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Contents

Foreword

The papers in this Record cover widely diverse subjects, with no unifying theme other than that they deal with matters of current interest in the field of aviation. They were presented at the 1988 TRB Annual Meeting at a session arranged and chaired by Willard G. Plentl, Sr., Chairman of the Aviation Section. These papers were reviewed and recommended for publication by the committees on Intergovernmental Relations in Aviation, Aviation Economics and Forecasting, Light Commercial and General Aviation, and Airfield and Airspace Capacity and Delay.

Identifying Potential Funding Sources for Airport Capital Improvements

ORIKAYE GOGO BROWN-WEST

The continuing financial problems of rural regional airports have motivated a search for ways of financing capital improvements, which are necessary for the efficient operation of the U.S. airport system. Direct airport revenues do not provide enough funds to defray operational costs, let alone pay for capital projects. Because airport authorities or local government units are required to provide matching funds for federal dollars appropriated, new funding sources must be found. This paper identifies some sources and concludes that they can singly or in combination provide the necessary monies to improve our airports.

Since the end of World War II, airports have developed as focal points of the nation's transportation system. Today, the airport system of the United States has grown to be the most extensive in the world. Most airport authorities, made up of several city, county, and regional airports, are owned and operated by units of their local government. But because the system is essential to both national transportation and defense, there is a large federal investment in it. Starting in 1970 as a result of the Airport and Airways Development Act (P.L. 97-258), and reinforced in 1982 by the Airport and Airways Improvement Act (P.L. 97-248), the federal government provides 90 percent funding for federally eligible items in airport masterplans. Where eligibility requirements, FAA regulations, and funding criteria for the type of airport are met, the cost of future improvements may be borne completely by the federal government or by federal and local matching funds.

In recent years, aircraft noise has become a major problem in the air transport industry, making airports targets of restrictions aimed at aircraft noise levels and other airport-related environmental concerns (*1*). As a result, airports have become political and special interest pawns, to the extent that the futures of many are determined through the local political process, leaving a few airports without adequate political, and therefore, financial support for capital improvements.

Many local and small regional airports are facing problems—unpredictable and often inconsistent levels of government contributions, declining levels of air carrier service, inadequate terminal space, decreasing concession income, landing fees, ground rents, and perennial operating deficits. Direct airport revenues from these sources have never been able to sustain operating budgets, let alone provide the necessary funds for capital improvements. The magnitude of the funds that are required to make major capital improvements at today's airports preclude financing out of current revenues. New funding sources must be found.

Oriann Interests, P.O. Box 1076, Salisbury, Md. 21801.

The purpose of this paper is to provide information to masterplan developers, whose onus it is to identify funding sources for the improvements they propose. The paper also proposes that in this era of Gramm-Rudman-Hollings budget restraints, sources other than government units are available for the financing of capital projects. Identifying these sources is important; for the airport system to continue to function efficiently, improvements in the physical infrastructure and updates of the operational hardware must be made.

FUNDING SOURCES

Public airports must compete for funds with other government activities. As with other budget items, they are scrutinized during budget preparation and often subjected to public debate, particularly if major improvements or new construction is anticipated. Although the local share required is only 10 percent, some communities find it difficult to provide that amount.

In 1986, a comprehensive investigation of various sources of funding for capital expenditure for some county airports in the Southeastern United States, mainly Alabama, Florida, and Mississippi (O. G. Brown-West, Airport Masterplan: Revenue Potential and Funding Sources Studies, Southeast Rural Airports, Oriann Interests, 1986, unpublished data), was made to determine (a) their ability to finance airport improvements, and (b) their political and fiscal feasibility. Using the model shown in Figure 1, the study identified the following potential funding sources:

- Revenues from excess airport land,
- General and special taxes,
- State and federal agencies,
- Bond financing,
- Shopping-list financing,
- Lease-purchase financing, and
- Reserve funds.

Revenues from Excess Land and Other Airport Properties

The study cited in the previous paragraph reveals that many airports have excess land and other properties that are not being used for aviation purposes. Such properties can be revenue-yielding if adapted for best use. In each case, it is essential to conduct an on-site inspection or examine maps and aerial photographs of all property owned by the airport authority for (a) suitability for development and (b) revenue potential,

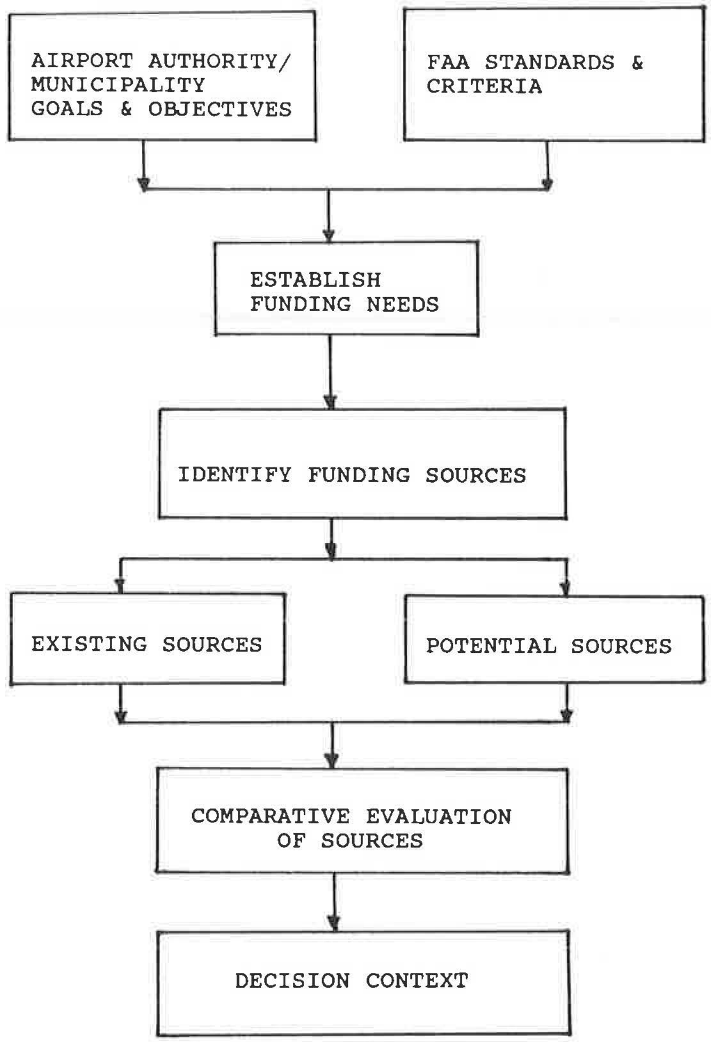

FIGURE 1 Framework for identifying funding sources for rural airports.

viewed in terms of contiguous land uses and the airport and the area's ability to provide best-use support services.

Based on the size and location of these surplus properties, the airport authority can decide which properties to dispose of and how to dispose of them. In localities where there are no established land use or land disposal policies, consideration of the following could determine the best use and the disposal method.

- The short- and long-term goals and expectations of the airport management, in particular, and the community, in general;
- The development of the airport as both a public facility and a capital investment for the area;
- Compatibility of future and existing land uses and with the airport as an aviation center; and
- The potential of the available property for providing funds for capital improvements for the airport and economic opportunities for the area.

If outright sale is the method adopted, an appraised value obtained from the tax assessor's office or private valuator can provide the amount to be expected from this source. In lieu of actual appraised values, a fair-market value can be obtained based on a comparison with identical land sales. In either case, the actual sale price will also depend on the attractiveness of the property, other externalities, and the urgency of the need for the funds.

General and Special Taxes

Various methods of financing the local share of capital improvements exist in many communities. Where the amount of funds required for future improvements exceeds the expected funding level, the imposition of general or special taxes to increase capital has to be considered. Such direct taxes are not uncommon, although politicians have found it difficult to justify their use to support income-producing activities such as aviation and public transportation. The fact that airports have been receiving financial support from government sources for other purposes, however, should make special tax support for capital improvements easier to justify.

Nonoperating Revenues from Government Sources

Airport income generated through nonoperational sources includes contributions by city, county, and state and FAA grants.

Although the amount of funding is not always easy to forecast because of the dependence of such grants on the availability of funds, taxpayers' other obligations, and competitive venture capital needs, a substantial amount of funding for operations is derived from contributions by these government sources.

The amounts are determined in the annual budgets by the governing boards of the local government units, the state comptroller's office, and the FAA regional director's office. Because these government units depend on revenues and disbursements from other sources, the amount they will contribute in any one year is a matter of conjecture.

Bond Financing

The most common way to obtain the capital funds necessary to finance airport and other transportation improvements is bond financing. This method has been used successfully in funding many airport capital improvements even though it is a one-shot financing approach and is therefore difficult to rely on for long-range or staged development. Many communities have the capability to issue municipal bonds to generate the necessary funds for airport improvements.

Revenue bonds (as opposed to general obligation bonds) are normally used for income-generating self-supporting activities, and, at competitive interest rates, seem the most viable source. Depending on the bond rating and bonding capacity, repayment through bond retirement can be accommodated within the project duration of up to 20 years. One disadvantage, however, is that when the bond issue is subject to voter referendum and approval, unforeseen delays in implementation can make the funding project a victim of rising construction costs, often preventing its completion.

Shopping-List Financing

Shopping-list financing is a commonly used method to subsidize transportation operations that are experiencing financial difficulties. In this approach, a subsidizing agency agrees to accept the responsibility for a given cost item on the capital improvement plan. The current practice of cities and local governments operating and maintaining the access roads and providing utility trunk services to the airport at no cost to the airport is an example of the shopping-list approach. It encourages operators to seek underwriters to support the airport improvement plan.

Lease-Purchase Financing

Capital expenses for airport equipment, runway extensions, navigation aids, and so on, can be met through a lease-purchase program. The airport using this method will prepare specifications for the capital improvement that will be bought or constructed by a private company or a government unit or agency. The facility is then leased to the airport authority at a yearly cost normally below what it would cost to borrow the necessary capital. At the end of the lease period, the title to the facility is conveyed to the airport authority without future payments. The rent over the years pays the total cost plus interest. This arrangement benefits the airport because the cost to the authority is minimal.

Reserve Funds

In the reserve-fund financing approach, funds are accumulated in advance for the needed capital improvement. This accumulation normally comes from interest on savings, funds in depreciation reserves, sale of capital assets, or surplus accruing from operating revenues. Most government units keep some proportion of revenue in reserve for unforeseen contingencies or financing of capital improvements. Where there is no formula as to how to use surpluses in reserve, good politics and money management often dictate that the funds be used to the advantage of the taxpayer. Using such funds for financing airport improvements should be regarded as being in the best interest of the taxpayers in any community.

Special Assessments

Airport improvements are undertaken to benefit the community as a whole, but particular properties and interests are most often the major beneficiaries. Most local or "regional" airports provide service to a significant area beyond their geographical and political areas of influence. The special-assessment approach requires that those who benefit directly finance such improvements through special assessments.

No city or single government unit alone can provide enough nonoperating revenue to finance capital improvement at a regional airport. If an airport's service extends beyond the boundaries of its home region, those cities and counties that benefit should provide a certain portion of the operating and capital improvement costs. Such an arrangement would complement capital improvement funds generated from the local community and elsewhere.

CONCLUSION

State and local agencies, working with the federal government, have provided the United States with the most extensive and best equipped airport system in the world. As a result of Gramm-Rudman-Hollings, the finances of the state and federal government are likely to be stringent in the years ahead. The financing problems of the recent past have stemmed from the inability of sponsoring agencies to convince the public and the politicians that the country's airports are experiencing financial difficulties and, therefore, need both private and public support. Since deregulation and the ensuing flight of the major airlines from the "uneconomic" rural routes, the public has come to appreciate the economic significance of regional airports, and is now inclined to financially support them.

Even in prosperous times, urban mass transit and other transportation systems have successfully used some of these innovative financing arrangements to augment government grants and subsidies. It is reasonable to expect pressure on lawmakers to reexamine their commitments to airport improvement. However, there is no reason why the same financing arrangements that have proven successful in other transportation systems cannot be used by regional airport management with the same success. The potential for funding exists in both the public and private sectors; both sectors complementing each other can make the costs of airport improvements in the United States affordable.

It is recommended that airport authorities and management investigate these sources and determine which approaches are politically and administratively feasible in their states, municipalities, or communities.

ACKNOWLEDGMENTS

Portions of this study were supported by grants from the FAA and the U.S. Department of Transportation through Wainwright Engineering, Inc. The author thanks the Panama City–Bay County Airport Authority, Bay County Committee of 100, FAA Airports District Offices, and Wainwright Engineering, Inc. for the opportunity to conduct this study.

