upheld, although the reasonableness of such fees was subject to close scrutiny.

U.S. District Court Judge D. J. Mazzone in his June 29, 1988, ruling on summary judgment for the Massachusetts Port Authority's (Massport's) adopted new fee structure states that

> [u]nder governing law only *reasonable* fees can be charged to those involved in interstate commerce, under the Commerce Clause. The Anti-Head Tax Act prohibits a fee unless the charge is a *reasonable* rental, landing fee or other assessment. [49 USC] Section 2210 requires that Logan be available under *reasonable* terms, and the Equal Protection Clause requires that the action taken by Massport have a rational relation to that state end (emphasis added) (*17*).

These rulings suggest that airport operators need to develop findings supporting the need for fee adjustments. [Massport's fees were approved because the judge was persuaded that they were reasonable, although this ruling is being appealed. See *New England Legal Foundation* v. *Massachusetts Port Authority*, C.A. 88-873-MA (D.Mass. June 29, 1988), appeal filed, No. 88-1971 (1st Cir. Sept. 28, 1988).]

FEE ALTERNATIVES

Capacity problems refer primarily to human beings and the amount of delay they, each and collectively, must endure. Ideally, any cost allocation scheme should reflect more accurately the costs and benefits accruing to each person using the aviation system, not the benefit to each aircraft.

Head Taxes

This type of charge assumes that each person should be charged an equal amount, under the theory that each receives equal benefit from the airport facility. If passenger space were the problem, higher charges per passenger would be appropriate. However, shortage of room for people in the terminal building is generally not the issue; rather, the runway landing and takeoff capacity, which is measured in aircraft operations per hour, needs to be considered. Under this theory, a single GA pilot delaying 500 other people would be charged the same fee as a passenger aboard a 747 aircraft. Because of the ease of ticket tax collection, this is how the largest percentage of federal aviation taxes is collected and is the dominant source of funds for the federal Airport and Airway Trust Fund. This method of charging is equitable among the passengers of commercial airlines but not equitable between GA and commercial passengers when capacity, and hence delay, becomes an issue. The Anti-Head Tax of 1973, however, prohibits local airports or other levels of government from enacting this type of fee or tax.

Landing Fees (By Weight of Aircraft)

This type of charge gained favor at airports as aircraft became larger and the jet age required substantially longer and stronger pavements. When condition of the pavement is the problem and pavement maintenance is the most important consideration, weight is an appropriate method of allocating costs. A close analogy is the concept of weight/mile taxes on the trucking industry. Pavement life is not used up by small aircraft, however, and deteriorating pavement is not the problem; the problem is the shortage of airport capacity. Landing fees are most often based on the weight of the aircraft because of convenience, not because weight-based landing fees are the most appropriate way to charge for the use of the airport. In fact, charging by weight is very similar in effect to the head tax, which has been prohibited.

Landing Fees (By Operation)

Under this scheme a charge is levied based on the operational costs of the airport divided by the total number of operations. In its purest form, all aircraft are charged the same landing fee. This, however, assumes that all aircraft have equal impacts on the airport and receive equal utility from the airport. The reality is that different types of aircraft carry different numbers of passengers, have different speed characteristics (the slower aircraft taking longer to land and take off), and weigh different amounts (heavier aircraft require stronger and longer runways). Logical pricing at capacity-limited airports would charge slower aircraft taking more time to land or take off more than faster aircraft. Nonetheless, it would probably be easier (from a political and practical standpoint) to set a uniform rate based on the average time of operation. In spite of uniformity concerns, this type of charge (or a permutation thereof) seems to best address concerns about capacity.

Peak-Hour Surcharge

A peak-hour surcharge is an opportunity-cost fee in addition to the basic cost of running the airport. This type of fee attempts to quantify the negative externalities imposed on others (i.e., the waiting cost to the airlines and the public). The average number of persons and flights delayed can be calculated. The cost of this collective delay can then be estimated to develop a cost-per-minute of delay. Each type of aircraft can then be classified as to the average time required to land and take off. A hypothetical example follows.

The FAA capacity study uses a figure of $23/person/hr (in 1985 dollars) to measure the cost of delay to the passengers (*18*). On the basis of an average passenger load of 130 people, 5 min is worth about $250 to the passengers for lost time. Assuming an aircraft and crew operating cost of $2,000/hr, 5 min is worth about $165 to the airline. Therefore, the cost of a 5-min delay for the hypothetical aircraft would be $415 (exclusive of airport and FAA costs). A slow single-engine aircraft can easily cause a delay of 10 min at hub airports, taking twice as long to land as a jet airliner. Assuming 130 persons per jet liner and a delay of 10 min for two airliners, the actual cost for the GA aircraft to land could be in excess of $1,660. This same capacity study estimated that in 1985 the total cost of airline delays from all causes approached $2.9 billion.

There are several problems with this type of charge. One is that although it is mathematically justifiable, it would have the effect of virtual exclusion of small aircraft. Another problem is that it would very likely be considered by the courts as discriminatory and confiscatory. Finally, this type of charge is not based on the expenses that the airport operator actually incurs; rather, it is based on externalized costs of the airlines and the commercial-airline passenger, and there does not seem to be any statutory basis for the airport operator to collect fees on this basis. (This is not to say that peak-hour landing fees based on foregone landings are not permissible.) This, however, does not mean that peak-hour surcharge fees are not appropriate, but merely that the evidence seems to indicate that the legal authority to levy or collect such a fee is questionable.

Assuming for the moment that Congress was willing to enact peak-hour fees (or to let the airports do so), the next question is "Who should receive the revenues?" Those who bear the brunt of the transferred societal costs would be a logical choice. Opportunity costs are the transferred societal costs to others, and the others at the airports are basically two parties, airlines and airline passengers.

The airports could collect these fees in addition to their basic landing fees and retain that portion of the opportunity-cost landing fee related directly to the airlines' out-of-pocket costs. The remainder could be remitted to the Airport and Airway Trust Fund (and eventually to the FAA) for airline passenger delay costs. The logic behind this proposal is that the airlines act as guarantors for the airports and generally agree to pay the necessary and usual charges of the airports through landing fees, leases, and assessments. Any additional monies derived from peak-hour landing fees by the airports would merely reduce the need for other airline charges at these airports.

The portion of peak-hour fees intended to reimburse the public for its costs could also go to the Airport and Airway Trust Fund. This would relate directly to the public's need for system improvements to reduce delays, which are primarily funded by the Federal Aviation Trust Fund and general federal tax dollars. The FAA recovers its costs principally through either aviation taxes or general tax dollars. To the extent that such user charges offset the general fund expenditures of the FAA, they would help balance the federal budget. [According to the *National Airway System Annual Report—FY 1987*, "In total, the general taxpayer subsidy to the FAA between 1982 and 1987 was about $7.5 billion" (*19*).]

Combination Fee (By Weight with a Peak-Hour Surcharge)

A fee structure for both GA and the airlines that combines a landing-weight fee with an opportunity-cost fee can be supported rationally. The airport operator would need to compile data showing the expected revenue from the average commercial operation and the average cost of operating the airport per operation. During nonpeak hours (assuming unused capacity) there would be no opportunity cost, but the basic cost of operating the airport would be charged. Some airports (John F. Kennedy and La Guardia, for example) have developed surcharge fees in an attempt to discourage GA during congested periods.

CASE STUDIES

Three commercial-service airports (Portland International, Seattle-Tacoma International, and Boston Logan International) are examined as follows to see how they could respond to current and future congestion problems. Although each of these airports is the largest in its respective state, they were chosen because they represent very different levels of commercial-service traffic (Table 2) and levels of congestion (i.e., below capacity, near capacity, and above capacity). They also differ in reliever airport systems and methods chosen to address actual or potential capacity problems.

Portland International

The port of Portland operates a four-airport system. The primary airport, Portland International Airport (PDX), is a transport airport and handled 241,000 operations in 1987. General aviation accounted for 62,000 (26 percent) of these (Table 3). The Practical Annual Capacity for PDX is approximately 300,000 operations. Because of additional constraints, however, including noise-abatement procedures, which "have the effect of limiting the airport to a single runway operation, special air traffic control (ATC) requirements for separation of aircraft, and 25 percent instrument approach conditions," the Annual Service Volume is estimated to be only 282,000 (Draft Portland International Airport Capacity Study. Executive Summary, unpublished). Demand at PDX is expected to exceed capacity by about the year 2000 (*20*). The three reliever airports, Hillsboro, Troutdale, and Mulino, have sufficient capacity to handle the GA traffic now using PDX, should the port choose to implement a policy of shifting GA traffic to reliever airports (with the exception of large private jets).

The port currently imposes no GA landing fees at any of its airports (Table 1). There is also no differential in the tie-down fees. Fuel flowage fees are $0.07/gal at PDX and $0.05 or $0.06/gal at the reliever airports. Ground-lease fees are basically the same at the three GA airports ($0.10 to $0.12/sq ft) but much higher at PDX for new leases ($0.35/sq ft). As a result, GA operations are unconstrained at all airports in the Portland system, and the mix of operations at each airport reflects the desirability of that facility, its convenience to the public, price, and the range and quality of FBO services. Portland International is the closest airport to the Portland city center and thus has the most desirable location for corporate and business GA users (who constitute about 80 percent of the GA traffic). Approximately 35 acres of land are

TABLE 2 COMMERCIAL CARRIER DATA (FAA DATA)

	Percentage of U.S. Enplanements	Passengers	Departures
Logan	2.42	9,695,876	111,799
Sea-Tac	1.66	6,651,868	92,003
Portland	.60	2,414,960	56,156

TABLE 3 TRAFFIC MIXTURE (FAA DATA)[a]

	Portland	Sea-Tac	Logan
Total operations, 1987	241,000	281,000	436,000
GA operations, 1987	62,000	17,000	50,000
GA as a percentage of total operations	26	6	11

[a]All operations data rounded to nearest 1,000.

currently used by GA for transient, corporate, and FBO activities, with more land for corporate use being made available in a newly developed area of the airport.

Port policy is the carrot-type approach to enticing GA traffic away from PDX to the relievers. The port maintains the relievers reasonably well (although maintenance is occasionally deferred and no permanent staff is assigned to two of the relievers) and has spent millions of dollars on capital improvements at the relievers over the last 10 yr. The port, however, has not provided any incentives to aircraft owners to move their based aircraft from PDX. Ground transportation is virtually nonexistent from the relievers to the city center and to PDX.

For an airport with excess capacity, such as PDX, the institution of a program to shift GA traffic is not warranted at this time. The institution of a minimum landing fee to end the subsidy for GA would, however, be appropriate from the standpoint of equity to the airlines and their commercial passengers.

Seattle-Tacoma International

The port of Seattle operates a single airport, the Seattle-Tacoma International Airport (Sea-Tac). The airport handled 281,000 operations in 1987, of which 17,000 (6 percent) were GA (Table 3). Other major airports in the Seattle metropolitan area are operated by a variety of private and public agencies. Although several of these are transport class, none of them are primary commercial-service airports. The Seattle-Tacoma International Airport is currently projected to exceed instrument flight rules (IFR) capacity by the year 2000 and visual flight rules (VFR) capacity by the year 2010 (*21*).

Adequate capacity exists at the other nearby airports to accommodate both local GA-based aircraft and total GA operations through the year 2000 and perhaps through the year 2020, depending on the rate of growth of GA aircraft within the Seattle metropolitan area. Boeing Field (King County International) is located 4 mi from Sea-Tac and is the primary GA airport in the Seattle-Tacoma metropolitan area. It is a very busy facility, having approximately the 10th highest number of itinerant operations in the United States. Because of the location of Boeing Field (closer to the Seattle city center than Sea-Tac is), there is very little pressure on Sea-Tac from GA. General aviation that does use Sea-Tac consists primarily of airline pilots flying to work, those wishing to clear customs, and corporate users wanting to transfer to connecting commercial flights. Very little land, less than 15 acres, is allocated at Sea-Tac for FBO and GA use. (The three existing FBOs collectively lease less than an acre and a half of land.) The port of Seattle has consciously limited the land for FBO use and has no plans to make more available (personal communication).

FBO lease fees at Sea-Tac are $0.40/sq ft. Overnight tie-down fees are $10 and minimum landing fees are $25 (Table 1); however, various pilots and FBO personnel interviewed indicated that they were not aware of the existence of the landing fee. This leads to the conclusion that collection efforts are not as efficient as they might be.

For airports with little GA traffic, such as Sea-Tac, shifting GA traffic will not have much effect on capacity.

Boston Logan International

The Massachusetts Port Authority operates a two-airport system, Boston Logan International and Hanscom Field, a reliever airport. Logan handled 436,000 operations in 1987; 50,000 (11 percent) of these were GA (Table 3). Logan has a heavy traffic load in part because it is a major point of departure for flights to Europe. Logan is the closest airport to the Boston city center and thus the most desirable location for corporate and business GA users.

Other major airports in the Boston metropolitan area are operated by a variety of private and public agencies. Although several of these airports are transport class, none is a primary commercial-service airport. This, however, is expected to change: "The Worcester, Mass., Airport plans to build a new, $12-million passenger terminal to accommodate explosive traffic growth. Three years ago the airport handled 58,000 passengers, and this year more than 300,000 are expected. The rapid growth of Worcester is supported by the Massachusetts Port Authority (Massport), which wants to help regional airports grow to relieve congestion at Boston's Logan International Airport" (*22*).

Logan Airport currently exceeds both VFR and IFR capacity during certain peak periods. Because of this, Massport has been attempting since 1980 to regulate demand with economic disincentives for small aircraft (or to charge actual costs, depending on one's point of view).

In August 1987, Massport announced a new plan to address delay and capacity problems. This plan is known as PACE (Program for Airport Capacity Efficiency). The following description is from PACE (*23*):

> At the current peak hour demand, delay in IFR-1 conditions reaches almost 65 minutes per airplane. Under such conditions the delay per airplane goes up to 20 minutes in the morning peak hour, drops to 10 minutes during the midday peak hours and then surges to over 60 minutes per airplane during the afternoon peak hours. . . . Based on this level of delay, almost 7000 passengers per hour . . . experience delay of up to 60 minutes each.
>
> [Under currently forecast increases in air traffic] the present maximum delay will rise from 60 minutes per person in IFR-1 conditions to 100 minutes per person in 1990 and to 280 minutes per person in 2000.

> General aviation operations constitute, on an average day, approximately 10% of the total operations at Logan while serving less than 1% of its passengers.
>
> [I]f the smaller planes were moved out of the peak hour, 98% of the passengers using Logan during peak hour would have delays cut by over 50 minutes each and less than 2% would suffer the inconvenience of using Logan before or after the peak hour.

Thus, Logan's rationale for raising the minimum fees is to create economic disincentives for smaller aircraft.

At Logan the new fee structure has two components. The first is based on time and includes all operational costs of Massport; the second is based on weight of the aircraft. This fee was purportedly formulated to cover the basic costs of operation (including fixed costs such as administration, navigational aids, lighting, crash/fire/rescue services, etc.), which, according to Massport, had previously been subsidized by passengers on commercial airlines. (The development of these fees has been the subject of considerable debate, especially with regard to the proper components of the rate base and the proper division of relative costs. That debate will be found in the legal records and not repeated herein.) The fee per pound of landed weight allegedly relates to the cost of construction and maintenance of the runway pavement. This fee structure does not contain an opportunity-cost component (peak-hour surcharge), although Logan is considering imposing such a fee in the future.

According to Massport officials, "general aviation operations at Boston Logan were down by more than one-third in the first month the PACE . . . plan was in effect at the airport" (*24*).

CONCLUSIONS

The type of GA using the airport needs to be analyzed carefully before an appropriate strategy can be chosen. For example, a Lear jet will fit into the commercial jet approach stream very well because of its speed characteristics. Business aviation desiring to connect with commercial flights will want to be as close as possible to the main terminal building, and so will smaller commuter flights and air taxi traffic. Therefore, the best GA candidates to shift to reliever airports will be other categories, such as recreational fliers, nonconnecting business traffic, and maintenance traffic (using aircraft maintenance and repair services). This discretionary type of GA user will be the most easily shifted with nominal fee levels.

For airports that do not have a delay problem, a fixed fee per operation would seem to be the most appropriate. For airports with a capacity problem, a fixed fee per operation and peak-hour pricing by length of time of approach and takeoff would act to smooth out peak demand and substantially reduce uneconomical use of the runways at these times by small aircraft.

Establishing Basic GA Fees

- Income derived from the airport, such as parking fees, building rental, agricultural leases, and other miscellaneous income, should be subtracted from the basic cost of airport operation.
- Other ineligible costs, including depreciation on the federally funded share of improvements, should then also be subtracted.
- The remaining cost can then be divided into the average number of landings handled in the previous year or expected for the next year. The resulting amount should then be compared with the regional average cost to ensure that extraordinary costs (or unreported expenses) are not distorting the true cost of operation.
- Determining the regional average cost of operation requires a survey of the airports within the geographic region, to determine the average cost of operating similar facilities.
- Based on such average costs and past experience for that particular airport, a basic cost for operating the facility can be estimated. This basic cost could also be apportioned between weight-related costs and operational costs.
- If the owner wishes to sell bonds for future improvements benefiting aviation, a surcharge can be calculated and added to the basic rate.
- The analysis then needs to be documented carefully.

Implementation of Peak-Hour Pricing

Peak-hour surcharges may require legislation allowing either the airport or the FAA to impose such a fee, depending on how the surcharge is structured.

One possibility for a peak-hour surcharge would be for the FAA to impose an FAA controller handling fee for each operation during peak hours. This fee would tend to discourage GA from using primary commercial-service airports during peak hours. Such fees are currently prohibited under the theory that such charges would cause pilots to avoid using the safety services the FAA provides. If such fees were legal, however, the FAA could require the airport operator to collect the fee. It could be piggybacked on the landing fee to make collection much simpler. This would implement true user-benefits, user-pays pricing for scarce controller time during peak traffic periods.

As a matter of equity, the institution of a usage-based fee system can be justified at all three of the airports studied. For airports with capacity problems the opportunity-cost, peak-hour pricing system can and should be considered. As James McCormick, vice president of economic affairs for the Airport Operators Council International, says:

> Peak-hour passenger charges are another market pricing option worthy of serious consideration, since air carriers schedule flights when they perceive passengers want to travel (creating peak hours) and would therefore not be very sensitive to differential landing fees. Passenger charges would allow airline customers to indicate if they really value traveling during congested periods, or are willing to travel during off-peak periods and save money. Such market signals could help optimize airline schedules and reduce congestion (*25*).

Assuming that congestion continues to worsen in spite of technological and new-construction efforts by the FAA, and assuming that airports are prevented from shifting demand by fees or regulation, the nation will be faced with two unpleasant specters: (a) no action and increasing delays at the nation's busiest airports and (b) increased federal regulation through the application of the High-Density Rule (14 CFR Part 93.121) by the FAA at more airports.

POSTSCRIPT

Subsequent to U.S. District Judge Mazzone's ruling, the U.S. Department of Transportation instituted an investigation of Massport's landing fees (FAA Docket 13-88-2) to consider whether such fees violated federal law. Administrative Law Judge Burton S. Kolko determined that Massport's new fee schedule did violate federal law. Judge Kolko concluded that Massport's fees were not reasonably grounded, but fails to explain convincingly why such fees are not related to Massport's actual costs nor why such fees are unreasonable, and he does not define what he considers to be reasonable fee levels.

To paraphrase the *FAA Community Involvement Manual* (*26*), it is essential that FAA personnel operate in such a way that they use their professional expertise to help airport managers and sponsors figure out what they can do to solve a problem, rather than constantly using their expertise to tell airport management what they cannot do. Although there are limits of feasibility, legal mandates, and so on, airport managers must get the feeling that the professional is using that expertise to find solutions, to be responsive to the nation's airport needs.

In 1983, Secretary of Transportation Elizabeth Dole wrote to the CAB on the report of the Airport Access Task Force and said in part:

> The Department also finds unsatisfactory the conclusion of the report that the use of market mechanisms for the allocation of resources would "likely be highly disruptive to public service and almost surely would add to the cost of air transportation." The use of direct charges or other fee mechanisms does not necessarily have to add to the cost of air transportation. Revenues collected as a result of such mechanisms could be used as an offset against other charges based in whole or in part on an operator's time of day, aircraft noise levels, or a number of other different factors. While we do not advocate any particular alternative mechanism, such direct fees could be structured to be no more disruptive than current fees and, on the positive side, could provide incentives for creating a quieter environment around an airport in the long run *or for achieving other goals of the airport and the surrounding community. In addition, a system of direct charges, locally developed and administered, would not require any type of Federal intervention* (emphasis added) (Letter from Elizabeth Dole to Dan McKinnon, March 4, 1983).

It would seem appropriate for Congress to take another look at this issue and to provide clear policy direction on airport user fees. Following such clarification it would be very helpful to local airport authorities if the FAA developed an advisory circular describing how such fees can be developed without violation of other federal laws and regulations.

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Toward Mediation: An Examination of Consensus-Building Techniques Applied to the Aircraft Noise and Airport Access Dilemma

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Current and forecast growth in operations at U.S. airports presents a mounting problem for the aviation industry, particularly major airport operators who are confronted by capacity constraints as well as an increasingly politicized constituency: local citizens who are no longer willing to tolerate the accompanying noise. Airport proprietors, legally responsible for environmental effects of airport operations, are resorting more and more to unilaterally developed noise-abatement plans that restrict access to the local airport. These plans can indirectly constrain the entire aviation system and often raise the constitutional question of restraint of interstate commerce. Beyond the federal aviation regulations already in effect, a comprehensive national policy on aircraft noise and airport access is not likely in the near future. In the absence of national guidelines, this paper examines the use of mediation as an effective option for making aircraft operations at many airports more compatible with their neighboring communities while maintaining adequate capacity at those airports to ensure an unrestricted interstate commerce system. There is evidence that formal and ardent commitment to participation in mediation from all parties, use of a preliminary dispute assessment, and the ability to distinguish positions from interests can help reduce noise and maintain capacity levels. Amending Federal Aviation Regulation Part 150 to make federal Airport Improvement Program funds available for mediation nationwide and institutionalizing a federal role in mediation would ensure adequate representation of the national interest as airports respond to political pressures to reduce noise.

THE AIRCRAFT NOISE/AIRPORT ACCESS DILEMMA

The 10 years since the Airline Deregulation Act was passed have seen dramatic changes in the way the nation's air transportation system operates. Partially as a result of the hub-and-spoke method of airline route system management, commercial aircraft operations have increased 50 percent since 1978. According to the FAA, 14 million commercial aircraft operations occurred at airports in 1978; by 1987 the number had reached 21 million. This figure is expected to escalate to 26 million before 1995 (*1*).

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With the continual growth in air traffic has come an increase in the volume of angry cries from some of the communities neighboring airports. Voicing strong consensus over perceived deterioration of their quality of life, they continue to organize increasingly sophisticated and effective barriers to airport operations and development. The effects are becoming more and more evident: in spite of a growing need, there have been virtually no new runway developments during the deregulated period, and with the exceptions of Denver and Austin, no new airports are planned to open before the end of this century. Moreover, effective community pressures such as those experienced at John Wayne and Burbank-Glendale-Pasadena airports in California have resulted in severe restrictions on aircraft operations. Although at the present time these are not major airports, an extension of the trend could lead to critical limitations on future airport capacity.

As Figure 1 indicates, there are more than 400 locations where noise-limiting policies are in effect. These measures include curfews, restrictions of aircraft or operations, noise limits, noise budgets, noise-related landing fees, restriction or elimination of flight training, and noise-abatement approach and departure limitations. Although the majority of airports have not yet imposed severe restrictions, some have attempted to significantly limit (Long Beach, California) or preclude (Paine Field, Washington) air carrier service. In the case of Long Beach, restrictive limitations have been moderated by FAA administrative review via the Part 150 process and by litigation brought by air carriers. At Paine Field, a limited mediation process was used in the late 1970s to preclude air carrier service; in light of the current regional need for aviation facilities, and potential legal challenges, this policy is being reexamined.

Moreover, because of the time constraints associated with the hub-and-spoke network, as well as flight time and time zone changes, a curfew at a destination airport may indirectly impose restrictions at an intermediate hub or even the origination airport many hours earlier. Potential innovation such as peak-hour pricing schedules would become less feasible under widespread application of time-related access restrictions.

If airports, particularly primary airports critical to the national system, continue their current trend of individually imposing uncoordinated access restrictions in response to community

FIGURE 1 Airports that have implemented noise-control strategies (*2*) (heavy lines denote regional boundaries).

pressures, the benefits derived from deregulation may eventually be negated by an assortment of locally induced re-regulation, which may place unacceptable limitations on interstate and foreign commerce.

Thus, a difficult dilemma has arisen for participants in the national transportation system: in the face of an increasingly vocal citizenry, can airport operators meet their obligations to provide an unconstrained air transportation system while maintaining control over aircraft noise regulations? Can air carriers continue to look to national legislation to prohibit local restrictions on airport access, or should they work more with local airport operators and business interests? What role should the FAA assume in the problem? Clearly, a workable solution must involve all parties and levels of interest.

In the absence of federal regulations or specific guidelines for airport proprietors feeling the need to impose restrictions, mediation may in many cases effectively serve both local and national interests. Mediation emphasizes "win-win" resolution by employing a neutral party to negotiate an administrative rather than a judicial resolution to a dispute among conflicting parties. This paper will examine the degree to which mediation can serve as a vehicle for airport operators, local communities, system users, airlines, and the federal government to convene for the purpose of developing a mutually agreeable solution to the noise and access problems in that locale—while giving due consideration to the growing demand for capacity nationwide. If mediation can introduce a systematic, comprehensive, and interactive process to document and ensure review of all aspects of the conflict and potential remedies, then it can serve as a welcome alternative to local political pressure and litigation as the primary means of generating access restrictions.

Alternatives: Strengthened Federal Noise Regulation, Litigation

Before mediation, the two most commonly discussed alternatives have been strengthened noise regulation and litigation. Additional federal noise regulation (beyond the existing provisions in Federal Aviation Regulation Parts 36, 91, and 150) would impose uniform noise restrictions throughout the nation, whereas litigation typically focuses on compensating for damages or restricting operations based on environmental concerns at an individual airport. What the former lacks in flexibility, the latter lacks in uniformity and predictability.