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Publication of this paper sponsored by Committee on Intergovernmental Relations in Aviation.

An Idealized Model for Understanding Impacts of Key Network Parameters on Airline Routing

CHAWN-YAW JENG

The objective of this study is to understand the impacts of the key network parameters—demand level, network size, and number of cities—on airline routing of city pairs, specifically on whether they should be served with nonstop or transfer flights. This objective is accomplished by using an approximate model under the single-hub network, at minimal cost. The proposed routing strategy uses angles to divide city pairs into two groups, based on their relative locations: those served by nonstop flights and those served by transfer flights. Costs that would be minimized include airline operating costs and the passenger costs of schedule delays, en route time, and transfer delays. The relationships between the optimal angle and network parameters are explored with a circular network configuration. The passenger demand is assumed to be homogeneous. A numerical example of applying the model to the U.S. airline network is presented. According to the model, demand has a positive and significant impact on the use of nonstop flights. However, number of cities and network size have negative and insignificant impacts. According to the model, as the time value of schedule delays alone increases, the time value of en route time alone decreases, or the time value of all delays decreases, more city pairs should be served with transfer flights. The total cost is generally not sensitive to the angle size. The model also reflects the hubbing phenomenon and the impact of demand on shaping the routing patterns in the U.S. airline network.

Routing is one of the key components of any transportation system. Carriers (e.g., trucking companies, freight airlines, or passenger airlines) cannot determine their operational plans, such as fleet and crew assignments, without knowing the routing configuration. Users (e.g., freight forwarders, shippers, or passengers) plan their shipping or travel routes based largely on routing configurations. A sound routing strategy will increase operational efficiency and be convenient for the users.

Hubs are cities—usually large ones—that carriers use as operational centers. Hubbing is a routing strategy in which passengers or goods are transported to their destination via spokes to the hubs rather than directly on nonstop flights. Because of deregulation, there has been a recent trend of using hubbing in industries, such as trucking, air freight, and air passenger transportation.

Among these industries, passenger airlines are unique in the following ways:

- Compared with goods shipped by trucks and freight airline passengers have high time values. They are generally concerned more with service frequency, en route travel time, and connection delays. For example, backtracking routes, which are common in the freight industry, are unlikely to be implemented in passenger airlines. Also, storing and consolidating methods used at the freight terminals can only be used for passenger airlines if they can be accomplished in a timely fashion by schedule coordination at the hub.
- Because of high taking-off and landing costs for the aircraft, passenger airline networks are structured with many routes and few stops along each route. The multistop routes used in the trucking industry are not appropriate for passenger airlines. Although they have many of the same features as passenger airlines, freight airlines do not have to deal with airport congestion because most of their flights are scheduled during off-peak hours. Thus, schedule coordination at the hub can be more flexible.

U.S. passenger airlines have gradually increased their hubbing activities since the passage of the 1978 Airline Deregulation Act (*1*). As a result, the number of cities with more than 1 percent of total enplaned passengers (of the U.S. network) increased from 25 in 1977 to 36 in 1981 (*2*). Under such hub-and-spoke operation, an airline's principal hub may serve as many as 100 cities with 500 flights departing daily.

Why does hubbing benefit airlines? Hubbing enables airlines to make the best use of assets such as aircraft, crews, and gate spaces. Aircraft load factor, defined as the percentage of occupied seats, can be increased by consolidating passengers destined to several cities into one spoke. Crew assignments and scheduling can be centrally supervised at the hub. Gate spaces can be used more fully by serving more flights in and out of the hub. Consequently, cost per passenger can be reduced.

Why does hubbing also benefit passengers? Although hubbing increases passengers' travel time, it can provide them more frequent flights, choice of destinations, and convenient connections without interline operation (i.e., using more than one airline in a single trip). For example, a United Airlines passenger taking any of the flights from Grand Rapids to Chicago can transfer within an hour to a flight to San Francisco. Previously, that passenger would either have had to take the single daily nonstop flight to San Francisco or arrive in Chicago to wait several hours and possibly change carriers. The same is true for other destinations west of Chicago. Fare reduction as a result of lower airline costs is another benefit to passengers.

Since hubbing provides economical operation for airlines and convenient service for passengers, hubbing should be emphasized in designing routing strategies. Both airline and

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passenger costs should be considered in determining the most efficient routing system. However, most studies of airline network routing either overlook the hubbing phenomenon or focus only on individual airline or passenger costs. They either analyze the problems empirically or apply traditional operation research techniques to obtain detailed solutions. They illustrate neither trade-offs nor cause-effect relationships among key network elements.

The objective of this study is to understand the effects of key network parameters, under the single-hub network structure and minimum-cost goal, on point-to-point (i.e., nonstop) and hub-and-spoke (i.e., transfer) operations of each origin and destination (OD) pair.

The proposed routing strategy is based primarily on relative locations of origins and destinations. The costs to be minimized include airline operating costs and passenger time costs. The key network parameters include demand level, network size, and number of cities or nodes. The demand is considered to be homogeneous and the airline network is structured in a circular configuration.

PREVIOUS STUDIES

The following literature review includes published works on airline network routing with emphasis on hubbing, first, and research methods on network routing, second.

De Vany and Garges (*3*) studied the relationship between fleet assignment and two service patterns: direct and hub-and-spoke. First, they found that the hub-and-spoke pattern offers high frequencies, which, in most cases can offset the lengthened flight times. Second, they found that this pattern establishes a feeder structure that permits greater filling of the wide-body jets and more efficient route assignments. Gordon (*4*) explored mathematically and empirically the relationships between scale economies and network shapes (including modes other than air). He concluded that

- Fully connected transportation networks are rare because of the existence of scale economies for most transportation modes,
- The greater the scale economy, the less connected is the network shape and the more concentrated the traffic pattern,
- Congestion at nodes should result in a more connected network, and
- The network shape, given a fixed-cost function, should depend on supply-demand or cost-service equilibrium.

Gordon and De Neufville (*5*) presented a method of choosing various configurations for air networks. One of their conclusions was that hub-and-spoke networks minimize overall schedule delays but point-to-point networks provide a more even service quality. Ghobrial (*6*) developed an equilibrium model of air network considering airline competition and passenger routing preference. The results suggested that network hubbing is efficient and airlines will probably find it advantageous to hub, despite the pricing penalties resulting from airport congestion imposed on airlines using major hubs. Kanafani and Ghobrial (*7*) showed hubbing to be inelastic to hub pricing and potential benefits to be gained to airports. Kanafani and Hansen (*8*) investigated empirically the effect of air network hubbing on airline productivity. Their findings indicated no direct connection between the degree of hubbing and airline cost over the 1976 to 1984 period.

O'Kelly (*9*) determined the optimal locations of a single hub and two hubs by minimizing flow-weighted distance. He found that the least-cost site in the United States generated by a single-hub model is northeast of Cincinnati, Ohio, and that, for a two-hub system, as the effects of scale economies increase, the locations of the two hubs move apart. Chan and Ponder (*10*) discussed the factors that contributed to the success of hub-and-spoke networks for the air freight industry. They also pointed out the need to study the thresholds of transition for different routing structures (e.g., single-hub, minihub, multihub, and point-to-point systems).

While these studies addressed various aspects of hubbing (e.g., aircraft technology, airport economics, equilibrium, productivity, air freight, and hub location and operation), they do not provide understanding of the trade-offs and cause-effect relationships among key network components.

Many mode-specific network routings have been examined using the traditional techniques of operation research. Most of the previously mentioned references on airline network routing also adopt this research method, which generally treats nodes and links as discrete entities. Then, either mathematical programming (e.g., integer linear programming, dynamic programming, tree-search techniques) or heuristic algorithms are applied to find an answer. Typically, an attempt is made to find an "exact" answer using the calculating power of computers. However, with these methods, the number of variables and constraints sometimes increases so fast as the network becomes larger that computing time and memory needs become prohibitive. Because detailed location-specific and demand data are required for all OD pairs, the collection and coding of these data are a massive job and a large source of errors. Clearly, these methods are ill-suited for cause-effect and trade-off analyses, in terms of human understanding, time, and cost.

By contrast, this paper adopts an "idealized model" approach, similar to the continuum approximations that were developed to study commuting, congestion, and minimum-cost-path problems in urban areas (*11, 12*). The idealized (continuous) model approach has been applied to scheduling, location, and zoning problems (*13–15*). More recently it has been used to examine many-to-one and many-to-many logistics problems. An idealized model of airline routing would approximate the service area with a continuum and would result in analytical expressions for distance traveled and other performance measures (*16*). The equations would be based on a few easily measured aggregate parameters, such as spatial densities, average demand rates, area sizes, and so on.

Although less precise, the idealized model approach is preferable to the programming and algorithm approach because it

- Requires less effort on input data preparation, solution computation, and model application;
- Is less sensitive to the scale and complexity of the network;
- Is more likely to lead to qualitative insights; and
- Is more convenient for sensitivity analysis.

The idealized model approach has been applied to both one-to-many and many-to-many networks. Few studies have been conducted on many-to-many networks. Among them, passenger networks—the subject of this paper—appear not to have been studied at all (*17*).

DESIGN OF STUDY

The airline passenger network is modeled as a single-hub network. Each OD pair can be served by one of two types of operation: point-to-point (i.e., nonstop flights) and hub-and-spoke (i.e., transfer flights through the hub). In other words, the maximum number of stops allowed for each OD pair is one. Although, in reality, most airlines have multihub systems and feature some multistop flights, this study does not address them.

Another important assumption of this study is that demand is inelastic with respect to time and cost. Because demand is fixed over time, the average schedule delay can be simply calculated as half of the average flight headway. Although understanding that demand-supply equilibrium, impact of competition, and temporal distribution are desirable goals, models including such phenomena are too complex. Also, the changes in demand as a result of airlines' marketing strategies are usually not significant within a short time period.

Other basic assumptions of the model are listed below:

- Because aircraft technology is important in shaping the routing structure, aircraft capacity is treated as an endogenous variable;
- Aircraft load factor is assumed to be constant; and
- The hub has enough gate capacity to handle all the flights.

As a common practice, airlines often maximize profits (i.e., revenues minus operating costs) subject to passenger service constraints (e.g., schedule delay, transfer delay, and line-haul time). This optimization problem (including objective function of airline profit and constraints of passenger delays) can be reduced to a Lagrangian function (a new objective function formed by summing the original objective function and the products of multipliers and delay constraints) using the Lagrange multiplier technique. These multipliers represent time values of various delays. Thus, these products become passenger time costs of various delays.

Since the passenger demands are assumed to be inelastic, maximizing profit is the same as minimizing the cost of servicing a fixed demand. Ignoring revenue portion, the above Lagrangian function can be rewritten as the sum of airline operating costs and passenger time costs. This final Lagrangian function, which can be regarded as the total cost of the airline network system, is the objective function to be minimized. It includes costs on the supply and demand sides. The supply cost is the airline operating cost; the demand cost is the passenger time cost due to schedule delays, transfer delays, and line-haul time. From these discussions it can be concluded that the minimizing cost approach adopted here is consistent with the airline's common profit-maximizing practice.

A circular network configuration assumes that all nonhub nodes are uniformly located along the circumference of a circle with a hub at the center. Real-world networks are approximated as circular networks needing only the radius of a circle and the number of nodes. The radius of the circle can be calculated by averaging all the distances between nonhub nodes and hub. Some distances can be easily expressed in terms of a few parameters *(17)*. Although this configuration is not totally consistent with reality, it represents node locations in a simple and symmetric pattern, allowing the primary issues of this study to be clearly and thoroughly explored.

A homogeneous demand pattern is used to approximate real-world demand. A constant p is assigned to each $n(n + 1)$ cell of the OD matrix to represent homogeneous demand for a network with n nonhub nodes. The greatest advantage of such a pattern is that the demand of the network can be described using only p and n. Although it is homogeneous in OD demands, traffic links that depend on routing strategy are not always homogeneous. This demand pattern is simple but does not easily accommodate the real-world situation.

MODEL DEVELOPMENT

The following symbols are used in this paper:

- p = average demand per OD pair (passengers per day),
- c_i = aircraft capacity of the ith link (passengers per aircraft),
- l_i = stage length (i.e., the distance covered per aircraft hop from take-off to landing) of the ith link (mi),
- δ = average income of air traveler (dollars per hr per passenger),
- α = a fraction such that $\alpha\delta$ represents average time value of passenger schedule delay,
- β = a fraction such that $\beta\delta$ represents average time value of passenger line-haul time (i.e., in-vehicle time),
- γ = a fraction such that $\gamma\delta$ represents average time value of passenger transfer delay,
- v_i = aircraft travel time of the ith link (hr),
- n = number of nonhub nodes in the network,
- d = radius of circular network (mi),
- k_i = average aircraft operating cost of the ith link (dollars per aircraft-mi), and
- t = average operating hours of airline (hr per day).

Aircraft operating cost per aircraft-mi (k_i) is the key element in determining total airline operating cost. Based on 1981 data of six different aircraft with capacities ranging from 115 to 500 passengers and stage lengths ranging from 200 to 2,500 mi *(1)*, k_i is a function of stage length (l_i) and capacity (c_i). k_i increases with c_i because larger aircraft consume more fuel and require larger crews for a given stage length. On the other hand, k_i decreases with l_i because a fixed portion of the operating cost for taking off and landing is independent of the stage length. In plotting these data versus c_i/l_i (i.e., passengers per aircraft-mi), a linear trend can be observed (Figure 1). Using these data, the following function for k_i is calibrated by regression:

$$k_i = a_0 + a_1 \left(\frac{c_i}{l_i}\right) \tag{1}$$

where a_0 = \$4.1/aircraft-mi and a_1 = \$15.6/passenger.

Actually, a_1 can be regarded as the fixed aircraft operating cost per seat for taking off and landing. And $a_1 c_i$ is the fixed portion of airline operating cost for flying l_i. On the other hand, a_0 can be regarded as the variable unit for aircraft operating cost under cruising speed, and $a_0 l_i$ is the variable portion of the

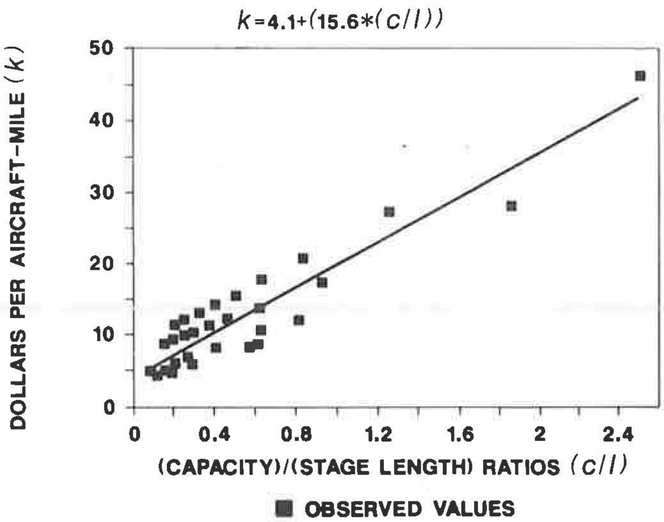

FIGURE 1 Aircraft operating cost function.

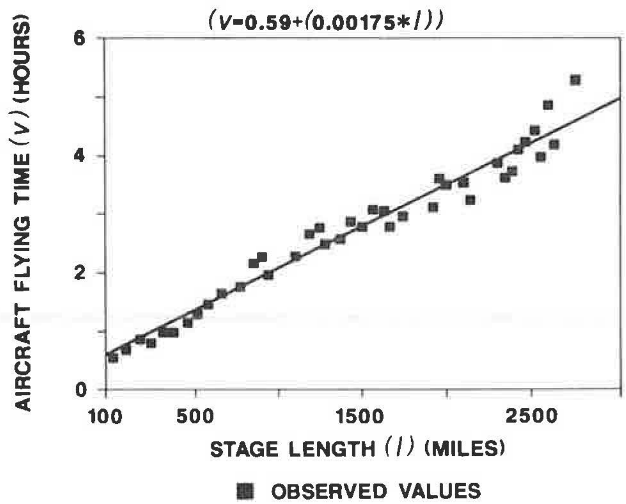

FIGURE 2 Aircraft travel time function.

airline operating cost of flying l_i. Although the linear assumption for c_i and l_i may not necessarily be in the best form for both physical meaning and data fitting, it simplifies the derivation for the rest of the model compared with other forms that could be used, such as square or product. The other forms show only marginal increase on R^2 for data fitting, however.

Aircraft travel time (v_i) is crucial in computing passenger line-haul time cost. It should include times for aircraft to take off and land and fly under cruising speed. Thus, the average overall travel speed should be smaller for shorter stage lengths because of the fixed portion of time spent on taking off and landing. Using random samples of nonstop flight data with stage lengths ranging from 100 to 2,500 mi according to system timetables published by Delta Airlines, aircraft travel time measured in hours is calculated by the difference between scheduled times at origin and destination. Travel times plotted against stage length (Figure 2) have a fairly linear functional relationship. Using these data, the following function for v_i is calibrated (also see Figure 2 about the fit) by regression:

$$v_i = a_2 + a_3 l_i \quad (2)$$

where a_2 = 0.59 hr and a_3 = 0.00175 hr/mi.

The value of a_2, which is approximately 35 min, can be regarded as the fixed taking-off and landing time regardless of the stage length. The inverse of a_3, which is approximately 570 mph, can be regarded as the cruising speed of the aircraft. This value matches reasonably well with most conventional jet planes (*18*). Based on Equation 2, the average aircraft overall travel speed drops from 490 to 340 mph when stage length decreases from 2,000 to 500 mi.

The time-value parameters (i.e, δ, α, β, and γ) are important in determining time costs for passengers. The value of δ in terms of 1981 dollars (the same monetary value as k_i) is calculated as follows. The average hourly family income of air travelers in 1979 is $14.70 (*19*). When the purchasing power of the consumer dollar (1979's is 1.25 times that of 1981) and family size counting only adults (1.65 adults per family in 1981) are considered, $12/hr per passenger results in δ.

According to the empirical studies (*20, 21*), the values of α, β, and γ ranged from 0.15 to 1.49 depending on trip purposes, transportation modes, trip length, passenger productivity, and so on. However, no clear distinction among α, β, and γ has been made. Based on how efficiently various time periods can be used by passengers, schedule delay, line-haul time, and transfer delay should have different values. Transfer delay has the highest time value ($\delta\gamma$) because that period cannot be efficiently used. Schedule delay has the lowest time value ($\delta\alpha$) because, by knowing the schedule in advance, passengers can coordinate their activities to use much of the delay period. Line-haul time has an intermediate time value ($\delta\beta$). Thus,

$$\alpha < \beta < \gamma \quad (3)$$

Reasonable values are assumed for these variables based on the above relationship. Conceptually, it is logical to assume the value of 1.0 for γ because this is the highest income a passenger can earn. Hensher (*21*) recommended 0.685 for travel time, which closely resembles the line-haul time in this study. Therefore, $2/3$ is assumed for β. By assuming $\gamma - \beta = \beta - \alpha$, which means that the time value difference between transfer delay and line-haul time is equal to the difference between line-haul time and schedule delay, α is assumed to be $1/3$.

SPLIT ROUTING

In the real world, airlines seldom use either point-to-point or hub-and-spoke operation exclusively. Two types of routings mixed with point-to-point and hub-and-spoke operations are proposed:

- Each OD pair is served, by splitting its demand, with both point-to-point and hub-and-spoke operations; and
- Destinations are served, by splitting them depending on their relative locations to the origin, with either point-to-point or hub-and-spoke operation.

The first method of routing is proved by this author (*17*) to be inferior to either point-to-point or hub-and-spoke routing (i.e., all-or-nothing in terms of demand) because total cost is a concave function of demand. Thus, only the latter method (called "split routing") is pursued further.

The idea behind split routing is to reduce the circuity (defined as the extra distance needed to serve an OD pair by hub-and-spoke rather than point-to-point operation) at certain locations for both passengers and airlines. For example, the circuity to serve OD pair AB in Figure 3 by hub-and-spoke operation is much greater than the circuity to serve OD pair AC by hub-and-spoke operation (i.e., the circuity from A to the hub to B is greater than from A to the hub to C). Thus, it is reasonable to serve the nodes closer to origin with point-to-point and the others with hub-and-spoke operation.

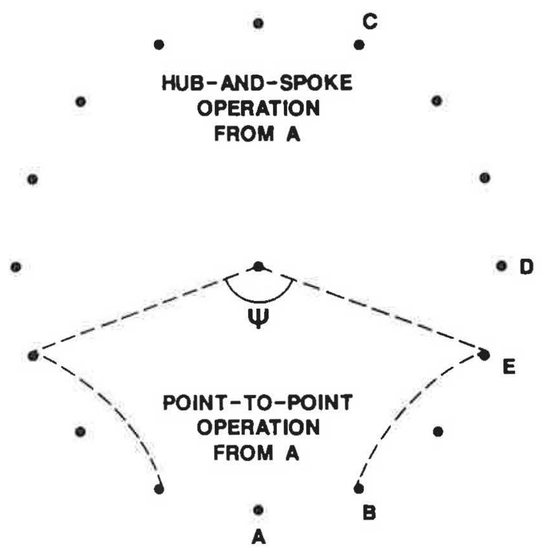

FIGURE 3 Illustration of split routing.

The problem here is to find the number of neighboring nodes on each side of nonhub node (q) served by point-to-point operation such that the total cost of split routing is minimized. Since all nonhub nodes are equally distant to the hub, it will never be optimal to serve node D and E from A in Figure 3 with nonstop and transfer flights, respectively, compared with serving them in the opposite way. Since q may vary with n, it is not a compatible measure for different network configurations. Instead, the split angle φ measured in radians (see Figure 3), corresponding to the length of arc occupied by neighboring nodes, is defined as

$$\varphi = 2\pi\left(\frac{2q + 1}{n}\right) \tag{4}$$

This split angle is used as the system measure to reflect various degrees of point-to-point operation.

Since all links have the same traffic and stage length for the hub-and-spoke operation, only one aircraft size (c) is needed. In other words, the flight frequency of all links will also be the same. Thus, the minimal transfer delays for the hub-and-spoke operation can be achieved by banking all individual flights from various origins into the first half of a common time slot (2 hours is used in this study) at the hub. Thus, passengers can transfer to their destination flight within the second half of the same time slot by spending approximately a 1-hour delay at the hub. In randomly sampling real-world connecting times at the hub from system timetables of major airlines, values range from 0.5 to 1.5 hr, which is consistent with the above assumption.

Figure 4 shows how to obtain the optimal split angle (φ^*) in terms of n, d, and p. [The derivation of each component is given in detail in the author's dissertation (*17*).] The following function of φ^* in the unit of radians is the result:

$$\varphi^* = 0.5\pi \frac{p^{0.6}}{n^{0.2} d^{0.3}} \tag{5}$$

where the constant 0.5 has the dimension of (radian) (number of nodes)$^{0.2}$ (miles)$^{0.3}$ (day)$^{0.6}$ (number of passengers)$^{-0.6}$ and the dimensions of n, d, and p can be referred to the previous definition.

Although φ^* can be numerically solved, the relationship between T_m (total cost for split routing) relative to T_m^* (optimal T_m) and φ can add more understanding. Figure 5 shows the relationship between the ratio $(T_m - T_m^*)/T_m^*$ and φ. The U-shaped curves in Figure 5 can be explained by the following trade-offs between φ and various cost components when φ increases.

- Schedule delay cost increases as a result of less frequent flights,
- Line-haul time cost decreases as a result of less circuity,
- Airline operating cost, which depends on the combining effects of smaller aircraft (increasing cost) and less circuity (decreasing cost), and
- Transfer delay cost decreases as a result of fewer transfers.

To find out the overall fit of estimated angles from Equation 5, the ratios of the difference (between estimated and theoretical angles) to the theoretical angles are calculated. It is found that 90 percent of the observations are within 20 percent difference. However, the system costs are shown to be rather flat near φ^* from Figure 5. It is found that the cost difference never exceeds 5 percent when the angle difference is within 20 percent.

The effects of changing n, d, or p to φ^* are presented in Figure 6. It shows that p has a positively stronger effect on φ^* compared with the negative effect of n and d.

By similar analyses, the effects of parameter (other than n, d, and p) variations on φ^* can be explored. Three examples are presented:

- Change time-value fraction β—By increasing β from $^2/_3$ to 1, the coefficient of Equation 5 increases to 0.58. Hence, the airline should use point-to-point operation for more OD pairs because the line-haul time savings from the circuity is more significant.
- Change time-value fraction α—By increasing α from $^1/_3$ to $^2/_3$, the coefficient of Equation 5 decreases to 0.31. Thus, the airline should use hub-and-spoke operation for more OD pairs since the schedule delay saving from scale economies is more significant.
- Change time value and time-value fractions—The following set of time-value parameters, which represents an example of low-value goods, is analyzed: $\delta = 1$ and $\alpha = \beta = \gamma = 1$ (i.e., no distinction on various time values, which is generally true for freight). The coefficient of Equation 5 decreases to 0.45. Thus, the low-value goods tend toward hubbing because they are less sensitive to both scale economies and circuity effects.