Federal Regulatory Approaches

As discussed in the following paragraphs, in the current political climate federal regulatory approaches to airports beyond the framework of the existing Federal Aviation Regulation (FAR) Part 150 program appear unlikely. Part 150, administered by the FAA, offers federal matching funds for planning and implementation of noise-mitigation and noise-abatement strategies. More than 159 airports have received funds since this program has gone into effect (*3*). Many of these have completed or are in the process of implementing Part 150 programs yet are experiencing continued noise-related community problems. Others have decided not to participate in this program, concluding that other options are more appropriate for their circumstances or choosing specifically to avoid federal administrative review of noise-restricting proposals. (Although some further refinements to the Part 150 program can be expected, the program will be likely to remain a means of identifying and mitigating noise impacts in more immediate airport vicinities. One feature to consider adding would be provision of funding for the mediated approaches discussed later in this paper.)

Another commonly discussed federal approach is the accelerated phaseout of FAR Part 36 Stage II aircraft. The airline industry has recently expressed some willingness to pursue a phaseout schedule for Stage II aircraft in exchange for an intervening federal policy limiting local imposition of noise and access restrictions. The federal government, however, remains unwilling to assume the legal liability for noise that might accompany legislated implementation of national noise policies. Nor is it willing to subsidize the private sector in accelerating replacement or upgrades of Stage II aircraft. Thus it remains most likely that airline industry economics will be the predominant factor in pacing fleet replacement.

Even if a federal schedule for elimination of Stage II aircraft is imposed, resulting in stricter limits on the level of noise produced by individual aircraft, it will not be likely to limit the number of operations that may occur at a given airport. Moreover, growing passenger volumes will encourage the use of the larger, and therefore relatively louder, variety of Stage III aircraft. Ultimate reductions in single-event noise levels achieved by Stage III aircraft are not likely to fully offset negative community perceptions associated with the increased frequency of operations. Burbank-Glendale-Pasadena in California is a good example of an airport that has secured a 100 percent Stage III fleet yet continues to struggle with a persistent community noise problem.

In 1986 the FAA announced that it was considering issuance of a federal policy statement on airport access and capacity issues in response to what it called the "current ad hoc response to access and use issues" (*4*). Issuance of any statement, however, appears increasingly unlikely. In addition to the federal government's legal and financial reservations, Executive Order 12612 requires federal agencies, including the Department of Transportation, which oversees FAA, to emphasize local solutions to problems whenever possible, unless a clearly legitimate national purpose cannot be met without national legislation (*5*). The Bush administration is unlikely to deviate significantly from this policy. James Burnley, DOT Secretary under the Reagan administration, asserts that a "one-size-fits-all" federal policy on noise is not politically feasible (*6*). Nor would it be likely to represent the degree of flexibility needed to reflect varying local and regional conditions.

Litigation

This paper does not attempt to review comprehensively the national record on litigation as an option or "solution" to the access dilemma. It is a persuasive, fundamental tool available often as a last resort to all parties. Although airport proprietor obligations regarding noise are themselves the result of evolving case law, reliance on litigation alone to resolve the access/noise issue is not, in the author's view, sufficient. Subsequent analysis of mediation will draw comparisons and contrasts with litigation to further document this conclusion.

MEDIATION AS A MEANS OF DISPUTE RESOLUTION

Before mediation can be examined as a possible tool in approaching airport access restrictions, it is necessary briefly to review the general concept. Negotiation pursues consensus solutions through voluntary, ongoing, face-to-face interaction among representatives of the disputing parties. These representatives agree to follow specified procedures throughout the duration of the process in an effort to identify a mutually beneficial solution to an agreed-upon problem. A mediated approach to negotiation uses a neutral party to convene representatives of the differing interests and direct their efforts toward resolution.

Like all methods of dispute resolution, mediation has its disadvantages. Those that are particularly germane to aviation are addressed in the case studies that follow. They illustrate that successful mediation may not occur without some formidable challenges, and therefore requires rigorous commitment to the process. The effort, however, may be justified by a superior outcome.

Whereas litigation imposes a win-lose outcome upon the involved parties, mediation uses voluntary interaction to arrive at a mutually supported outcome. Complex technical and scientific issues can be discussed and documented with the assistance of neutral experts. Because consensus requires universal commitment to the outcome, resulting decisions are generally implemented without further process, and are less likely to be challenged. They are therefore more likely to endure. Subsequent legal challenges, if they occur, would tend to have less effectiveness if a mediation process already addressed all the relevant interests and issues and established a documented consensus for the court to review. Table 1 further illustrates the differences in focus and outcome between litigation and mediation. (Although mediation is contrasted and compared with litigation, it should be noted that for the airport operator, litigation is typically not an option. Rather, it is a manifestation of community interest and pressure, and often incites local noise-based regulation of aviation or airport access. As a choice for the operator, mediation may therefore be preferable to unilateral regulation. As suggested in Table 1, litigation is not available to the airport operator except as a defendant.)

Mediation should not be considered strictly as an alternative

TABLE 1 ALTERNATIVE APPROACHES TO DISPUTE RESOLUTION (*7*)

CHARACTERISTICS	MEDIATION	LITIGATION
OUTCOME	o Win-win; improved relationships. o Promotes innovative and appropriate outcomes.	o Win-lose; impaired relationships. o Favors financial compensation, which often fails to address real problem.
PARTICIPATION	o Voluntary.	o Mandatory.
REPRESENTATION	o Specially selected for each case. o Complete; balanced.	o General purpose elected or appointed officials. o Exclusive; favors those with greatest resources.
STYLE OF INTERACTION	o Direct, face-to-face. o Cooperative.	o Indirect (through attorneys). o Adversarial.
ROLE OF INTERMEDIARIES	o Assisted; various roles for intermediaries.	o Unassisted. No role for intermediaries.
PROCEDURES	o Unique rules and procedures in each case. o Focuses on issues.	o Same rules and procedures in all cases. o Focuses on process.
METHODS OF REACHING CLOSURE	o Voluntary. o Those most familiar with issues choose compromises toward mutually supported outcome.	o Mandatory. o Third party unilaterally decides outcome.
COST	o Moderate to high in short-term; low in long-term if successful.	o Low to moderate in short-term; potentially very high in long term.

to litigation. It is more accurately presented as an instrument that can be used to augment the standard choices of litigation and other traditional decision-making methods. In some instances the use of mediation may not be warranted at all. Because the characteristics of disputes differ widely, no single approach to resolution is universally appropriate.

Features of a Successful Dispute Resolution

When should one pursue a mediated resolution? There are no absolute conditions that guarantee success. Because of the degree to which circumstances influence the outcome, even professional mediators cannot agree on the exact properties of a successful negotiation. Susskind and Cruikshank, authors of *Breaking the Impasse: Consensual Approaches to Resolving Public Disputes* (*7*), offer their list of "preconditions to success" as an indication of the wisdom of attempting to mediate a conflict. The authors assert that before starting out, the initiating party should get positive responses to the following:

- Can key players be identified, and if so, persuaded to participate?
- Are the power relationships sufficiently balanced?
- Can a legitimate spokesperson for each group be found?
- Can realistic deadlines be set?
- Can the dispute be framed so it does not focus primarily on sacrosanct values?

Gail Bingham, author of *Resolving Environmental Disputes: A Decade of Experience* (*8*), examined 161 environmental disputes and identified several factors common to the successful outcomes. She found that successful mediation processes most often included:

- direct participation by those with the authority to implement the decision;
- a dispute assessment conducted by the mediator to determine whether to proceed with a voluntary dispute resolution process, and if so, what the nature and rules of the process should be;

- parties with incentives to negotiate with one another; and
- willingness of the parties to identify the interests that underlie each other's positions, and to invent new alternatives that satisfy these interests.

She also found that the combined positive effect of these factors can often offset a deficiency or the existence of potentially negative factors.

Role of the Mediator

The mediator role may be filled by one party or a team of mediators. More critical than the number of mediators is the neutral position that all mediators must maintain throughout the mediation process. Mediators must serve at the mutual pleasure of the participants.

The mediator role may vary, depending on the situation and the mediator, but it usually involves determining whether mediation is appropriate, assisting the interests in developing the process and agreeing upon procedures, and facilitating the discussions between the parties. Mediators ensure that any technical information is shared and understood by all participants, and often work with the participants to develop suggested solutions (provided, of course, that they have no vested interest in those suggestions). Mediators also assist the negotiating parties in establishing communication with their constituents as well as others who are outside the process but concerned with the issues and outcome.

ROLES, INTERESTS, AND OPPORTUNITIES OF PARTIES INVOLVED IN ACCESS PLANS

With the general concept of mediation identified, it is necessary next to review the specific roles, interests, and opportunities of the parties potentially involved in the airport access topic, and examine these roles within the context of the three discussed resolution models.

FAA

The FAA faces a peculiar duality of purpose. The Federal Aviation Act, the Aviation Safety and Noise Abatement Act, and the National Environmental Policy Act have charged it not only with maintaining and improving the safety and efficiency of the national air transportation system, but also with protecting the public health and welfare from the negative effects of aircraft noise (*9*). Congress has given the agency the authority to review, comment, and issue approvals on local proposals, but not to initiate local policies concerning noise and access restrictions. Following review, the FAA may challenge an airport's proposed restriction if

- the initiative is a burden on interstate commerce;
- it invades the exclusive safety jurisdiction of FAA;
- a local authority is attempting to use one of the powers preempted by FAA; or
- the initiative violates existing contracts between FAA and airport authorities.

Only on rare occasions does the FAA initiate litigation, for it is a lengthy and costly process requiring extensive review and approval by many departments within the executive branch.

Recognizing the agency's dual responsibilities, Administrator T. Allan McArtor testified before the Senate that the FAA is "seeking balance between the needs of interstate commerce requiring a national approach to airport access and the rights of local communities to protect themselves against undue noise. This is a delicate but essential balance. I do not believe the answer lies in federal pre-emption [of local operators' authority over noise] nor 100 percent local solutions" (*5*).

Participation by FAA region or district officials may be essential to workable local access plans; a federal voice in a locally based process may provide the kind of balance McArtor envisions. The FAA participated peripherally in the developmental stages of the Minneapolis-St. Paul noise budget, through comment at public hearings and notification to the airport authority of concerns with the originally considered mandatory noise rule. Leonard A. Ceruzzi, assistant chief counsel of the Legal Services Division, subsequently asserted that this kind of participation is worthwhile because it "saved a lot of time, effort, and energy," and probably prevented litigation (*10*).

Protection of the national interest may require an even stronger federal role. Federal participation might include identifying workable combinations of service levels, facilities, and capacities with which a national system can function. In instances in which an airport serves as the primary or only origin or destination point for a region (e.g., Boston, Seattle), a domestic hub for which adequate substitutions are not likely (e.g., Chicago, Dallas-Ft. Worth), or a key international gateway (e.g., Miami, Los Angeles), the national system could not function without capacity matched to forecast demand. Conversely, an airport that enjoys alternatives for service to its region (e.g., Washington National) may have opportunities for more restrictive noise and access policies. By identifying and documenting these varying conditions within a national framework, the federal role can help to assess the impact of proposed access restrictions under each scenario.

If the FAA determines that a proposed restriction does not adequately protect the national interest, or believes that a process is not being correctly pursued, it may ultimately have to resort to its traditional role of comment, refusal of funds, or litigation in the national public interest.

Airport Operators

The airport operator is responsible for siting the airport and maintaining operations to ensure access to adequate air transportation. It is also responsible for any detrimental effects of actions taken in the pursuit of these goals, including adverse impacts on the airport environs. "At the same time that the airport sponsor wants to facilitate the growth of air commerce, it must recognize that the local citizenry has reasonable expectations for an environment free of intolerable levels of noise resulting from aircraft operations," explains the Airport Access Task Force report to Congress (*11*).

The courts have maintained the proprietor's right to protect itself by permitting planning and implementation of noise-abatement and noise-mitigation actions as well as airport access restrictions, provided the restrictions address a demonstrable noise problem (*12*).

In response to pressure to lessen environmental impacts, an airport may conduct a planning process within or apart from the Part 150 program. Conducting a mitigation or abatement process independent of Part 150 eliminates both FAA's administrative review and approval role (thereby leaving the national interest potentially unrepresented) and the ability to receive the associated noise program funding.

An airport operator may also choose to develop and implement a variety of noise-based access restrictions. These may be determined unilaterally, or may be established as a result of a litigated, negotiated, or mediated process. If the airport operating authority makes a commitment to mediation, it will probably need to assume the role of process sponsor, including securing financial and political support.

Airport operators' relationships with the airlines are usually direct, often contractual, arrangements. These agreements often require air carrier commitment for airport bond financing and revenue support for major capital improvements.

System Users and Air Carriers

Airport users include passenger and package express air carriers, travelers, shippers, and local businesses—anyone who directly or indirectly benefits from goods or persons passing into or out of the region by air. With the major exception of the airlines, the airport user has had little or no direct input into matters of airport access and other air-system-related matters. Air carriers have no direct legal standing in the development of restrictive noise programs or procedures beyond the ability to initiate litigation to enjoin implementation. The carriers' strong, almost symbiotic financial relationship with many airport operators gives them considerable power, however. Many restrictive-access plans would require jointly accepted amendments to airline-airport agreements and thus make the carriers a critically necessary party to any mitigation effort.

Even air carriers without strong contractual positions have often managed to exert significant influence over threats of access restrictions. At the national level, representation by the Air Transport Association (ATA) has concentrated the carriers' political power, and provides a vehicle for clear articulation of the industry's views on access plans: " 'Unilaterally developed, uncoordinated constraints' have become a 'dagger pointed at the heart of commerce' " (*13*).