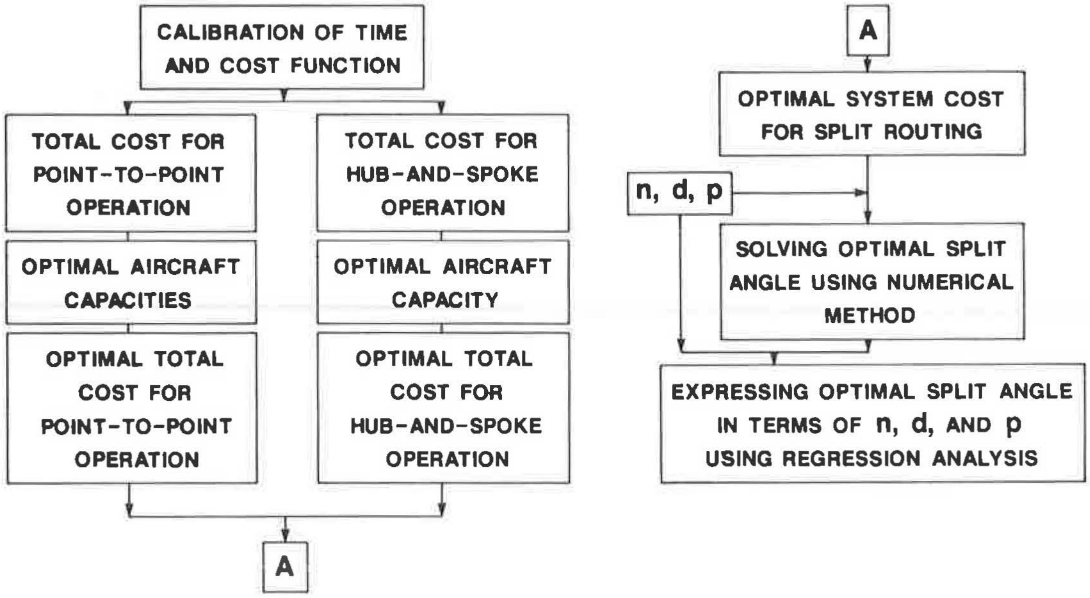

FIGURE 4 Flowchart of model derivation.

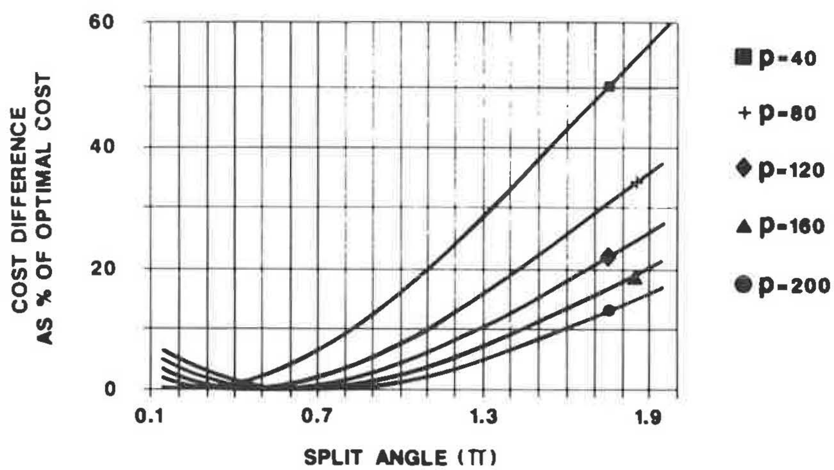

FIGURE 5 Total system cost difference versus split angle.

MODEL APPLICATION

The U.S. airline network is used as an example for application. No attempts are made here, because of the incomplete data from the airlines and the idealized model structure of this study, to verify the model with the real-world individual airline network. Rather, some qualitative implications from applications are assessed with real-world aggregate statistics.

The U.S. airline network is studied chronologically for the years 1977, 1981, and 1985. The nodes are cities and Standard Metropolitan Statistical Areas requiring aviation services. According to the criteria from FAA, nodes with more than 0.05 percent of total enplaned passengers in the network are selected for this case study. There are 150, 129, and 116 nodes for the years 1977, 1981, and 1985, respectively. Although these nodes represent only about 30 percent of the certified points in the 50 states, their passenger enplanements account for 96.8, 96.4, and 97.6 percent for the years 1977, 1981, and 1985, respectively (*2*).

Since only a single-hub network is considered in this study, Kansas City, Missouri, near the gravity center of the United States mainland territory, is selected as the hub. To calibrate the demand parameters of the previously developed model, only daily demand generated from each node is needed. The total daily costs of different years are compared on a common value of the 1981 dollar because the developed model is calibrated based on 1981 data.

For homogeneous demand, total daily demand generated from all nodes (TD) and the total number of nonhub nodes (n) are needed to determine the value of p:

$$\frac{TD}{n(n+1)} \qquad (6)$$

The total number of passengers (10 percent samples) for the 3rd quarter in 1977, 1981, and 1985 (*22*, Table 11) is adjusted accordingly to obtain TD. Table 1 gives the values of the

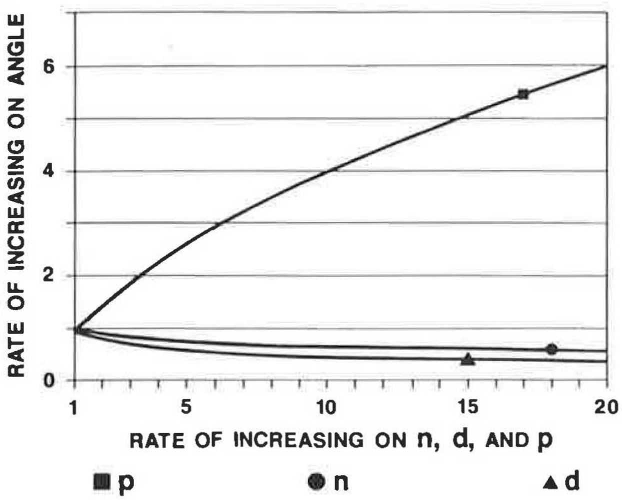

FIGURE 6 Effects of network parameters on split angle.

TABLE 1 PARAMETERS AND SYSTEMS MEASURES OF MODEL APPLICATION

	Years		
	1977	1981	1985
Network parameters			
n (no. of nodes)	149	128	115
p (passengers per day)	19	28	50
d (radius in mi)	875	903	917
System measures			
Split angle (φ, radian)	0.14π	0.18π	0.25π
No. of neighboring nodes ($2q$)	9	10	13

parameters needed and the system measure found in this section.

One additional parameter needs to be calculated for the circular network: the radius d, which is equal to the mean of all the air distances between nonhub nodes and the hub. The great circle distance in nautical miles can be calculated by the following expression (*23*):

$$\cos^{-1} [\sin (LA_O) \sin (LA_D) + \cos (LA_O) \cos (LA_D) \cos (LO_O - LO_D)] \quad (60)$$

where LA_O and LO_O are the latitude and longitude of the origin and LA_D and LO_D are the corresponding measures of the destination. By multiplying the expression by 1.15, the nautical miles are converted into statute miles. Knowing the values of latitudes and longitudes of nodes, the resulting d's for 1977, 1981, and 1985 are shown in Table 1.

The split angle (φ) covering the range of nodes served by point-to-point operation from each node was derived according to Equation 5. The values of n, d, and p for 1977, 1981, and 1985 and the values of φ^* and their corresponding number of nodes (see Equation 4) served by point-to-point operation from each node are listed in Table 1.

The values of the network parameters used so far are either averaged over an entire year (e.g., the demand) or retrieved at the end of the year (e.g., the network size). However, the data may not always be available (e.g., there may be only partial OD demands in terms of time and locations). Moreover, the data are also dynamically altered (e.g., changing seasonal demands or changing network to cope with competition). In the manipulating process, errors may also be introduced into these data. Thus, the input data of the model used in the real world may not represent the "true" values. The effects of these data variations on the system measure need to be investigated.

The COV (coefficient of variation, which is equal to the ratio between standard deviation and mean) of the system measure and input parameters are used to measure the data variations. The COV of a system measure, when a particular network parameter is treated as a variable, is equal to the absolute value of the exponent of that network variable in the derived equation for that system measure, multiplied by the COV of that network variable (*17*). However, this finding is true only for the equations with exponents on their components of input parameters, such as Equation 5. For example, the estimating error of φ^* resulting from the demand variation is only 60 percent of the data error from the demand itself. Since all the exponents of network parameters in Equation 5 are less than or equal to 1, the estimating errors of the system measure are never worse than the data errors from the network parameters. The robustness of the developed model has been demonstrated here.

IMPLICATIONS FROM MODEL APPLICATION

Two qualitative implications from model applications—hubbing phenomena and impact of demand on routing—are compared to real-world aggregate measures. The purpose is to show that the abstract model from this study, despite its simplifications and approximations, can still provide some insightful information by appropriate interpretation.

Hubbing Phenomenon

The findings from this study strongly indicate that it is economical to incorporate the hub-and-spoke operation into the routing strategy. In the real world, the same phenomena are observed:

- The number of enplanements is a measure of hubbing because each trip through the hub is counted as two enplanements. Thus, the larger the number, the higher the degree of hubbing. In order to be compatible for various demand levels, the percentage of total enplanements for each city is a more appropriate indicator. From the increasing percentage of total enplanements and decreasing number of cities with more than 0.05 percent total enplanements shown in Table 2 (*2*), the degree of hubbing indicated by the average percentage of total enplanements per city increased over the years. Since average percentages of both medium and small cities are stable, the large cities play a key role in shaping the hubbing network. It appears that the increasing number (but decreasing average percentage) in 1977 to 1981 and increasing average percentage (but decreasing number) in 1981 to 1985 of large cities are the driving forces behind the increased hubbing in these two periods after deregulation in 1978.
- Figure 7 shows the percentage of total enplanements for the top 10 airports (*2*). The cumulative percentages (44.9, 47.6, and 44.2 for 1977, 1981, and 1985, respectively) show the increasing then decreasing degree of hubbing. Moreover, the

TABLE 2 PERCENTAGE OF TOTAL ENPLANEMENTS BY CITY SIZE

	Years		
	1977	1981	1985
All cities (> 0.05%)			
No. of cities	158	153	124
Total %	96.8	96.4	97.6
Average % per city	0.61	0.63	0.79
Large cities (> 1%)			
No. of cities	25	36	26
Total %	68.1	70.0	72.8
Average % per city	2.7	1.9	2.8
Medium cities (0.25% to 0.99%)			
No. of cities	39	43	37
Total %	18.3	18.9	18.1
Average % per city	0.46	0.44	0.49
Small cities (0.05% to 0.24%)			
No. of cities	94	74	61
Total %	10.4	7.5	6.7
Average % per city	0.11	0.1	0.11

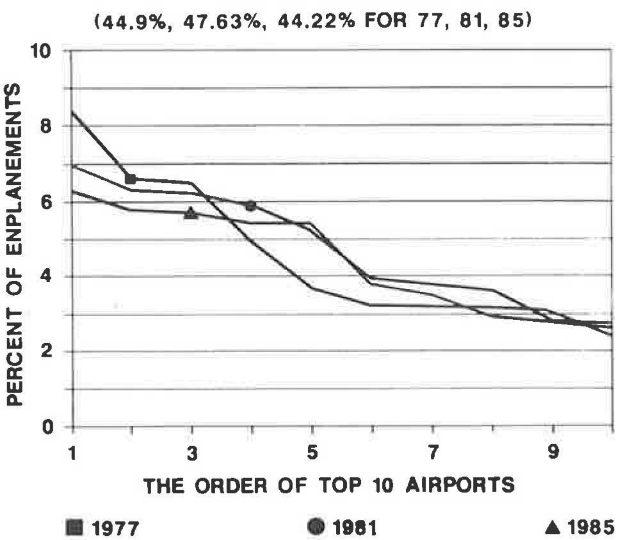

FIGURE 7 Percentage of enplanements for top 10 airports.

percentage of enplanements for the top three airports declined from 1977 to 1985. Both observations suggest that the large hubs are less concentrated (i.e., enplanements are spread more evenly) although the overall degree of hubbing of the entire network increased after the deregulation in 1978.

Impact of Demand on Routing

One of the important findings of this study is that demand has the most significant impact on shaping airline network routing in terms of providing more nonstop service. With approximately the same number of nodes and size of networks over the years (Table 1), the changing routing patterns in terms of system measure can be attributed primarily to the impact of demand. This can be verified if application results can qualitatively match real-world phenomena. According to Table 1, the optimal system measure indicates that increasing percentages of OD pairs (or passengers) are served with nonstop flights from 1977 to 1985. Some real-world aggregate statistics correspond to this observation:

- The number of OD pairs receiving nonstop flight service in the United States increased by 4 percent from 1978 to 1983 (*24*).
- The percentage of 145 cities connected with large, medium, and small cities (by FAA's definition) by nonstop flights was 31 percent, 14, percent, and 5 percent, respectively, for 1977; they increased to 34 percent, 17 percent, and 6 percent, respectively, for 1984 (*25*).
- According to the dissertation of Ghafouri-Varzand (*25*), the connectivity (measured by the connectivity index, defined as the ratio between the sum of the reciprocal harmonic mean of the actual trip times and the sum of the reciprocal harmonic mean of the ideal trip times) is significantly better in 1984 than in 1977. This indirectly implies that the larger portion of OD pairs are served with nonstop flights in 1984.
- Table 3 shows transfer enplanements as a percentage of total enplanements at several major hubs for 1977, 1981, and 1985. Generally, the decreasing percentage over the years implies that more passengers are served with nonstop services.

TABLE 3 PERCENTAGE OF TRANSFER ENPLANEMENTS AT MAJOR HUBS

	Years		
	1977	1981	1985
Chicago, Illinois	53	48	45
Dallas, Texas	55	53	52
Atlanta, Georgia	74	76	70
Denver, Colorado	49	57	54
Miami, Florida	58	63	56

From these cross-references between theoretical findings and practical observations, it appears that hubbing and the offering of more quality service with nonstop flights has occurred after the passage of the 1978 Airline Deregulation Act. This convenient route configuration can thus induce higher passenger demands, as shown from the real data. Because of the significant impact demand has on routing structure, as the model suggests, more nonstop services have been provided, as is shown from the real data.

Although higher demands were achieved by incorporating hub-and-spoke operations into routing structure over the past years, to overemphasize hubbing may not be desirable. The failure of hubbing-oriented carriers such as People's Express (although there may have been other factors contributing to the failures, such as competition and management, which were not considered in this study) supports this argument. In other words, for a new airline, the hub-and-spoke operations should be regarded as an interim tool to raise demand rather than an ultimate routing strategy. The point-to-point operation should be increasingly emphasized as the demand grows, as shown in this application.

CONCLUSIONS

The most important finding of this study is how network parameters affect the network routing pattern. Demand has positive and very significant impacts on the use of point-to-point operation. However, the number of nodes and the area size have negative and very insignificant impacts. Other important findings regarding the model itself include the following:

- Serving an OD pair with both point-to-point and hub-and-spoke operations is less efficient than using either operation exclusively.
- Serving all OD pairs in the network with either point-to-point or hub-and-spoke operation is less efficient than dividing them into two groups by their locations, and serving them with split routing.
- As the time value of schedule delay increases or the time value of en route time or income decreases (i.e., low-valued goods), more OD pairs should be served with hub-and-spoke operation.
- The total cost is not very sensitive to aircraft capacity and system measure in the vicinity of its optimum.

Additional findings pertaining to the model applications include the following:

- The developed model performs reasonably well with limited data needed to describe the hubbing phenomenon and assess the significant impact of demand on routing structure.
- The overemphasized hub-and-spoke operation may not be efficient based on the model applications. As demand increases, point-to-point operation should be used more.
- The developed model is shown to be robust in terms of gracefully absorbing data errors from the real world.

In the real world, routing decisions are made by considering additional factors such as competition, dynamic supply-demand interaction, and resource constraints. With idealized network configurations and simplified assumptions involved in the proposed routing strategy, the developed model can neither fully represent the real airline networks nor the "optimal" system. However, the purpose is to understand the basic impacts of network parameters on proposed routing strategies through a simple and approximate model. Although the findings from this study may not be appropriate for direct application to the real world, they should provide a basis for understanding more complicated airline network routing models and for practical planning of routing systems. For example, knowing the network parameters that have insignificant effects on routing strategy should allow more time for considering other aspects of the airline system not included in this study. The proposed approach should also have limited application for other transportation modes such as buses, trucks, and railroads.

ACKNOWLEDGMENTS

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Dynamic Forecasting of Demand and Supply in Nonstop Air Routes

VIJAYA KUMAR AND YORGOS STEPHANEDES

Passenger air-travel forecasting is receiving renewed emphasis as a result of increasing congestion and delays at airports across the country. Addressing the forecasting problem, a set of dynamic demand and supply models were developed for a given airline on a nonstop air travel route (Twin Cities to Chicago). The dynamic specifications were developed using time-series analysis and the causal relationships between cause and effect were confirmed with Granger causality tests. The models were developed based on a modest amount of monthly data from sales receipts and schedule information over the 1979 to 1983 period. In general, the models forecast demand and supply with reasonable accuracy, with an average forecasting error of less than 4 percent. Application of the forecasting equations to policy analysis indicates that, although the effect of improved service (more seats available) on demand lasts for approximately three months, the major impact is strongest during the first month, concurrent with service changes, implying little loyalty by passengers to their airline. The policy results also indicate that the airline's reaction to a sudden surge in demand is more sluggish and lags demand change by a month, probably as a result of the costs involved in crew and aircraft allocations.

Passenger air-travel forecasting is receiving a renewed emphasis after several years of neglect. The emphasis in this rather specialized field is due largely to increasing concerns about the levels of congestion and delay at airports as well as the more general effects of deregulation on intercity intermodal travel. Over the past four decades, intercity travel has changed dramatically in terms of cost, speed, and comfort. Yet today, only one-third of the population makes regular trips by air (*1*), indicating that air travel is probably at just a fraction of its potential. At the same time, existing air travel is overloading many air corridors and air terminals. To be sure, the present overcrowding has been precipitated by the deregulation of the airline industry.

The deregulation of discount fares in 1978 provided a means for the airlines to attract more passenger traffic. More than two dozen new airlines have been created to meet the growing demand, which has surged to unprecedented peaks. However, because the government is no longer protecting inefficient carriers, high-cost operators have been especially hard hit by ferocious competitive pressures. Prior to deregulation, obtaining new-route authority was usually the most serious barrier to an airline's internal expansion, because the Civil Aeronautics Board (CAB) took a restrictive view toward awarding new routes. With deregulation, new-route authority became available with only minimal delay. As a result, airlines wanting to expand quickly found a merger useful in obtaining aircraft ground facilities and other scarce factors of production. Smaller airlines experienced increased incentives to consider merging with one another or with larger airlines for economic survival.

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Deregulation has further created strong incentives for the commercial airlines to extract the greatest possible output from the existing fleet. Besides increased hours of use, aircraft are now scheduled so as to better fit particular markets or city-pairs, an improvement made possible by enhanced freedom in route selection and abandonment. Planes are also now flown on somewhat longer hops on average, as well as later at night and earlier in the morning (which makes the increase in load factors all the more remarkable). In addition, aircraft seem better positioned relative to their markets by time of day and geographic location, thereby filling previously missing gaps in the hub-and-spoke networks created by regulatory restrictions.

These changing conditions are forcing air carriers to make critical decisions about fare pricing, fleet expansion, route structure, and flight scheduling. Of all the available alternatives, service changes and fare pricing, applied selectively to individual intercity routes, appear to be two of the most feasible solutions. However, selection of appropriate fare policies and operating requirements calls for employment of rigorous methods for estimating air passenger demand on different routes and evaluating performance of the new service under consideration. If the evaluation process is to be effective in the long term, it must be dynamic in nature and address and overcome specific problems characterizing the unstable equilibrium between demand and supply and the short- and long-term effects of demand and travel patterns resulting from the new service.

The methodology and findings presented in this paper are part of a larger project in intercity travel. The objectives of that project included the development of simple and realistic yet rigorous models that can be used to forecast intercity travel demand and supply. Primary considerations were the availability of data for development and use of the models and the effectiveness of the models for intercity route policy analysis. The work presented here is only a modest attempt in developing a tool for estimating the impacts of air travel supply on demand and vice versa, through time. While the initial application is in nonstop, route-level service by one airline, the method is being extended to situations involving stops and multiple routes as a part of a larger hub-and-spoke network.

In the mid and late 1960s, several research efforts were directed toward the development of intercity travel demand forecasting tools. Among them, direct demand models began to dominate. However, because of their aggregate nature, these models proved inaccurate and grossly overestimated future growth. Further, the models were not policy-oriented since most of their variables were related to the socioeconomic characteristics of the cities and were not under the control of the transportation planner.

In 1969, the National Cooperative Highway Research Program (NCHRP) designed and financed a detailed research study (*2*) to define the social and economic factors affecting intercity travel and to use resulting relationships with existing traffic prediction tools to forecast intercity travel. The models developed in the NCHRP were based on a vast amount of aggregate data obtained from various counties across the nation having different socioeconomic characteristics. For this reason, the models performed reasonably well when applied at the regional level but proved useless at the route or corridor level. In addition, since these models did not include variables representing the service levels, their usefulness in evaluating transportation-related policies was very limited.

In the 1970s, economists, transportation planners, and system analysts began to contribute to the development and empirical estimation of a class of demand functions based on the logit and related models of discrete choice. Disaggregate approaches to analyze travel demand showed very promising results and a wide variety of advances have been achieved to date.

Despite the preponderance of logit models as tools of demand analysis in urban travel (*3, 4*), not much attention was paid to extending the disaggregate approach to intercity travel until 1974. In 1974, Watson (*5*) attempted to compare model structure and predictive power of aggregate and disaggregate models of intercity mode choice. The results of his study indicated that disaggregate models provide better statistical explanation of mode choice behavior. Several tests showed that the errors associated with the aggregate models were several times as large as those associated with the disaggregate models.

Following Watson, Stopher and Prashker (*6*) and Grayson (*7*) explored the feasibility of using an existing data base, namely, the National Travel Survey (NTS) for the development of intercity passenger forecasting procedures. The results of their study indicated that NTS data are not suitable for a disaggregate modeling approach. A large number of assumptions were necessary to cope with multiple airports, schedule and fare changes during the year, access and egress characteristics, and so on. For this reason, the reliability of the model coefficients was questionable. In particular, the model by Stopher and Prashker (*6*) included intuitively incorrect signs and, therefore, the estimates of modal shares were not meaningful. Grayson's model was found to perform better on the national and regional levels than on the route-by-route level.

For the first time, in 1978, a time-series analysis of intercity air travel volume was carried out by Oberhausen and Koppelman (*8*) to produce short-term forecasts. These authors used the Box and Jenkins approach (*9–11*) to develop univariate models, which account for monthly as well as seasonal patterns in a time-series of historical data. Results showed that univariate models produced reasonably accurate forecasts. The study also included the estimation of a bivariate time series model incorporating air fare as an explanatory variable. Though this model did not produce a significantly better fit of the data, it was found to be potentially useful from a management standpoint because it facilitated the comparison of elasticities and the evaluation of alternative strategies.

Finally, in a recent study, Abkowitz and Tozzi (*12*) developed regional air demand models using air traffic, demographic, and economic data, and the Ordinary Least Squares technique. A comparison of these models with those derived with prederegulation data indicated that the basic factors which influence regional travel have not changed since deregulation. The results of the study also showed that the regional air travel market is distinctly different from longer haul and other specialized markets.

Although most of the work to date has addressed specific intercity travel demand issues, no study has effectively addressed the dynamic interactions between demand and supply and the ways in which such interactions may affect the implementation of specific policies through time.

DATA

The data used for this analysis were obtained from a Twin Cities-based commercial airline and covered the time period from October 1979 through April 1986, a total of 79 months (data points). The air route considered is Minneapolis/St. Paul to Chicago. A summary of available data follows:

- Total number of available seats (ASEATS),
- Total number of revenue passengers (RPASS),
- Passenger Load Factor (PLF),
- Number of departures per week day (NDEPWD),
- Number of DC10 departures per week (DC10PWK),
- Number of Boeing 727 departures per week (S727PWK),
- Number of Boeing 747 departures per week (S747PWK),
- Round trip economy fare (EFARE), and
- Round trip full fare (FFARE).

The total number of available seats (indicating supply) was obtained by multiplying the average seating capacity for each aircraft type (including DC10s and Boeing 727s and 737s) by the number of departures per week that aircraft type made. Where the monthly data on revenue passengers were not available (second and third quarters of 1984), the system-wide load factors were used at the route level to estimate the unavailable data points.