Because air carriers have such a large stake in the outcome of an access-restriction policy, they may have strong incentives to participate in a mediated effort if they believe that all other parties are committed to that effort. Alternatively, carriers can use their financial resources to pursue legal challenges to excessively restrictive plans on grounds similar to those used by the FAA. However, because of the high costs of litigation they may defer to the FAA, hoping a federal lawsuit or regulatory measures will stop the plan. As discussed earlier, reliance on FAA is not an ideal strategy, because few suits are filed by the federal government.

One frequent complaint of the airlines in their objections to unilaterally imposed access restrictions is that the economic beneficiaries of unrestricted air travel are not taken into consideration. Although the benefits of air transportation to the economy are enormous, they are often indirect, and thus do not inspire a constituency to argue their merits.

Chambers of commerce and other representatives of local businesses may prove beneficial in this regard. These organizations are more apt to realize the importance of accessible air travel to the vitality of the local economy and so are interested in having their opinions heard. In the Puget Sound region, for example, a collective effort on behalf of all the chambers of commerce in the area has been formally organized to ensure direct or indirect representation of the system users and promote adequate long-term commercial-aviation capacity.

Residents of Affected Communities

Although community residents have traditionally had little say in local airport management, the trend is reversing. Citizens—both individually and in groups—are wielding increasing clout with elected boards, councils, and commissions that directly or indirectly operate airports.

One basic problem local groups face is a lack of internal consensus regarding not only their vision for resolution but also the very definition of the problem. For example, some neighborhoods may be concerned with runup noise, whereas others may dispute where aircraft flight paths should be located. In other instances a fundamental concern over noise may be masked or reinforced by an expressed concern over broader topics such as "growth of the airport." These can result in "positions" opposing even airport activities not directly related to noise that are inconsistent with their fundamental "interest." Residents' "not-in-my-backyard" views and choice of relevant issues may require internal resolution before a workable basis for discussion with airport and airline representatives can be established.

THREE EXAMPLES OF CONSENSUS-BUILDING APPROACHES TO THE NOISE/ ACCESS DILEMMA

In the following case studies at three major airports, elements of negotiation and mediation have been used successfully to reach mutually agreeable solutions to the noise/access dilemma. In each case, some or all of the relevant parties were brought together to develop acceptable means of limiting the impacts of noise while maintaining efficient use of existing capacity.

The principles of negotiation were exercised at Minneapolis-St. Paul not only as an alternative to litigation, but as an outgrowth of administrative and legislative initiative by the Metropolitan Airports Commission (MAC). A formal series of negotiation sessions involving the affected parties was initiated by the Stapleton International Airport authority. This process, which came to closely resemble mediation, served as an alternative to litigation. In addition, it met the requirements of an intergovernmental agreement that would pave the way for construction of a new airport. A newly developing example is taking place at Seattle-Tacoma International Airport and represents a case in which the principles of mediation have been applied from the outset.

Minneapolis-St. Paul

In the early 1970s Minneapolis-St. Paul gained a reputation as a leader in airport noise control, yet a substantial growth in hub traffic following deregulation rendered its programs less adequate. Capacity demands quickly overcame noise-abatement policies, to the dismay of local residents. As a result of citizen protests, the governor and the MAC, the airport proprietor, formed a working group to make recommendations with respect to a "noise budget." (A noise budget is a regulation that limits the amount of noise at an airport. It may allot specific noise levels to individual carriers or may simply cap the single-event or aggregate noise level at the airport.) This group, which included members of the community, was endorsed by an established and vocal anti-noise committee. After 18 months a noise budget ordinance was drafted requiring an immediate 19 percent reduction in average daily aircraft noise energy levels, climbing to a 24 percent reduction over 5 yr (1992). However, threats of litigation from the airlines, primarily Northwest (which controls about 85 percent of the operations), and hints of litigation from the FAA led the MAC to attempt to negotiate agreeable reductions with the air carriers. It imposed a 2-month deadline on these one-on-one negotiations, which would be followed by unilateral enactment of the ordinance in the event of no agreement.

A voluntary agreement was ultimately reached with the seven major airlines for an immediate 11 percent reduction in total noise levels, leading to 24 percent reduction by 1992. Additionally, sound insulation of two schools was to be financed by the airlines. The voluntary noise budget has been so successful that airport staff reports reductions are already at the 1991 target level of 22 percent, with no threats of litigation. These reductions, however, are partially attributed to the consolidation of schedules resulting from the merger of the airport's two largest carriers.

The MAC sought to reduce noise levels at the airport without cutting into its capacity. By employing the principles of negotiation (although falling short of actual mediation), it was able to elicit input from citizens and air carriers and subsequently institute a voluntary rule that allows airlines to increase flights yet significantly reduces cumulative noise levels: in part, a "win-win" solution to a difficult situation. Issues including litigation over flight tracks may remain, however, and the long-term adequacy and capacity of the primary airport remains a topic of discussion.

Denver Stapleton

Denver's Stapleton International Airport is the fifth-largest airport in the nation in number of annual operations. When it became apparent that demand at Stapleton was going to exceed existing capacity, the city of Denver, which operates the airport, began plans to expand. Several citizens' groups concerned over the adverse environmental impact of the proposed expansion threatened litigation to block the project. Their efforts convinced the city and county of Denver that cooperation with the surrounding jurisdictions was the only way the project could proceed (*14*). Thus, an intergovernmental agreement with Adams County (the site of the proposed airport) allowed plans for the new airport to continue, provided the airport operator install a permanent noise-monitoring system, conduct a $20 million sound-insulation project funded by the airport from airline leases and landing fees, and institute an interim noise budget.

To satisfy the noise budget requirement, the city of Denver first attempted unilaterally to impose an aircraft "fleet mix" rule. This rule would require the airlines to use a certain percentage of Stage III equipment and limit their use of Stage II aircraft at Stapleton. Because of the vehement opposition of the airlines, however, the city council directed the airport, the airlines, and the communities to negotiate. They were given 6 months to achieve a compromise that would cap the total airport noise levels without severely affecting the airlines or reducing the level of air service provided at the airport.

Representatives of the communities, air carriers, the airport operator, and the FAA met every 2 weeks in 5- to 8-hr sessions beginning in September 1986. As additional parties (e.g., cargo carriers, community groups) expressed interest in the process they were invited to join the discussions. Formal minutes taken by the airport preserved the legal history of the negotiations. Although this process did not initiate as "mediation," at this point it had taken on most of the characteristics of mediation, with the exception of an independent mediator.

The negotiations came to an impasse when the airlines and the public could not agree to a level at which to cap the noise. To resolve this dispute the city of Denver decided on the sound energy average of the two contending noise levels. Noise was then allocated to airlines based on each airline's historical contribution to the noise environment at Stapleton. By choosing the types of aircraft it uses and the time of day it operates, an airline can control the amount of noise it produces, and increase the degree of flexibility within which it can operate.

Noise reduction at Stapleton has exceeded expectations in every evaluation period since the budget went into effect on June 5, 1987. Although the airport attributes this reduction in noise impacts to previously planned fleet upgrades and the leveling off in the growth of airline operations, community reaction to the changes has been positive.

Conversely, although both United and Continental, which together occupy 85 percent of the space at Stapleton, participated throughout the process, Continental challenged the finalized budget in an administrative appeal. It was not successful, however, and no further challenge to the budget is expected.

Plans for the new airport have met with further complications because of a dispute with United and Continental over financing (*15*). While the future of the new airport is being debated, the noise budget and other controls remain intact.

Seattle-Tacoma

Seattle-Tacoma International Airport (Sea-Tac), operated by the port of Seattle, has long been in the forefront of noise compatibility planning and mitigation efforts. Direct measures to mitigate noise impacts began in 1974 with a home acquisition program that has since grown into a comprehensive

$200 million noise remedy program providing sound insulation and transaction assistance as well.

Since 1983 a noise-abatement staff has also been working with the communities both within and beyond the remedy program areas to reduce the impact of operations from Sea-Tac. A 3-yr flight track project was conducted by a joint citizen-airline-pilot committee to evaluate the levels of compliance to noise-abatement rules (primarily approach and departure flight paths). Recognizing that virtually all feasible efforts had been taken to mitigate jet noise and that most conventional abatement measures had also been identified, the committee recommended the formation of a noise-management project to seek new programs to address the overall amount of jet noise and any possible access restrictions that might be implemented at Sea-Tac. The committee specifically recommended the use of mediation in this process.

A team of two professional mediators was subsequently selected by the committee and hired by the port of Seattle to identify the interests and assemble representatives for the mediation process, develop an overall negotiating process, determine the issues to be discussed, and establish the guidelines under which a consensus will be pursued.

During this preliminary dispute assessment (referred to as a "convening" process), the FAA, airlines, ATA, Airline Pilots Association, airport users, and communities endorsed the project and agreed to participate. Each group comprises a "caucus" that has selected one or two negotiators to represent its interests during the actual mediation. The FAA named senior representatives from the Northwest Mountain Region. Airlines are represented by senior management from two major carriers, another each from cargo and commuter carriers, and by an ATA representative. Airport users are represented by a chamber-of-commerce-based coalition. Five geographical sectors of the community are represented. Approximately 20 negotiators are participating in the mediation, which began in December 1988.

As the focus has turned to the task of carrying out the mediation, the largest obstacle has been the difficulty of identifying an agreeable scope. Whereas citizens want the discussions to focus on capacity issues such as new runways (and even a new airport), the port, the FAA, and the airlines prefer to restrict discussions to ways of limiting current noise levels. Although the situation has not threatened the success of the process, it has been cause for some delay.

Criteria Applied: Measures of Success

With the arguable exception of balanced power relationships, Minneapolis-St. Paul, Denver, and Seattle all meet Susskind and Cruikshank's preconditions to a successful mediation. Although neither Minneapolis nor Denver used assisted (or mediated) negotiation, Table 2 analyzes these examples, as well as Seattle (where mediation has been initiated), in relation to Bingham's model for successful mediation.

Bingham asserts that none of the characteristics shown in Table 2 will by itself determine the outcome of an agreement. Examination of the three case studies, however, demonstrates that the stronger the presence of Bingham's criteria, the more likely that a "win-win" solution will result. The following section will further examine these case studies in detail, and will discuss additional conclusions to be drawn from these efforts.

Direct Participation by Implementing Authority

Each of the three cases examined here benefited from the direct participation of the implementing authority. Both the MAC and the city of Denver participated directly in their respective discussions. Thus, they were able to swiftly carry out those policies to which they (and the other parties) had made a commitment.

The port of Seattle has taken this concept one step further. To ensure participation by the "implementing" authority, full participation by all relevant parties is required. (Because it is unknown what remedies might be recommended as a result of the mediation, the implementing authority may well be a party other than the airport operator.) Moreover, each "caucus" has been asked to select representatives with the authority to direct or implement any actions it endorses. Thus, the port is represented by the director and deputy director of aviation, the FAA is represented by senior management at the region level, and the airlines are represented by senior management as well.

TABLE 2 BINGHAM'S CRITERIA FOR SUCCESS

Criteria	Minneapolis-St. Paul	Denver	Seattle-Tacoma
Direct participation by implementing authority	Yes	Yes	Yes
Preliminary dispute assessment conducted by the mediator	No	No	No
Incentives to negotiate			
Airlines/system users	Mixed	Mixed	Strong
Citizens	Tentative	Mixed	Mixed
FAA	Weak	Weak	Strong
Willingness to identify others' interests and invent mutually satisfactory alternatives	Strong	Strong	N/A

Preliminary Dispute Assessment Conducted by the Mediator

Of the three examples, only Seattle has made a commitment to a full mediation process, including a preliminary dispute assessment. By Bingham's definition, such an assessment involves determination of whether to proceed with a voluntary dispute resolution and, if so, what the nature and rules of that process will be. The port of Seattle extended that role to include a determination of which parties should participate.

Some of the community representatives were hesitant to participate in the process, believing that the real issues—growth and capacity—were beyond the stated scope of the discussions. As a result, the mediators attempted to bring these citizens to the table by soliciting "good faith" concessions from the port. Although no concessions were made, citizens eventually agreed to participate as they came to a better understanding of the process. Despite some concern over this approach, the port staff remains supportive of the concept of preliminary dispute assessment as well as the convening role given the mediator. The staff recognizes that the mediator's primary responsibility to the process, not the sponsor, is a necessary if sometimes unpleasant element of mediation.

Incentives to Negotiate

Incentives to participate may be born of a desire to gain from the negotiation or result from unattractive alternatives to participation. A common problem with distributional issues such as noise, however, is that incentives to participate are often unclear until the process is under way. Often only after groups learn through discussion what can realistically be achieved will they formulate clear incentives to negotiate. Parties with unrealistic goals may therefore refuse to participate, believing they will benefit more from litigation. Because mediation may be difficult to initiate with no clear promise of gain (other than the visible goodwill gesture of participation itself), a preliminary dispute assessment may be warranted in spite of the previously mentioned difficulties.

The perceived balance of negotiating power mentioned by Susskind and Cruikshank may be essential in getting parties to the table. Those with excessive power, such as the airlines, may feel that they will lose it in a consensus-oriented process; those with too little power, such as smaller community groups, may fear that their voice will not be heard. Again, a neutral convenor may be useful in this regard.

Desire for capital improvements at Stapleton, and especially a new airport, brought the airlines to the table in Denver. Of course, this type of enticement is not available to all operators. The greatest incentive to the airlines, therefore, may be the threat of unilaterally imposed restrictions in the event of no agreement. Both Minneapolis-St. Paul and Sea-Tac were able to secure airline cooperation by offering participation in the development of a potentially restrictive program. The airlines chose direct involvement over passive reaction.