METHODOLOGY

While many methods exist for analyzing the data and developing demand-supply specifications, there are two major methods that are distinguished by the way time is treated in the analysis:

- Cross-sectional analysis employs data from different areas but at the same point in time. The analysis assumes that all variables are in equilibrium during the planning period. Any delayed interactions (e.g., between passenger demand and air travel seats) are overlooked. Results are applicable to long-term assessment.

- Time-series analysis employs data from one area but at different points in time. The analysis makes no assumption about long-term equilibrium. Results can point to relations among variables as they occur through prespecified time increments. Therefore, this method is applicable to short-term analysis.

Most studies in this area of research have relied on cross-sectional methods that can determine correlations but cannot break those correlations into causal links. However, it is important that the demand and supply specifications developed be causal rather than descriptive, that is, be able to formulate and test hypotheses on the relation between causes for change and their estimated impacts. Time-series techniques address the issue of causality more directly than do cross-sectional techniques and this is the major reason they form the basis for this analysis.

VARIABLES

Air travel demand between any two cities depends on the travel characteristics along the route as well as the demographic and socioeconomic characteristics of the cities. The travel characteristics include travel cost, schedule delays, discount benefits, safety record of the airline, service frequency, and courteous inflight service. Similarly, the service supplied by an airline is primarily influenced by passenger demand, energy prices, and resource availability. Concurrent work by this research team and related work in the literature indicate that demand for business and nonbusiness (mostly pleasure) travel directly depends on the full fare and economy fare. Further, passenger load factor affects the availability of tickets, thus influencing demand. It is also believed that the service supplied on a particular route by an airline depends mostly on demand.

Ideally, when forecasting air travel demand and supply, it would be desirable to enhance the transferability potential of the specifications by including such variables as population, business employment, tourist activity, and characteristics of all airlines competing in the route. However, this research deals with only one airline and the principal objective is to first identify the important causal links between demand and supply characteristics of that airline ceteris paribus. For this reason, it was hypothesized that changes in air passenger demand and supply could be explained by changes in certain relevant policy variables such as service frequency, travel costs, and load factors. While this does not constitute an exhaustive list of all possible variables, it does appeal to two important points, that is, the variables make sense as likely contributors to changes in demand and supply, and, importantly, data were readily available for this airline to measure these variables over time.

To be sure, price and schedule changes made by the competition can significantly influence the demand characteristics of an airline. Therefore, including service characteristics of competing airlines, should, it is believed, improve the explanatory power of our model specifications. However, at the time this study was initiated, data on competing airline characteristics were not readily available. For this reason, variables referring to airline competitors have not been included in the analysis. However, in continuing work on this topic, the characteristics of airline competition are being incorporated in the model specifications.

Having identified the possible causal variables, historical data were collected on demand, supply, fares, and load factors and a series of Granger causality tests (*13*) was conducted to test the initial hypotheses and identify the direction and magnitude of causality among the variables. The appropriate lag structure for each independent variable was then determined and the final models developed using the vector autoregression method.

Determination of Causality

To determine the existence and direction of causality between demand and supply and other variables, a series of causality tests was performed. The effect of seasonality could be incorporated in these tests by employing a seasonal dummy variable. However, in order to keep the demand and supply models relatively simple, the seasonal parameters were not included. Instead, time-series data were deseasonalized every 6 months to remove the major seasonal effects.

The first step in determining whether a variable X (e.g., available seats) "causes" a variable Y (e.g., revenue passengers) consists of formulating the null hypothesis that X does not "cause" Y. Next, X is regressed on past, present, and future values of Y, i.e.,

$$X_t = a_1 X_{t-1} + a_2 X_{t-2} + \ldots + a_q X_{t-q} + b_0 Y_t + b_1 Y_{t-1} + \ldots + b_q Y_{t-q} + c_1 Y_{t+1} + c_2 Y_{t+2} + \ldots + c_k Y_{t+k} + e_t$$

for some integers q and k where X_t, Y_t = variables X and Y at time t and e_t is the residual. Under this hypothesis, all future coefficients of Y should be zero, i.e., $c_h = 0$ for $h = 1, 2, 3, \ldots k$. If they are all zero by an F-test, no causality is likely. On the other hand, if even one future coefficient is not zero, then X is said to cause Y. To be sure, even this test cannot replace the experimental demonstration of a causal relationship. The test only implies that changes in one variable precede, in a statistical sense, changes in another variable; such precedence is necessary but not sufficient for true causality.

From several conversations with airline officials, it was concluded that the effect of demand on supply and vice versa could last up to roughly 3 months. For this reason, the regression equation for the causality test was developed using three leads for the independent variable. The results of the causality tests are summarized in Table 1. Based on a 10 percent level of risk that the test statistic could lead to false rejection of the null hypothesis, the results of causality tests indicate that the following variables cause RPASS: ASEATS, EFARE, FFARE, and PLF (Passenger Load Factor), thus confirming initial beliefs. However, the Passenger Load Factor was not available for several time periods and, therefore, system-wide average values would have to be used in the analysis thus decreasing model validity. Further, Load Factor is not a useful policy variable. NDEPWD (Number of DEPartures per Week Day) does not cause RPASS. A possible explanation for this is that the airline increased the seating capacity on this route by adding bigger aircraft (such as DC10s) and not by changing departures significantly. Consequently, the models did not capture any impacts on demand due to service frequency. As expected, the causality tests indicate that RPASS causes ASEATS.

TABLE 1 RESULTS OF CAUSALITY TESTS

Test Hypothesis	Probability of Correct Hypothesis (%)	*F*-Value
FFARE does n0t affect RPASS	0.033	7.60
PLF does not cause RPASS	0.018	7.55
EFARE does not affect RPASS	0.018	5.03
ASEATS does not affect RPASS	0.048	3.14
NEPWD does not affect RPASS	0.910	0.17
RPASS does not affect ASEATS	0.090	3.58
EFARE does not affect ASEATS	0.310	1.89
FFARE does not affect ASEATS	0.340	1.67

Estimation of Lag Lengths

The Oberhausen and Koppelman study (*8*) indicates that the lag structures associated with air passenger demand are a relatively short 3 to 4 months. To confirm this hypothesis, a series of tests was conducted in which two systems of regression models with differing lag lengths were compared against each other through a chi-square test. A null hypothesis was formed in which the unrestricted equation (with up to six lags) was assumed to have better predictive capability than the restricted one (with fewer than six lags). The results of the chi-square tests indicate that the system with two lags can adequately represent the demand and supply pattern. The estimated chi-square value was significant at the 8 percent level (chi-square = 45.1 at 64 degrees of freedom).

Based on the results from the causality tests and lag length analysis, two specifications for demand and supply were developed using the vector regression method. A summary is provided in Table 2. At 90 percent confidence level, the *t*-statistics presented in that table indicate that most model parameters were statistically significant.

TABLE 2 DEMAND AND SUPPLY MODELS

Independent Variable	Lags	Dependent Variable: RPASS[a] Coefficient	RPASS[a] *t*-Value	ASEATS[b] Coefficient	ASEATS[b] *t*-Value
RPASS	0	–	–	–	–
	1	0.2605	2.3	–0.2995	–1.82
	2	–0.1502	–1.3	–0.0025	0.15
ASEATS	0	0.5011	8.6	–	–
	1	–0.2208	–2.3	0.6277	5.23
	2	0.1042	1.2	–0.0988	–0.86
FFARE	0	92.172	1.8	–	–
EFARE	0	–221.28	–2.3	–	–

NOTE: Dashes indicate not applicable.
[a] $R^2 = 0.73$.
[b] $R^2 = 0.80$.

APPLICATIONS

Test of Model Performance

The above demand-supply models were developed with the data from the Twin Cities to Chicago route for the period October 1979 through January 1983. The models were first tested by simulating their own data for the same period (Figures 1 and 2). To determine their forecasting capabilities, the models were then used to forecast demand and supply from February 1983 through January 1985 (Figures 1 and 2) and the results were compared with observed data.

The comparisons indicate that the absolute percentage error associated with each individual monthly forecast is within 20 percent. The average percentage error in demand forecasting indicates an underestimation of 3.5 percent; in supply forecasting, it indicates an overestimation of 1.8 percent. As the two figures illustrate, the general trend of the estimated demand and supply follows that of the observed values.

Note that the model underestimates demand during the first 4 years and overestimates during the fifth year. However, data for certain time intervals were not available directly from the airline company and, therefore, system-wide average load factors and constant capacity for different plane sizes were used in deducing these data. This may not have resulted in some underprediction in demand and slight overprediction in supply.

The residuals or error terms for a true model are expected to be distributed as white noise, that is, identically normally distributed with zero mean and constant variance. The *Q*-statistic, used to test this hypothesis for the residuals of the demand and supply models, is chi-squared distributed within the 10 percent confidence limit for 59 degrees of freedom, indicating that the specified models adequately represent the demand and supply.

Policy Example

The models developed here can be used to assess the forecast impact of contemplated changes in airline policy prior to their implementation. For example, let the number of seats supplied by the airline on a given route change by a one-time 10 percent increase this month (i.e., at $t - 0$). Most airlines are faced with situations where they may have to provide more (or fewer) seats as a result of an unusual event (such as changes in energy prices, important national events, holidays, etc.). Sometimes, airlines offer very low prices for a limited period as an introductory offer. Other times, they intentionally increase their service level or capacity in order to dominate the market and capture more passengers. In such cases, the demand equation can be used to forecast the resulting changes in demand this month, next month, and in the months beyond.

The forecast impacts of the seat-supply policy on demand are illustrated in Figure 3. As the figure indicates, demand increases by a maximum of 2.4 percent practically at the same time with the supply increase, but decreases steadily thereafter until it falls back to its original value before it finally returns to it in the long term.

The impact analysis indicates that the effect of service change lasts 3 to 6 months but the major impact is strongest during the first month. This is typical of airline travel. In particular, conversations with airline officials reveal that most tickets are sold within the first few weeks following the service improvements. This indicates that air travelers tend to take immediate advantage of the best offer, leading to the conclusion that they may not be loyal to their airlines.

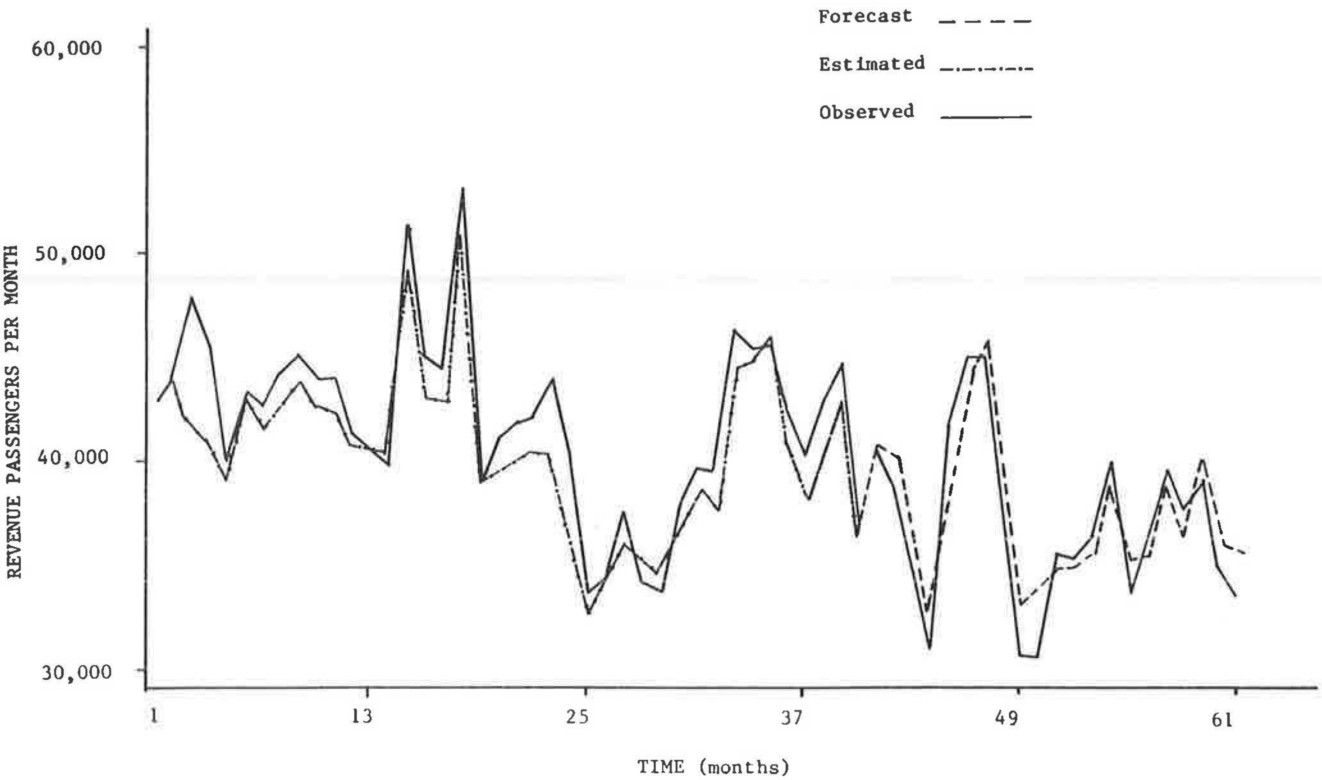

FIGURE 1 Observed and estimated values of demand.

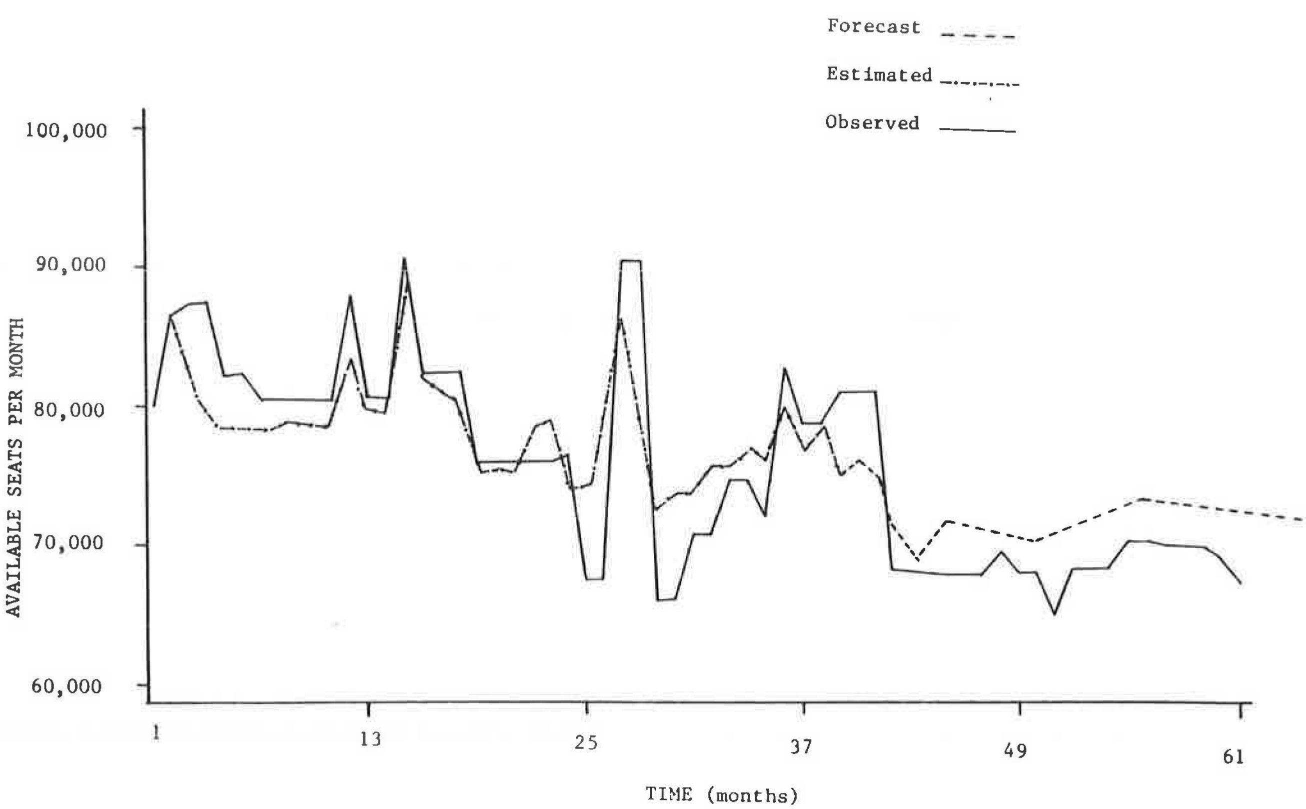

FIGURE 2 Observed and estimated values of supply.

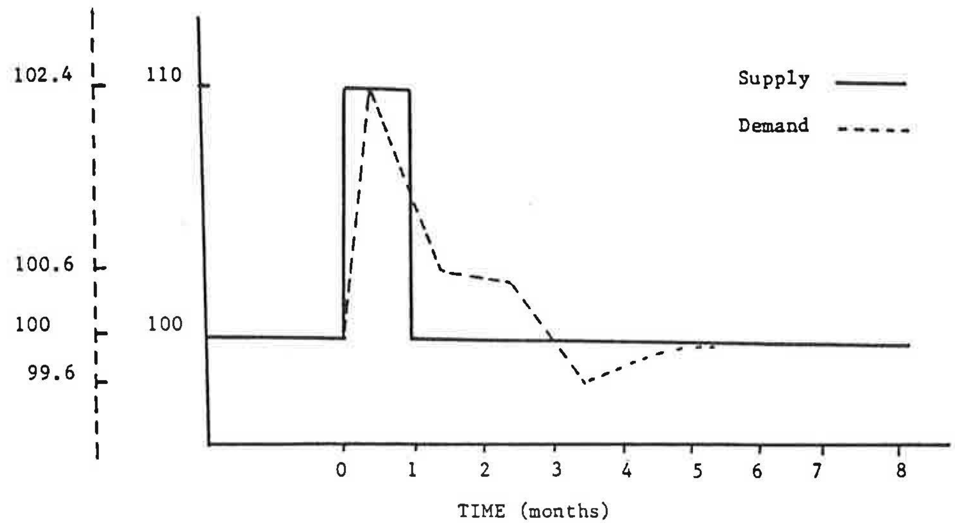

FIGURE 3 Influence of supply on demand.

The estimated impacts of air travel demand on supply are illustrated in Figure 4. As the figure indicates, a 10 percent surge in demand causes supply to increase by 1.3 percent in the second month; it then gradually decreases and finally reaches its original level by the seventh month. From Figures 3 and 4, it is also evident that the airline's reaction to a sudden surge in demand is more sluggish (the significant effect lasts longer) and slower (lags by a month) than the passengers' response to a corresponding sudden improvement in the service supplied. This impact behavior appears to be consistent with the current practices adopted by most airlines with regard to service changes. More specifically, the higher costs involved in changing the flight schedule information and reallocating the flight crew discourage most airlines from making frequent sudden changes in the service supplied.

The models developed in this research could also be used to test the impacts of different pricing policies through time. In particular, full fare and economy fare could be increased or decreased, at the same time or at different times, and their resulting impact on demand and supply studied. For instance, it was determined that fare elasticity of demand is −1.1 in the first 4 months but zero in the long term. Further, by combining these models with a ticket choice decision model, it would be possible to determine the optimum values for full fare and economy fare in order to maximize the overall profit on this route. Work along these directions is currently in progress.

CONCLUSIONS

Time-series models were developed that can be used to identify the time-dependent impacts of demand on supply, and vice versa, in nonstop air routes. Developing the models, which are based on causal relationships, required a modest amount of data that can be easily obtained from sales receipts and schedule information. The model performance is satisfactory, with average forecasting errors below 4 percent. By including seasonal data, the models could be further improved in terms of their forecasting abilities.

Application of the forecasting equations to policy analysis indicates that, although the effects of improved service (more

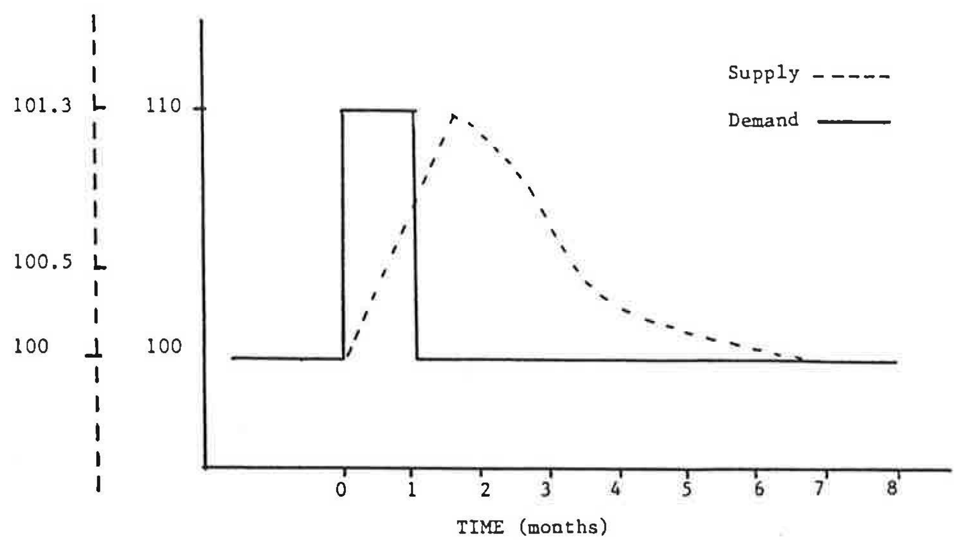

FIGURE 4 Influence of supply on demand.

seats available) on demand last for approximately 3 months, the major impact is strongest during the first month, concurrent with the service change, implying little loyalty by passengers to their airline. The policy results also indicate that the airline's reaction to a sudden surge in demand is more sluggish and lags the demand change by a month, probably as a result of the costs involved in crew and aircraft reallocations.

Current approaches adopted by most airlines in setting their pricing strategy, schedule changes, and so on, are classified. For this reason, we were unable to meaningfully compare the forecast method with the current practices followed by the airline industry.

The work presented here is only a modest attempt in developing a tool for estimating the impacts of air travel supply on demand and vice versa, through time. While the initial application is in nonstop, route-level service by one airline, the method is being extended to situations involving stops and multiple routes in intercity multimodal travel.

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Weather Briefing Use and Fatal Weather Accidents

RICHARD GOLASZEWSKI

This paper examines the quantitative reduction in risk associated with use of a weather briefing. It examines fatal weather accidents (accidents where weather is cited as a cause or a factor) that occurred during the 1964 to 1981 time period and documents statistics showing that pilots of these flights had a lower incidence of use of weather briefings than the pilot population overall. The study also notes that weather accidents represent almost 40 percent of all fatal accidents. They are characterized as being related most often to flight in low ceilings or when fog or rain is present. The types of pilot error in fatal weather accidents include continued visual flight into adverse weather conditions, improper preflight planning, and improper inflight decision making. The study uses Bayesian decision theory to estimate the probability of an accident with and without weather briefings from observable parameters such as the probability of an accident, the probability of use of weather briefings, and the probability that an accident flight had a weather briefing. The results show that a fatal weather accident is about 2½ to 3 times as likely if a flight did not have a weather briefing. The study also shows how increasing the incidence of use of weather briefings can reduce fatal weather accidents.

Although the safety value of obtaining weather briefing information prior to flying is well recognized by most aviators (*1, 2*), there has been almost no empirical research into the reduction in risk associated with the presence of such information for a flight. There is a history of interest in improving the dissemination of weather information in the United States (*3, 4*). But, even though a weather briefing is a regulatory requirement for cross-country flights in the United States (*5*), some pilots elect to fly without one.

The question of how aircraft accident rates would change if more or fewer flights had access to weather briefing information is difficult to examine directly because little information is available about the use of weather briefings for aircraft flights that did not result in an accident. Thus, it has been difficult to develop exposure-based measures of the increased risk of flying without weather information, in conditions where it could have made a difference in the outcome of the flight. Moreover, the absence or presence of weather briefing information is often unknown or not recorded during accident investigations by the National Transportation Safety Board (NTSB) or the Federal Aviation Administration (FAA).

This paper explores the value of a weather briefing in general aviation flying in the United States. It first develops data for weather-related accidents. It shows that fatal weather accidents occur under conditions that relate primarily to degraded ceilings and visibility, and nonfatal weather accidents occur under conditions that are dominated by unfavorable winds. The types of pilot causes cited in the accident record differ between fatal and nonfatal weather accidents.

The analysis employs Bayesian decision theory to infer the reduction in risk associated with the presence of weather briefing information. The probability of an accident given a weather briefing is compared to the probability of an accident given no weather briefing. These parameters are estimated using observed values for the probability of a weather briefing in the population of all flights and the probability of a weather briefing in accident flights. These data are applied to fatal accidents for which weather conditions were cited as a cause or factor in the NTSB accident records.