Citizens at all three airports have exhibited skepticism of the process and hesitancy to participate. Seattle may be experiencing the most difficulty with citizens, particularly those who were not involved in the Part 150 noise-mitigation planning. In addition to suspicions that the port has ulterior motives for supporting mediation, many citizens may well have unreasonably high expectations resulting from lack of familiarity with the aviation system and noise impacts, and with the mediation process in general. In any case, citizens are facing obstacles in overcoming disorganization and internal discord to achieve workable coalitions. Both the port staff and the mediators are attempting to remedy this situation by working closely with the citizen caucuses, providing technical information as well as seminars and literature covering the principles of mediation.

Conversely, citizens in Minneapolis-St. Paul have been organized and involved in airport issues on a more united front for nearly 20 yr. In addition to developing political savvy, they have become well educated on the complexities of the issues. This has enabled the MAC to work with them on a much more productive level.

Throughout negotiations in all three cases, the role of the FAA has been somewhat tentative, reflecting the conflicting concerns of the agency about federal liability for noise and the efficiency of the national system. Although the FAA supported MAC's efforts in the Twin Cities as an alternative to the establishment of an allegedly illegal ordinance, it refused to participate in the process, preferring to maintain its traditional observer status. Participation by the FAA in the agreement was limited to input at public hearings and comments on objectionable proposals. Beyond traditional objections to interstate commerce restrictions, there was no critical link to the national system.

Evidence exists that the philosophy on federalism may be shifting, or at least adjusting to the realization that the national noise problem is not fully going to be met locally. As Seattle enters the preliminary stage of mediation, the FAA has expressed the desire to participate in the actual negotiations and has supported this by designating senior Northwest Mountain Region officials as representatives.

Willingness to Identify Others' Interests and Invent Mutually Satisfactory Alternatives

Success of the mediation relies considerably on the participants' ability to distinguish positions from interests and thus present a unified position on each issue. Often a party will remain staunchly unyielding on a position, when in fact the underlying interest could be met in a different manner. In addition, each party must make a strong effort to understand the positions and underlying interests of the other participants. If parties fail to discuss their interests openly, the creative development of mutually satisfactory alternatives may be stifled.

This potentially fatal misreading is common to airport development projects, particularly those that enhance (or appear to enhance) capacity. For example, citizens may interpret plans for construction of a parking garage as a means to increase capacity and therefore noise. Their position may be to block construction, when in fact their interest is to reduce aircraft noise levels. All three airports have encountered this problem when plans to expand have become public. The position of many citizens in Denver, Minneapolis-St. Paul, and Seattle has been to block growth. How well parties are able to separate the issues contributes in large part toward their eventual success.

Other Potential Complications to Success

Other factors beyond those suggested by Bingham may hamper a prompt resolution. The following may be particularly applicable to aircraft noise and airport access issues.

Lack of Adequate Technical Information and Understanding

Resolution of airport noise issues is often hindered by insufficient information on all sides. Communities, although growing in political sophistication, are often still uninformed about the myriad technical and operational constraints that limit an airport's ability to implement seemingly simple solutions. Residents may well be ignorant of the national interstate commerce issues. Airport operators do not always have a thorough understanding of the airline scheduling and cost implications of certain restrictive measures. Airlines do not experience the political heat or fully appreciate the responsibilities of the local public officials in some situations. Finally, even the FAA is often unaware of the strength of political pressures emanating from the community. In Seattle, the port authority has expressed willingness to finance the services of independent experts (who would be selected, if necessary, by the mediating parties) to ensure that these issues are identified, discussed, and documented.

Abuse of the Process as a Means of Securing Delay

Those who benefit from a less restrictive status quo (such as the airlines) may attempt to delay or prevent resolution by refusing to participate. A publicized deadline can minimize the use of such tactics. Without imposing a publicly declared 2-month deadline, the MAC might never have secured the voluntary agreements from the airlines critical to their noise budget. Similarly, Denver's use of a 6-month deadline resulted in the establishment of a noise budget within a mere 7 months.

What If Mediation Fails?

In the event the parties fail to reach consensus, the conflict may lead to litigation, unilateral administrative action, or other forms of negotiation. This should not discourage parties from entering into mediation, however. Although a failed mediation may incur additional cost in time and expense, the documentation and exchange of information, as well as the potential for better understanding among the parties, that results from the process can be beneficial in clarifying issues and even accelerating the pace of subsequent measures.

CONCLUSION

Aircraft noise is an inevitable externality of a successful aviation industry. As long as air transportation remains a common form of long-distance intercity travel, communities will be galvanized around the aircraft noise issue with increasing sophistication and effectiveness. In the absence of national guidelines, a number of airport proprietors where high-activity air operations occur will respond with restrictions on access that can decrease the capacity of the system nationwide. If an element of commonality is not introduced into the system, locally based reregulation can ultimately gridlock the system and destroy some of the benefits of deregulation.

The FAA and other elements of the aviation industry have focused on the need for more airports to meet capacity demands. Yet without a better means to deal with the associated noise impacts, it is unlikely that either new airports or other developments to improve capacity will occur.

Currently, the only alternatives to politically inspired local regulation are new federal noise regulation, litigation, and mediation. New national regulations addressing noise beyond the existing programs are unlikely in the current political climate. Litigation is a poor alternative: it is neither inclusive nor flexible and often results in inefficient and inappropriate outcomes. Mediation, if pursued comprehensively, is an approach that can lead to quieter skies while maintaining air transport system capacity. Mediation employs a neutral party to convene the interested parties for developing consensus solutions to a dispute.

As demonstrated by the efforts of the three case study airport authorities, resolution of noise concerns can be well served by voluntary, direct, and ongoing interaction among representatives of conflicting interests. The process of thorough documentation and review can systematically identify and evaluate alternatives for noise reduction.

Capacity concerns can also be served under nationwide use of mediation that documents and quantifies any reductions in capacity and local, regional, and national impact. Direct FAA participation can identify and protect the essential elements of national interest in the air system.

Mediation is potentially a workable and potent solution to a growing problem, but its benefits cannot be realized without a full commitment by all parties. Difficulties will be encountered throughout the process, from deciphering technical data to meeting sunshine laws. Sufficient time and financial resources can help to overcome these obstacles.

Institutionalizing the mediation process by incorporating it into the Part 150 program would benefit not only airport proprietors but the national system. The allocation of Airport Improvement Program funds for such processes would help defray the costs; federal participation would provide the critical link to the national system.

The use of mediation to resolve aircraft noise disputes is still young, and fully conclusive examples are absent. If the current effort at Sea-Tac proves successful, it may be a valuable model for similar situations elsewhere. Continuing attention to the developments in Seattle will be worthwhile as the industry comes to grips with the aircraft noise/airport access dilemma.

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Use of a Knowledge-Based Expert System to Maximize Airport Capacity in Harmony with Noise-Mitigation Plans

ROGER L. WAYSON

Noise control and capacity are major concerns at many major airports. Expected growth will exacerbate these problems. Because of high cost and public opposition to new facilities, managers are trying to squeeze what they can out of the existing airports. Unfortunately, requirements for noise control and capacity are seldom in harmony. An appropriate balance between noise abatement and capacity requires considerable analysis and compromise. The overriding concern at many airports is compliance with noise limits mandated by law or regulation. Effects on capacity are secondary as long as they do not interfere with regular operations. However, congestion and delay during peak hours are forcing some airports to reevaluate their noise-abatement strategies. New computer tools are needed by the airport operators and noise-control specialists to analyze the effects of noise-mitigation measures on capacity. The use of artificial intelligence may be one way to use computers to assist in the noise mitigation/capacity analysis. This paper explores the use of expert systems, a subset of artificial intelligence, to accomplish this goal. Rule formulation is derived to permit analysis of the effects of noise-control strategies on capacity. Two attempts to incorporate these rules into a knowledge-based expert system commercial shell are discussed. The first attempt was only partially successful but highlighted the need to carefully review the limitations of any selected shell. The second attempt proved much more successful and showed good agreement with opinions obtained during interviews at selected airports. This work indicates that expert systems may be used to seek an optimum balance between noise mitigation and airport capacity.

Aircraft noise and inadequate capacity are vexing problems at many major U.S. commercial airports. Aircraft operations are expected to increase, and this will exacerbate the problems. J. Donald Reilly of the Airport Operators Council International recently stated that "the lack of adequate capacity will be the major problem facing U.S. aviation over the next fifteen years" (*1*). Because of the high cost and public opposition to new facilities, management is trying to squeeze what it can out of existing airports. Only in a few cases, such as Denver, are new airport facilities being considered. However, the interest of airport neighbors in aircraft noise control is often at odds with efforts to increase airport activity. Optimization of each (noise abatement and capacity) in the limits possible requires considerable analysis and compromise.

To analyze the effect of noise-mitigation measures on capacity, new computer tools are needed by the airport operators and noise-control specialists. The use of a subset of artificial intelligence (AI) called expert systems may be one way to effectively use computers to assist in the noise mitigation/capacity analysis. Correct implementation of such software could allow concurrent evaluations of noise-control plans and effects on capacity. This paper explores the use of expert systems to accomplish this goal.

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APPLICABILITY OF EXPERT SYSTEMS TO AIRPORT CAPACITY/NOISE-CONTROL ANALYSIS

Before beginning a detailed discussion of expert systems, a brief overview is necessary. Expert systems are a subset of the field of AI, which is a branch of computer science. Artificial intelligence is an attempt to copy the way humans think. Many advances have been made in AI, including natural language processing (the ability to understand the written or spoken word), pattern recognition (the ability to see and recognize an object), robotics (the ability to move or accomplish physical tasks), and development of expert systems (simulation of how humans gather and process information to solve specific problems).

A human expert uses education and experience to solve particular types of problems, usually in a narrow (specialized) scope. The expert uses established rules and sometimes rules of thumb (heuristic rules) to develop a solution. Judgment, reasoning, and the ability to make decisions are all required in the solution process. A computer program that solves problems in a similar way, using knowledge contained in the program, is known as a knowledge-based system.

In the computer, knowledge is represented as rules or attributes. A rule is simply a logical progression based on facts. An example of a rule is

If an object is an animal,
And the animal has feathers,
Then the animal is a bird.

The use of attributes in the program is a way to associate properties with an object. For example, the object, bird, may have a list of attributes recognized by the program, of which one could be feathers. Accordingly, the computer would "associate" birds with feathers. This association could be used to control processing of information.

It is important to understand how an expert system pro-

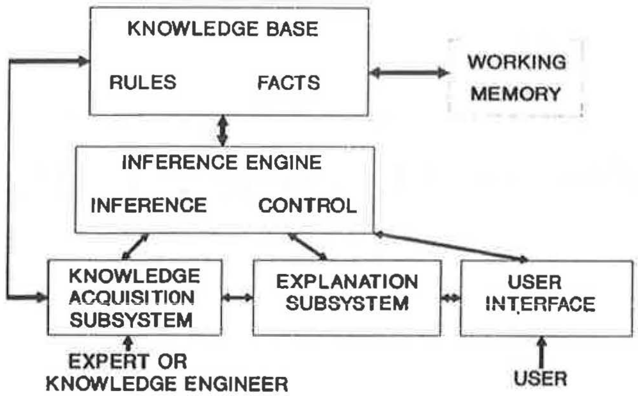


FIGURE 1 The architecture of a knowledge-based expert system (*2*).

cesses information. Conventional computer programs organize knowledge on two levels (data and program), but most expert systems organize knowledge on three levels (data, knowledge base, and control). Knowledge-based expert systems (KBES) differ from conventional programs because the problem-solving model is treated separately, rather than appearing only implicitly as part of the program. This part of the KBES (control) is known as the inference engine and selects sections of the overall program as needed to reach a conclusion.

Conventional programming algorithms have been used in design application programs in an attempt to incorporate expertise from data bases in the form of chained logic trees. The major developments in knowledge engineering, however, have occurred when the problem-solving techniques (the inference engine) and the domain-dependent knowledge were separated, permitting the continual addition of new domain knowledge within the existing problem-solving framework. This concept is shown graphically in Figure 1 (*2*). Also of note in Figure 1 is the division of the system into independent subsystems, which allow working memory to be stored, explanations to be provided to the user, and a user-friendly interface to be used. This KBES computer methodology could be very useful to airport officials.

The way in which rules are applied is usually graphically shown by the KBES in a logic tree. The logic tree shows the progression of the rules as applied for a particular input and problem by the KBES. It should be noted that different input for the same problem would result in a different logic tree. The logic tree is very important because it allows the user to review how the particular decision was reached.

There are three general categories of KBES development settings: languages, environments, and shells. An AI language, for example LISP, allows flexibility in programming but is time consuming to implement because the program must be developed from "scratch." Environments are less flexible but have many programming helps available to speed up the programming effort. Shells are the least flexible but very quick to implement because they are essentially an empty expert system with an inference engine waiting for rules and attributes. Because of time constraints and the nature of the project, a commercially available shell was chosen. In this way, quick prototyping could occur, allowing an analysis of the practicality of KBES for the problem at hand: airport capacity/noise-mitigation measure relationship.

Expert systems are increasingly applied to complex, real-world problems (*3–6*). Artificial-intelligence methods were seldom used in civil engineering before 1970. One of the first applications was developed in 1966 at the Massachusetts Institute of Technology by M. L. Manheim, using a hierarchical structure to decide highway location (*7*). Simple rules were used and the applications were limited. Manheim demonstrated, however, that AI could be used for decision making in civil engineering. After 1982, interest in the use of expert systems grew quickly, and extensive applications of AI in the field of civil engineering have been documented (*8*).

A KBES computer tool could be used by airport operators and noise-control officers to model and help optimize the balance between airport capacity and the noise-control goals. The knowledge base of the expert system could also provide guidance during evaluations, run separate conventional language programs to perform evaluations of various scenarios, and be much more user-friendly than conventional programming.

The use of a KBES instead of a conventional program to help solve the problem of developing airport capacity in harmony with noise control is indicated because, although many tasks are mathematical or occur in repeated patterns (logical rules), others are based on experience (heuristic rules). A KBES, unlike conventional computer languages, can easily accommodate both types of rules and the knowledge base can constantly be updated without reprogramming. Accordingly, a KBES acting as an interactive, user-friendly computer program could incorporate judgment, experience, rules of thumb, intuition, and other expertise to provide knowledgeable advice that would be difficult in any conventional programming.

KBESs have other advantages over strict logic programming because of the use of attributes (object-oriented programming) and the transparency of dialog and knowledge representation.

By allowing attributes to be associated with items, such as separate noise-control strategies, properties are associated with that item. This allows "decisions" to be made not only with specific rule programming but also by allowing noise-control strategies to be evaluated by their properties. The logic tree can grow continually as various forms of knowledge (rules, data, or attributes) are added to the system without changing the logic used in processing. Transparency of dialog and knowledge representation allow the user to be concerned only with relevant data for the program operation (i.e., user-friendly screen prompts), without specific data formats. In effect, the user "consults" with the software by supplying only the needed information, without becoming involved in the processing or decision making. Information can be stored in the knowledge base and be increased incrementally as system knowledge grows, without the program having to be redefined.

KBESs are usually developed through the cooperation of a "knowledge engineer" and a technical expert. For the purposes of this prototype work, the author has applied himself to the role of knowledge engineer. Technical expertise was obtained from the staff of the FAA and interviews with four airports that have active noise-control programs (Los Angeles International, Seattle-Tacoma, John Wayne/Orange County, and Nashville International).

The benefit of using a KBES may be best illustrated by an example. The management of Atlanta's Hartsfield International Airport analyzed the effects on capacity of noise-control programs (*9*). A detailed analysis was performed to relate noise-abatement measures to aircraft delays. Results showed that noise-abatement restrictions could cause up to 56,800 hr of aircraft delay annually by 1996. Various noise-control options were analyzed using the Airfield Delay Simulation Model (*10*) and the Capacity Delay Model (*11*).

The noise-abatement strategies were suggested by the airport management, and had probably been developed through experience and trial and error. In this instance, the list was probably complete. Had the staff been inexperienced, however, it would have been very difficult to develop a comprehensive list. The use of a KBES could allow such analyses to become commonplace, conform to FAA guidelines, and enable junior staff to produce useful results with minimal supervision.

Other benefits of the KBES are an expedited FAA review of local efforts and the fact that alternatives are less likely to be overlooked. A preprocessor might have helped to speed up the analysis and add accuracy to the overall procedure in Atlanta by selecting analytic programs and assembling data files. However, system control, guidance, decision assistance, and acquired knowledge would still have been absent. The use of an expert system could overcome all of these problems.

An expert system is not a substitute for professional judgment, but it can provide guidance, especially to junior staff. FAA-accepted practices and solicited expert opinions can be built into an expert system. In addition, local experience can be recorded so knowledge is not lost through personnel turnover.

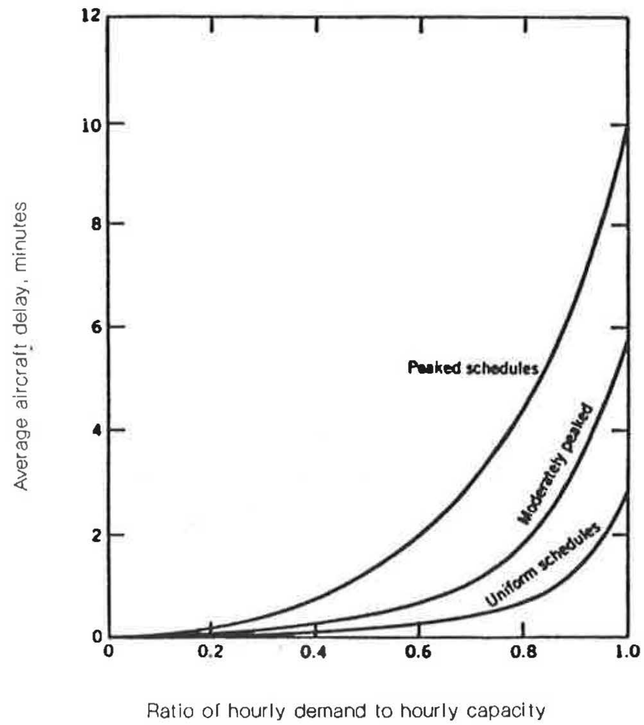


FIGURE 2 Relationship of demand-capacity ratio and demand fluctuation to average hourly aircraft delay (*15*).

CAPACITY AND ITS RELATION TO NOISE ABATEMENT

Airport capacity can be expressed for a variety of time periods, including hourly capacity, daily capacity, and annual service volume. Annual service volume and daily capacity are relatively insensitive to noise-control measures.

Hourly capacity is more responsive. This short-term measure is particularly useful in determining the effects of restrictions on airport operations during peak "push" hours, when capacity is under the greatest strain. Figure 2 shows this concept graphically. As demand increases (all other parameters held constant), the ratio of hourly demand to hourly capacity increases, causing increased delays. Any operational procedure such as noise mitigation that reduces hourly capacity increases delay. If the ratio of demand to capacity exceeds 0.8, even a small increase in demand or reduction in capacity will cause a substantial increase in delay.

Many airport planning studies refer to "practical capacity," which corresponds to a "reasonable" or "tolerable" level of delay (*12, 13*). That is, delays to departing aircraft of a predetermined length of time (often an average of 4 min) may be acceptable during the two adjacent peak hours of the day. For purposes of analysis, however, the FAA-recommended capacity measure is the "ultimate" or "saturation" capacity (the maximum number of aircraft that can be accommodated per unit of time without regard to delay) (*14*). For the purpose of this study, "ultimate" hourly capacity will be used as a reference when evaluating effects on capacity.

Hourly airport capacity is a function of taxiway, runway, airspace, and gate capacity. Different noise-control measures affect different combinations of these components. The capacity of each component is independent and for all but airspace capacity can be calculated using the methodology in *Airport Capacity and Delay* (*14*). Effects of noise-control measures on capacity can be analyzed by comparing the calculated capacity of the airport before and after the imposition of a noise-abatement measure.

Subcomponents of the airport hourly capacity (C_h) are mathematically defined in the FAA circular as

Runway: $C_h = C^* \times T \times E$ (1)

where

C^* = hourly capacity base,
T = touch and go factor, and
E = exit factor.

Taxiway: defined by graphs (*15*)

Gate: $C_h = G^* \times S \times N$ (2)

where

G^* = gate capacity base,
S = gate size factor, and
N = number of gates.

A graphic of how this methodology is used for runways is shown in Figure 3. The taxiway hourly capacity is selected from a graph and the gate capacity methodology is similar to the runway method.

The saturation airspace capacity may be calculated by using the error-free separation space as the maximum throughput capacity and calculating the increased separation space and

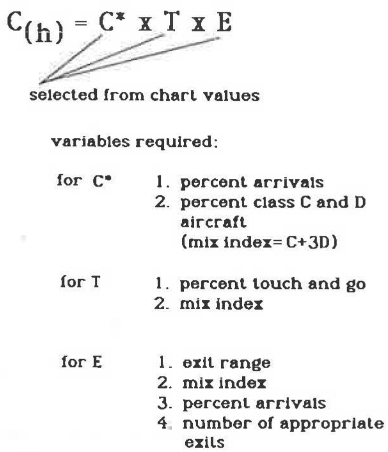


FIGURE 3 Visual description of FAA runway capacity evaluation (as defined in text).

therefore decreased airway capacity. This concept is graphically shown in Figure 4. Mathematically this reduces to (*15*):

1. Aircraft overtaking lead aircraft:

$$m(v_2, v_1) = L_s/v_2 \qquad (3)$$

2. Lead aircraft faster than following aircraft:

$$m(v_2, v_1) = L_s/v_2 + L[(1/v_2) - (1/v_1)] \qquad (4)$$

where

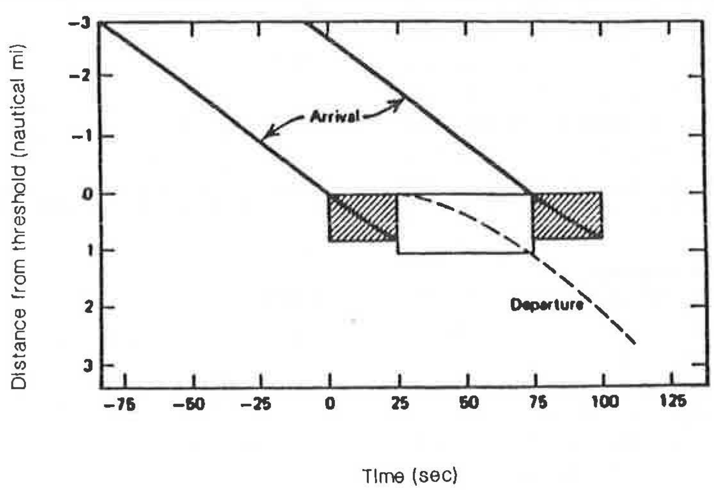
$m(v_2, v_1)$ = error-free minimum time separation over threshold for Aircraft 2 following Aircraft 1,
v_1 = speed of lead aircraft,
v_2 = speed of following aircraft,
L_s = minimum safety separation, and
L = length of common approach.

The value $m(v_2, v_1)$ could be calculated and compared with the increased time needed for the increased separation distance. From this increased time, the reduced amount of aircraft permitted to land could be calculated and the effect on capacity determined. For example, implementation of a noise-control measure that affects airspace would increase L_s from the minimum safe separation and could change L. Inserting the new variable values and making a comparison with the minimum-separation case would provide a measure on the effect of the airspace component on throughput capacity.

To evaluate how noise-control measures affect each subcomponent of capacity, strategies in effect at major U.S. commercial airports were evaluated. The FAA maintains a comprehensive listing of airport noise-control actions in its Airport Noise Control Strategies Data File (*16*). This data base includes approximately 400 airports, which accommodate more than 95 percent of the total U.S. air traffic (*17*). Thirty-seven noise-control strategies have been identified and are listed in Table 1. Some of these 37 noise-control strategies do not affect capacity directly. Numbers 1 through 8 are commitments to allow proper planning and policy analysis. Noise-control strategies numbers 27 through 33 involve land use control or insulation. These strategies reduce constraints that would otherwise be placed on airport capacity because of noise-mitigation measures but do not directly affect capacity. These 15 strategies contain components related to capacity but in themselves do not affect capacity and need not be considered further.

Control measure No. 9 (Restriction on Ground Runup) does not affect capacity if implemented. Control measure No. 26 would have to be evaluated on a case-by-case basis. Control measure No. 35 could reduce delay by the redistribution of traffic between two airports, but the capacity of the airport under evaluation would not change. These noise-control measures were not included in the prototype KBES development.

The remaining 19 noise-control strategies (numbers 10 through 25, 34, 36, and 37, which are shown in bold type in Table 1) can have a direct effect on airport capacity. To deter-



NOTE: Open box = runway occupied by departure. Cross-hatched box = runway occupied by arrival.

FIGURE 4 Time-distance diagram for two approaching and one departing aircraft (*15*).

TABLE 1 FAA NOISE-CONTROL STRATEGY CATEGORIES

CATEGORY NUMBER	DESCRIPTION
1	STATE NOISE LAW
2	LOCAL NOISE LAW OR ORDINANCE
3	AIRPORT MASTER PLAN
4	ANCLUC PLAN
5	PART 150 NOISE EXPOSURE MAP APPROVED
6	PART 150 NOISE COMPATIBILITY PLAN APPROVED
7	DEVELOPMENT OF AN EIS
8	NOISE MONITORING EQUIPMENT: TEMPORARY OR PERMANENT
9	RESTRICTION ON GROUND RUNUP
10	**LIMIT ON THE NUMBER OF OPERATIONS BY HOUR, DAY, MONTH, YEAR OR NOISE CAPACITY**
11	**PREFERENTIAL RUNWAY SYSTEM**
12	**RUNWAY RESTRICTIONS IMPOSED FOR SPECIFIC AIRCRAFT TYPE**
13	**USE RESTRICTION BY AIRCRAFT TYPE OR CLASS**
14	**USE RESTRICTION BASED ON NOISE LEVELS**
15	**USE RESTRICTION BASED ON PART 36**
16	**USE RESTRICTION BASED ON AC 36-3**
17	**COMPLETE CURFEW**
18	**ARRIVALS AND/OR DEPARTURES OVER A BODY OF WATER**
19	**DISPLACED RUNWAY THRESHOLD**
20	**ROTATIONAL RUNWAY SYSTEM**
21	**MAXIMUM SAFE CLIMB ON TAKEOFF**
22	**TAKEOFF THRUST REDUCTION**
23	**REVERSE THRUST LIMITS**
24	**FLIGHT TRAINING RESTRICTION**
25	**WEIGHT OR THRUST LIMIT**
26	INFORMAL FLIGHT OPERATION RESTRICTION
27	ZONING
28	PURCHASE LAND FOR NOISE CONTROL
29	USE OF CAPITAL IMPROVEMENTS TO DIRECT DEVELOPMENT
30	BUILDING CODES AND PERMITS TO CONTROL NOISE
31	NOISE EASEMENTS
32	PURCHASE ASSURANCE
33	SOUNDPROOFING PROGRAMS
34	**NOISE USE FEES**
35	SHIFT OPERATIONS TO A RELIEVER AIRPORT
36	**LOCAL PATTERN RESTRICTIONS**
37	**NAVIGATIONAL AID ASSISTED DEPARTURE**

mine which components of capacity are affected, the required input data for the FAA capacity model was evaluated for each FAA-listed control strategy. Table 2 lists each capacity component and the data input required to use the FAA methodology of evaluation.

The use of measures 10, 11, 17, 20, 23, and 24 places restrictions on runway use and so limits runway and taxiway capacity.

Measures 12 through 16, 19, 25, and 34 require changes to both the runway and gate usage. In addition, because these strategies directly affect fleet mix, the number of passengers that may be accommodated could also be affected.

Controls 18, 21, 22, 36, and 37 affect flight paths and circulation, and may reduce capacity by diverting aircraft from the most direct route. This occurs off airport property and usually before the final glide path. The effect on saturation capacity may be calculated if the increased flight distance can be estimated, as previously discussed.

Capacity measure evaluations must be chained to the appropriate noise-control strategy in the KBES to permit analysis of the selected noise-control measure.

The effect of airport noise on surrounding communities is usually measured by the population residing within the area that equals or exceeds the noise level of 65 dB, L_{dn} on the "A" scale. L_{dn} is the cumulative sound energy over a 24-hr period, adjusted to include a 10-dB penalty for noise exposure occurring during nighttime hours (10:00 p.m. to 7:00 a.m.). The "A-weighted" scale is an approximation of the way the ear would perceive the sound, accounting for frequency components. Levels above this metric (65 dB, L_{dn}) are considered to interfere with activities at sensitive receivers (i.e., resi-

TABLE 2 REQUIRED INPUT DATA FOR THE FAA THROUGHPUT CAPACITY METHODOLOGY (*14*)

OUTPUT	INPUT NEEDED
1. Hourly capacity of runway component	a. Ceiling and visibility (VFR, IFR, or PVC) b. Runway-use configuration c. Aircraft mix d. Percent Arrivals e. Percent touch and go f. Exit taxiway locations
2. Hourly capacity of taxiway component	a. Intersecting taxiway location b. Runway operation rate c. Aircraft mix on runway being crossed
3. Hourly capacity of gate group components	a. Number and type of gates in each gate group b. Gate mix c. Gate occupancy times
4. Airport hourly capacity	Capacity outputs from 1,2, and 3 above

dences, hospitals, homes for the aged, and so on). Accordingly, it is important to determine the number of receptors subjected to levels above this criterion. Aircraft noise levels in excess of 65 dB, L_{dn}, are generally encountered on or near the airport and are usually described graphically by a noise contour that surrounds the airport. *Airport Environmental Handbook* (*18*) describes the noise criteria in more detail.

Various mathematical models are used to determine the location of the 65-dB contour. An expert system could be used to help select the proper analysis method and act as a preprocessor to run the appropriate model externally from the KBES. The result would be reported to the user and could be added to the KBES knowledge base.

For example, if control measure No. 13 (Use Restriction by Aircraft Type or Class) were imposed, then the fleet mix would change, affecting capacity. The noise contours (airport "footprint") would change as a result of changes in the aircraft fleet. The FAA's Integrated Noise Model (INM) could be used to evaluate the change in the noise contour (*19*). The input file for the FORTRAN model (INM) would be developed by the KBES from stored knowledge and information. If other data were needed to complete the input file the user would be prompted by screen formats for any additional required data. Once the proper input file was prepared, INM would be executed by the KBES. After processing, the KBES would report results to the user (both noise and capacity). Various scenario outputs could be stored for future reference. Statistical interpolations could be performed by the KBES to present alternative levels of implementation, to allow the user to determine if the noise-control measure should be implemented in whole or in part.

In this way, working interactively with the KBES, compromises could be made to allow the noise-abatement goal to be reached (perhaps by suggestions to use other control measures in conjunction with control measure No. 13) while it was ascertained that required capacity for needed operations was not lost. In some cases this may not be possible; and this, along with the effect on capacity, would be reported to the user. At this point, further consultation (user with KBES) could occur to provide evaluation of other possible scenarios that would be suggested by the KBES.

In some cases other noise-control metric methodologies may be required. For example, if control measure No. 18 (Arrivals and/or Departures over a Body of Water) were proposed, use of the INM model alone might not be adequate. After determining the effect on capacity, the KBES could compare the land area and population of the affected residential zones before and after imposition of the measure, using demographic and cartographic data maintained in the knowledge base. The effectiveness of noise-control measures could be determined through comparisons of the population submitted to noise levels above a threshold.

SELECTION OF A KBES SHELL FOR PROTOTYPE DEVELOPMENT

An airport capacity/noise-control model could use a language commonly used in AI such as LISP, OPS-5, EXPERT, PROLOG, DUCK, SMALLTALK, FLAVORS, KEE, or LOOPS. The resulting model would be flexible and could be programmed to handle most conditions. As previously discussed, however, an expert system "shell" would allow quick development of the prototype. So, although use of a commercially available shell involves some loss of flexibility and generality, the time savings make this approach more desirable. Important considerations in selecting a system include the type of chaining (forward or backward), reasoning method (rule-based or inductive reasoning), allowance for degree of certainty of answer, text and graphic capabilities, data interface, the ability to interface with other languages, the ability to display the logic progression, hardware requirements, and price.

A backward-chaining KBES was initially thought to be desirable for this analysis, because the hypothesis that there exists a best noise-control measure that sacrifices the least capacity for given conditions was well defined. A rule-based system also seemed appropriate, because most considerations would be mathematical, legally enforced and required, or based on past experience (heuristic rules). As such, rules could be defined to drive the inference engine and be evaluated by the system using properly phrased questions, presented to the user as screen prompts. Additionally, rules could easily be added to update the system, change operational considerations, and modify the system for individual airports.

Logical rules were developed for the various noise-control strategies. For example, strategy Number 13 (Use Restriction by Aircraft Type or Class) would affect the aircraft fleet mix, causing hourly runway capacity to change. The new mix might also cause taxiway capacity to change. The gate mix would likewise be affected. All of these subcomponents of airport capacity must be considered together to determine the cumulative change in airport capacity. Because each is independent, the component with the greatest effect would be the limiting factor.

Heuristic rules are rules of thumb and experience gathered over long periods of time, usually by trial and error. For example, if strategy Number 25 (Weight or Thrust Limit) were implemented, airlines might not be able to make long-haul flights from the airport because of limits on fuel loading required. The KBES must also "consider" the number of seats available if aircraft size is limited and compare that information with the demand for air travel. The effect of thrust limits on aviation safety would also have to be considered. Accordingly, heuristic rules must also be formulated and expressed in a form usable by the KBES.

The ability to determine the probability that an answer is correct was thought to be only slightly useful for this prototype project but could be important if a full system were implemented. Text and graphic capability was thought to be important for reporting the results of the analysis, especially for the logic tree. The ability to display the logic progression is essential to inform the user of the basis for KBES decisions. The ability to interface with data bases and programs in other source languages is desirable to allow efficient calculations, run other models, and access past data. Hardware was limited to personal computers.

Many AI "shells," ranging in price from $99 to $7,500, fulfilled these requirements to varying degrees. Funding limitations for the project determined the selection. Two commercial tools that met most of the prescribed requirements, INSIGHT-2® and DECIDING FACTOR®, were available to the author without cost. DECIDING FACTOR seemed more applicable because of its flexible input format (to allow easy rule addition). Also, although DECIDING FACTOR cannot access data files or other programs, it does allow the user to exit the program and return after performing other operations. Accordingly, DECIDING FACTOR was the first choice for this project. Unfortunately, attempts to duplicate results of studies by trained experts using the developed DECIDING FACTOR KBES were only partially successful. Evaluation and troubleshooting revealed that the selected shell and developed rules were incompatible in some ways. It was difficult to program noise-control measure attributes (as rules) to be sufficiently recognizable during operation. This impeded attempts to program broad heuristic rules and led to the input of many specific rules. The inability of the shell to run external programs also proved to be a problem, requiring the user to exit the program and return to complete the analysis. With proper programming, most of these problems could have been overcome, but only with limitations.

To help overcome these limitations, a second KBES shell, VP-Expert®, was purchased. This shell was more flexible in rule recognition and allowed interfacing with external programs to build the input data files and execute programs. Output data could be imported to the KBES shell and stored in the knowledge base.

RULE DEVELOPMENT

The preliminary work involved the use of DECIDING FACTOR. The process begins with a top-level hypothesis that the user would like to test. For example, for this KBES development the goal is to determine which noise-control measures could be implemented to meet noise criteria while minimizing effects on capacity. Noise controls are assumed to be independent of each other. The hypothesis is inferred from a series of intermediate goals also placed in a question format.

An intermediate goal is treated as a hypothesis with lower-level evidence to determine its truth value. For example, the intermediate goal: "Is the selected noise-control measure infeasible?" is solved by the KBES by reviewing the knowledge base on the selected control measure, which contains a list of types of control measures and their attributes (in rule form). The knowledge is stored by the program in a logic structure that might be compared to a pyramid. The top-level diagnosis is supported by lower-level inferences, based on factual assertions (rules). The outcome of rule "decisions" is based on information contained in the knowledge base and by responses given by the user to support decisions above it.

Each leaf (node) of the logic tree corresponds to a question that the user will be asked if the data are required for processing. The weighting of the final answer (the goal) is determined by the answers the user supplies along the path through the "leaves" or nodes. Figure 5 shows a simple diagram of how this logic tree was implemented into the KBES shell. For the first shell development (DECIDING FACTOR), answers to screen prompts can be rated by the user on a variable scale (based on a rating of -5 to $+5$, where -5 is a no and $+5$ is a yes). The ratings reflect the certainty of each answer, an elementary form of fuzzy reasoning.

The questions direct the line of reasoning so as to arrive at the top of the "tree" and derive a course of action that will satisfy noise criteria while allowing the maximum capacity. Each decision leads to the overall conclusion of which noise-control measures should be implemented, at what degree, to allow the least effect on capacity. Subsequent runs of the system could define additional courses of action as different control measures are selected by the user.

By combining the expert's knowledge, represented by rules programmed in the inference tree, the DECIDING FACTOR

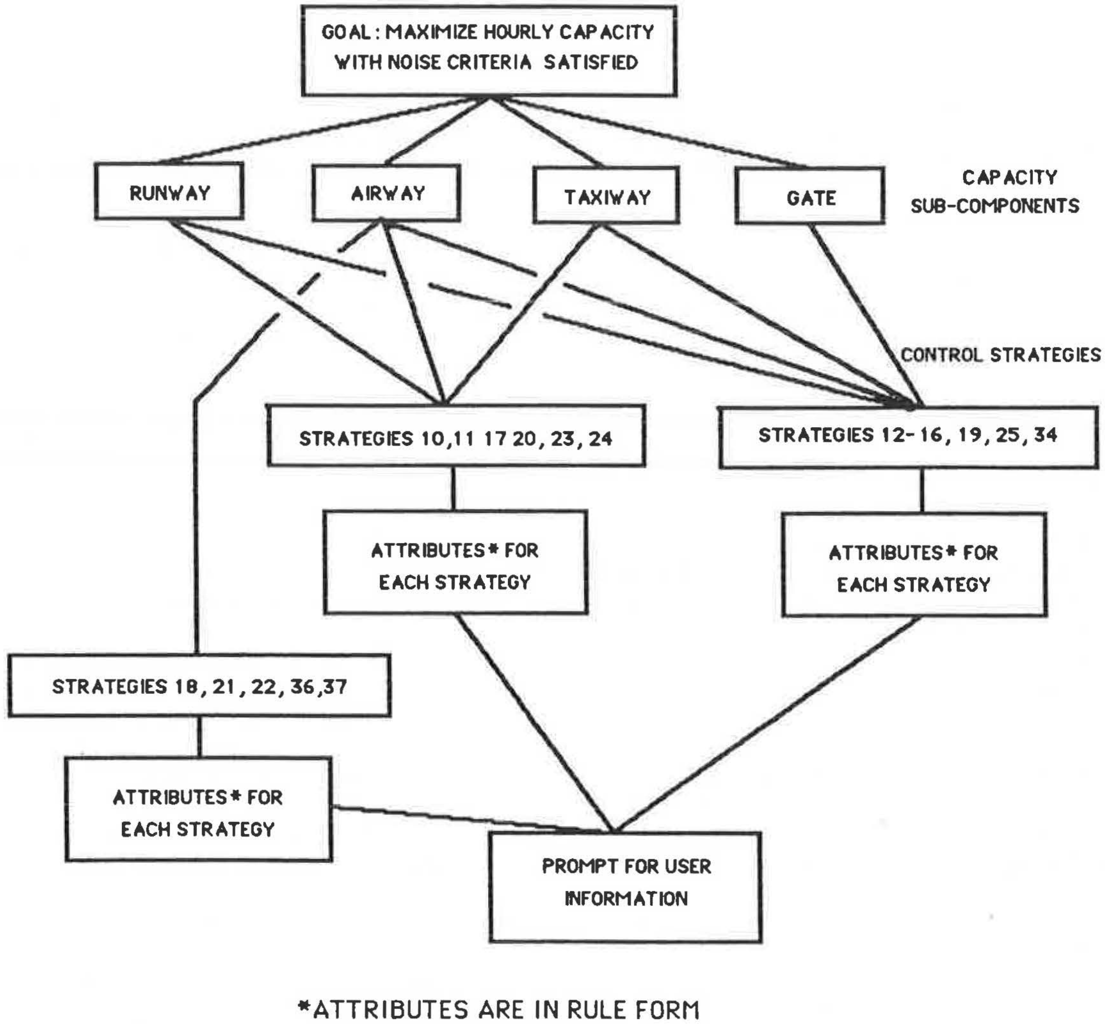


FIGURE 5 Simple diagram of rule hierarchy from domain engineering development.

shell allows intelligent natural language explanations of the reasoning paths. The shell can also provide additional background information entered by the knowledge engineer to elaborate on the required input. This allows explanations of questions asked of the users, to avoid confusion and ensure correct information entry. Input is facilitated by self-explanatory, graphic prompt screens. An example computer input screen for the DECIDING FACTOR shell is shown in Figure 6. This figure shows a simple question that only requires the "bar" to be slid (using a mouse or arrow keys) to the appropriate point to answer the question. The user is shown the answer to ensure correctness. For example, in Figure 6, the bar is in the center (at 0), so the corresponding answer DON'T KNOW (numeric value of 0.0) is displayed. The importance of the question to the solving of the goal is also presented. Other screens only require selection from several presented answers or input of numeric values.

This brief discussion of the shell DECIDING FACTOR should be sufficient to allow the reader to understand how this particular KBES shell was developed. Additional details are available in the software user's manual (*20*). Even though this selected shell was only partially successful at duplicating the findings of experts, the author believed that the relationship of capacity to noise control was suitable for analysis by AI and that the concepts developed to merge these two issues were correct. Accordingly, a second shell was obtained and the basic rule structure developed in the first shell was adapted for the second shell.

The limitations of the original shell had led to development of many rules that encumbered the shell. The second attempt, using the VP-Expert model, did not include the entire planning process. The effort was concentrated on the noise-control measures that directly affected all four subcomponents of capacity: Control Strategies 12 through 16, 19, 25, and 34 (see Figure 5). This work was sufficient for proof of the concept that AI can help to achieve a balance between noise and capacity.

The domain knowledge that had been gathered and pieced together in the development of the first KBES was used to guide quick programming of the VP-Expert shell. As before, the software development involved a predefined inference engine, user interface, and commands unique to the shell. The reader may wish to review the user manual (*21*) for complete implementation details. The same logic-tree structure

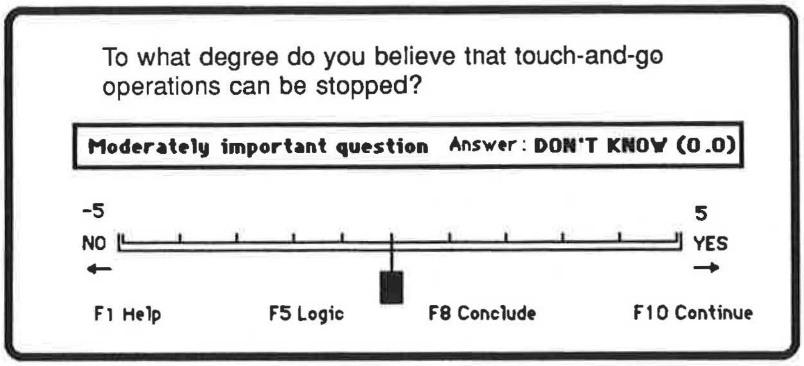


FIGURE 6 Image of screen used in DECIDING FACTOR to prompt user for answer and limit of belief.

was used and changed as appropriate (rules, data, or knowledge) in each leaf (node). VP-Expert permits rules to be used as needed. The knowledge engineer is permitted to program rules without assigning the order in which rules are to be executed. The software ensures that all applicable rules are implemented during the decision process. Conclusions cannot be drawn on the basis of partial information, which was a problem with the first shell. Alternate scenarios may be treated in different ways and heuristic rules are more easily applied to the program. Attributes are included as clauses. For example, a typical clause used as an attribute is:

IF STRATEGY_NO = 12 THEN RUNWAY31_CAP = 0 DISPLAY "RUNWAY 31 CAPACITY WILL NOT BE AVAILABLE. IS THIS ACCEPTABLE?"

Based on the user answer, Control Strategy 12 will either be further evaluated or dismissed as infeasible.

After implementation of all rules, an initial evaluation of the model was conducted based on information gained in interviews at the four airports. This evaluation is discussed in the next section.

EVALUATIONS AND RESULTS

To evaluate the implementation of the KBES, tests were conducted for each defined strategy (noise-control strategies numbers 12 through 16, 19, 25, and 34). For example, it was assumed that an airport wished to evaluate the effect of implementing noise-control strategy Number 14 (Use Restriction Based on Noise Levels). As illustrated in Figure 7, the program first tests the strategy to determine if it is among the 19 FAA-defined control strategies that were determined to affect capacity (TESTING 1). The KBES determines this by comparison with a listing. If it is not among the list, the KBES advises the user that this strategy will not affect capacity and asks if the user would like to continue the evaluation. If it is among the list of the 19 control measures that affect capacity, the first attribute rule for that particular control strategy is applied. In this simple, prototype case, the KBES first determines if the airport is an international airport (shown as TESTING 3 in Figure 7). If so (TESTING 4 in Figure 7), the heuristic rule attribute for international airports is "fired." This programmed attribute recognizes that international and hub airports support many long-haul operations requiring particular aircraft and full fuel loading. The KBES delineates which aircraft are required for these operations (again from a list) and determines the sound-level contribution for each [based on *Estimated Airplane Noise Levels in A-Weighted Decibels* (*22*)]. These aircraft types are matched with a list of the aircraft types that use the airport. The noise level for each match is compared with the noise-level restrictions proposed by the airport. The list may vary with time of day, such as at John Wayne Airport, where lower noise limits are imposed at night. If the effect of limiting those aircraft that exceed specific noise levels is determined to be detrimental to the airport, this fact is reported to the user. If it is not considered detrimental, or if the airport is not a hub or international airport, then the analysis is allowed to proceed (TESTING 4 to CONTINUE 2).

At this point (TESTING 5) the selected strategy is reevaluated to determine what subcomponents of capacity are affected and how. Noise-calculation programs are then called and executed (with the KBES constructing the input file by calling programs written in other computer languages) to determine noise-abatement effectiveness. It should be noted that the KBES "remembers" the control strategy attributes and calls the appropriate rules (TESTING 5 and TESTING 5.1). Decisions are thus made on the strategy number based on rule attributes with no user input. In other words, based on the knowledge engineer's rules, the program makes "decisions" and only asks for information from the user when required. Finally, the effect on capacity is determined (STEP 3). Values for chart variables from *Airport Capacity and Delay* (*14*) were supplied manually for this prototype development. Full development should use the FAA computer model for capacity computations.

If another noise-control strategy had been selected, the rules would not have occurred in the same way and the same rules might not have been used. For example, if Control Strategy Number 11 (Preferential Runway System) had been selected, after determination of whether the selected strategy was among the 19 defined control measures that affect capacity, the first question would have been: Does the airport have sufficient capacity to limit runway use during peak hours of operation? Rule firing would have been based on this rule to begin the line of reasoning.

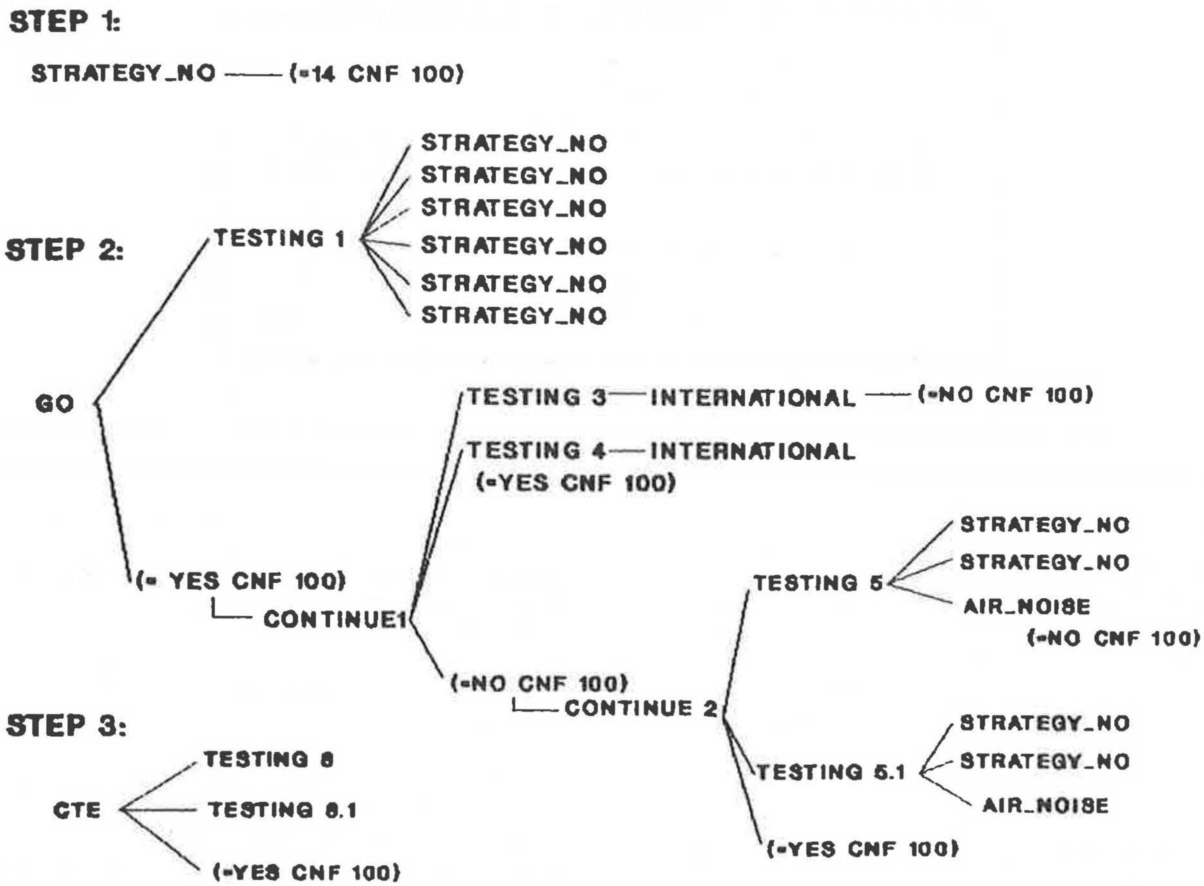


FIGURE 7 Flow chart displaying evaluation of noise-control measure No. 14 for hypothetical airport.

Simple analysis of the other defined control strategies (numbers 12 through 16, 19, 25, and 34) was conducted using VP-Expert and reasonable results were obtained consistent with what was expected from interviews conducted at the four airports. It should be noted that the results were considered consistent with airport opinions. Numerical evaluations were not possible because airports generally did not know how much airport operations were actually being affected by implementation of noise-control measures. For example, one airport reported that a preferential runway noise-control measure (noise-control strategy No. 11) reduced capacity by "about one-fifth." For this test case, capacity was predicted by the KBES to decrease by 16 percent. This was considered to be a very good result and to support the use of KBES in assisting airports in noise/capacity analysis. It is unfortunate that other more definitive testing did not materialize.

CONCLUSIONS

The use of KBESs in airport planning, specifically concerning noise control in harmony with capacity, would provide a valuable tool for the airport operator/noise-control officer to assist in efforts to keep up with the growing demand in air travel. The idea of using the 19 defined noise-control strategies with the defined FAA throughput capacity methodology in a KBES seems to be a promising analytic tool for evaluating the independent runway, taxiway, and gate components of capacity. Airway components of capacity would need to be evaluated using other methodologies, such as the minimum safety clearance between approaching aircraft as a degree of saturation capacity. The ratio of change could then be used to determine change in overall capacity. Although the first attempt to use a KBES was only partially successful, it allowed development of the rules needed to implement a useful KBES. The second attempt, based on the evaluation of the model from the first attempt, proved much more successful. More research is needed, and the next effort could be based on the results found during this project. Any selected shell should allow attributes of noise-control measures to be entered easily and recognized by the computer during the evaluation. The use of graphics would also enhance any new development. Validation by comparison of results with those of a trained individual at selected airports should be accomplished to help ensure proper programming. The shell must be able to use other computer programs in conventional languages, and models such as the FAA Capacity and Delay Model should be chained to the KBES control. Additionally, access to varied noise-prediction algorithms or models as required (such as INM) would greatly assist the user, allowing all noise evaluations to be performed under the control of the KBES.

KBESs do not offer a panacea to the programming problems associated with the implementation of a noise-control strategy without loss of capacity. Neither do KBESs offer a replacement for an experienced, trained noise-abatement officer. With a proper shell, however, knowledge at individual airports could be stored, the FAA could provide policy assistance, and noise-control expert opinions could be incorporated. This would permit continuity in programs and be a great help to junior staff.

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