Changes in risk are estimated for single-engine and multiengine piston airplane accidents during the 1964 to 1981 time period. The change in risk varies by the estimated incidence of use of weather briefings in the overall population and the subset of fatal weather-related accidents. A "best" estimate is made along with upper and lower bounds on the estimates. The results show that, for single-engine piston airplanes, a fatal accident is over 2½ times as likely for flights that do not have access to weather briefing information.

WEATHER ACCIDENT DATA

Data showing the incidence of use of weather briefing information by type of flight and type of aircraft for U.S. general aviation are given in Table 1 (*5*, p. A-14). Among the principal aircraft types, multiengine piston and turbine engine aircraft have the highest incidence of use of preflight weather information. These data also show that about 50 percent of all local flights and 13 percent of all cross-country flights have no preflight weather briefing information. However, because a local flight is defined as one within 25 mi of the origin airport, a pilot is likely to encounter little change in the current weather. FAA regulatory standards (*6*) recognize this difference and impose more stringent weather information requirements on cross-country flights. The distribution of nonfatal and fatal weather accidents between local and cross-country flights is shown in Table 2. (Single-engine and multiengine piston airplanes account for the large majority of general aviation accidents. The remainder of this analysis is limited to these aircraft types.) The large majority of fatal weather accidents occurs on cross-country flights; local flights are significant only for nonfatal single-engine piston airplane accidents.

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TABLE 1 PERCENTAGE OF USE OF PREFLIGHT WEATHER INFORMATION SERVICES BY TYPE OF FLIGHT AND TYPE OF AIRCRAFT (5)

	Preflight Weather Information					
	FAA		Other		None	
Type of Aircraft	Local	Cross-Country	Local	Cross-Country	Local	Cross-Country
Single-engine piston (1 to 3 places)	31.8	70.7	17.8	19.0	53.4	15.9
Single-engine piston (4 places and over)	35.8	78.1	17.3	13.2	48.2	14.5
Multiengine piston	52.4	89.8	19.0	7.8	33.3	6.4
Rotorcraft piston	41.7	100.0	16.7	0.0	41.7	0.0
Rotorcraft turbine	53.8	76.0	11.5	28.0	46.2	12.0
Turboprop	75.0	89.5	25.0	10.5	0.0	6.1
Turbojet	0.0	97.1	0.0	2.9	100.0	0.0
Glider	12.0	N/A	28.0	N/A	60.0	N/A
All aircraft	34.3	79.5	17.6	13.2	50.0	12.6

NOTE: 1981 data.

TABLE 2 INCIDENCE OF LOCAL VERSUS CROSS-COUNTRY-FLIGHT WEATHER ACCIDENTS, 1964–1981

	Local		Cross-Country		
	No.	%	No.	%	Total
Multiengine piston airplanes					
Fatal	17	2.0	842	98.0	859
Nonfatal	39	4.8	774	95.2	813
Single-engine piston airplanes					
Fatal	277	7.8	3,266	92.2	3,543
Nonfatal	2,462	23.1	8,197	76.9	10,659

SOURCE: NTSB Accident Record

The principal benefits of weather briefings are likely to be evidenced in an examination of weather accident flights. As indicated in Table 3, weather accidents account for a significant proportion of all accidents (approximately 20 percent). In addition, a higher proportion of weather accidents involve fatalities than do nonweather accidents. Fatal accidents account for about 25 percent of all weather accidents in single-engine airplanes. In contrast, over 50 percent of the multiengine piston airplane weather accidents involve fatalities. This can be explained, in part, by the fact that these aircraft generally have a higher exposure to adverse weather, have a larger mass on collision, and may have higher impact speeds than do single-engine piston airplanes. (Annual accident rate data for single-engine and multiengine piston airplanes are contained in Appendix A, which is available from the author.)

The weather cause/factors for fatal weather accidents in single-engine piston airplanes are given in Table 4. Seven specific weather cause/factors account for almost 90 percent of

TABLE 3 COMPARISON OF FATALITY INCIDENCE, WEATHER VERSUS NONWEATHER ACCIDENTS, 1964–1981

	Weather Accidents		Nonweather Accidents	
	No.	%	No.	%
Single-engine piston				
Fatal	3,543	24.9	5,714	10.6
Nonfatal	10,659	75.1	47,988	89.4
Total	14,202	100.0	53,702[a]	100.0
Percent of all accidents	20.9		79.1	
Percent of fatal accidents	38.2		61.8	
Multiengine piston				
Fatal	859	51.4	986	15.1
Nonfatal	813	48.6	5,554	74.9
Total	1,672	100.0	6,540[b]	100.0
Percent of all accidents	20.4		79.6	
Percent of fatal accidents	46.6		53.4	

[a]Eight accidents classified as injury index unknown.
[b]One accident classified as injury index unknown.
SOURCE: NTSB Accident Record.

TABLE 4 FATAL AND NONFATAL WEATHER ACCIDENTS, INCIDENCE OF WEATHER CAUSE/FACTORS, FOR SINGLE-ENGINE PISTON AIRPLANES, 1964–1981

Cause/Factor	No.	Percentage
Fatal Weather Accidents		
Low ceilings	2,085	58.9
High-density altitude	234	6.6
Fog	230	6.5
Rain	154	4.4
Unfavorable winds	138	3.9
Thunderstorm activity	121	3.4
Turbulence	104	2.9
Subtotal	3,066	86.5
Total	3,543	100.0
Nonfatal Weather Accidents		
Unfavorable winds	5,336	50.1
Low ceilings	874	8.2
High-density altitude	845	7.9
Carburetor/induction icing	811	7.6
Updraft/downdraft	665	6.2
Sudden windshift	348	3.3
Fog	293	2.8
High temperature	297	2.8
Subtotal	9,469	88.8
Total	10,659	100.0

NOTE: The first weather cause/factor citation is used to define a weather accident. No multiple citations are used.

SOURCE: NTSB Accident Record.

the fatal weather accidents. In fact, one cause/factor, low ceilings, accounts for almost 60 percent of those. Four of the seven fatal weather accident cause/factors (all except high-density altitudes, unfavorable winds, and turbulence) are related to degraded ceilings or visibility.

The weather cause/factors for nonfatal weather accidents are shown in Table 4. There are substantial differences between fatal and nonfatal weather accident cause/factors for the single-engine piston plane. There is a significant decrease in the importance of low ceilings and fog as cause/factors in nonfatal weather accidents and a substantial increase in accidents with unfavorable winds (or other wind-related categories) as a cause/factor.

The pilot cause/factors for fatal and nonfatal single-engine piston airplane weather accidents are shown in Table 5. The fatal accident pilot cause/factors are dominated by continuation of VFR (visual flight rules) flight into adverse conditions. Other fatal weather accident cause/factors are typified by improper planning or decisions. The nonfatal weather accidents are characterized by a wide range of pilot cause/factors that relate either to wind conditions in general or to difficulties in take-off and landing.

Weather cause/factors for multiengine piston airplane fatal and nonfatal weather accidents are shown in Table 6. Fatal accidents are characterized by low ceilings, icing, and cause/factors associated with precipitation. Eight weather cause/factors account for over 90 percent of all fatal multiengine piston airplane weather accidents. In comparison, nonfatal weather accidents are most often associated with unfavorable winds. However, in contrast to single-engine piston airplanes, this aircraft type shows a greater similarity of weather cause/factors between fatal and nonfatal accidents.

TABLE 5 FATAL AND NONFATAL WEATHER ACCIDENTS, INCIDENCE OF PILOT ERROR CAUSE/FACTOR, FOR SINGLE- ENGINE PISTON AIRPLANES, 1964–1981

Cause/Factor	No.	Percentage
Fatal Weather Accidents		
Continued VFR flight into adverse weather conditions	1,583	44.7
Improper preflight preparation or planning	329	9.3
Attempted operation beyond experience/ability	231	6.5
Failed to obtain/maintain flying speed	206	5.8
Initiated flight in adverse weather conditions	203	5.7
Improper in-flight decision or planning	197	5.7
Spatial disorientation	123	3.5
Subtotal	2,872	81.1
Total	3,543	100.0
Nonfatal Weather Accidents		
Improper compensation for winds	1,115	10.5
Failed to maintain directional control	843	7.9
Failed to obtain/maintain flying speed	836	7.8
Inadequate preflight preparation or planning	816	7.7
Poor judgment	727	6.8
Improper operation of powerplant or powerplant controls	726	6.8
Continued VFR flight into adverse weather conditions	638	6.2
Improper level off	602	5.7
Improper operation of brakes or flight controls	427	4.0
Misjudged distance or speed	386	3.6
Improper in-flight decision	381	3.6
Unsuitable terrain	309	2.9
Subtotal	7,806	73.2
Total	10,659	100.0

NOTE: The first pilot cause cited in weather accidents is used to define pilot error rankings. No multiple citations are used.

SOURCE: NTSB Accident Record.

The data in Table 7 indicate that most fatal weather accidents for multiengine piston airplanes have pilot cause/factors associated with flying into adverse weather or improper operations in such conditions. Although nonfatal accidents evidence some problems with a pilot's inability to deal with severe weather or with improper response to adverse weather conditions, they are associated more often with flight techniques such as problems in level off, directional control, speed control, operation of power plant controls, and so on.

The data in Tables 4 through 7 show that fatal weather accidents occur more often in precipitation or degraded visibility conditions and have different pilot cause/factors than do nonfatal weather accidents. When weather cause and pilot cause are considered together, fatal weather accidents appear to represent a more homogeneous subset than do nonfatal weather accidents. (For more information, see Appendix B available from the author.) For these reasons, it appears that fatal weather

TABLE 6 FATAL AND NONFATAL WEATHER ACCIDENTS, INCIDENCE OF WEATHER CAUSE/FACTORS, FOR MULTIENGINE PISTON AIRPLANES, 1964–1981

Cause/Factor	No.	Percentage
Fatal Weather Accidents		
Low ceilings	512	59.6
Icing (airframe, prop, etc.)	68	7.9
Fog	53	6.2
Rain	37	4.3
High density altitude	31	3.6
Turbulence	28	3.3
Thunderstorm activity	25	2.9
Snow	23	2.7
Subtotal	777	90.5
Total	859	100.0
Nonfatal Weather Accidents		
Unfavorable winds	210	25.8
Low ceilings	163	20.1
Icing (airframe, prop, etc.)	94	11.6
High density altitude	58	7.1
Fog	57	7.0
Carburetor/induction icing	51	6.3
Rain	48	5.9
Updraft/downdraft	35	4.3
Snow	25	3.1
Subtotal	741	91.1
Total	813	100.0

NOTE: The first weather cause or factor is used to define a weather accident. No multiple citations are used.

SOURCE: NTSB Accident Record.

TABLE 7 FATAL AND NONFATAL WEATHER ACCIDENTS, INCIDENCE OF PILOT CAUSE/FACTORS, FOR MULTIENGINE PISTON AIRPLANES, 1964–1981

Cause/Factor	No.	Percentage
Fatal Weather Accidents		
Continued VFR flight into adverse weather	220	25.6
Improper IFR operation	129	15.0
Improper preflight preparation or planning	75	8.7
Improper in-flight decision or planning	70	8.2
Failed to obtain/maintain flying speed	44	5.1
Initiated flight into adverse weather	38	4.4
Spatial disorientation	36	4.2
Attempted operation beyond experience/ability level	29	3.4
Attempted operation with known deficiencies in equipment	26	3.0
Subtotal	667	77.6
Total	859	100.0
Nonfatal Weather Accidents		
Improper level off	67	8.2
Improper IFR operation	66	8.1
Inadequate preflight preparation or planning	59	7.3
Improper operation of powerplant or powerplant controls	48	5.9
Failed to maintain directional control	48	5.9
Improper in-flight decision or planning	45	5.5
Continued VFR flight in adverse weather	40	4.9
Failed to obtain/maintain flying speed	36	4.4
Misjudged distance or speed	33	4.1
Improper compensation for winds	32	3.9
Improper operation of brakes or flight controls	27	3.3
Poor judgment	25	3.1
Subtotal	526	65.0
Total	813	100.0

NOTE: The first pilot cause factor cited in weather accidents is used to define the pilot error rankings. No multiple citations are used.

SOURCE: NTSB Accident Record.

accidents are likely to be more influenced by the absence or presence of a weather briefing than are nonfatal weather accidents. Thus, further analyses in this paper are based on fatal weather accidents only.

USE OF WEATHER BRIEFING INFORMATION

The data in Table 8 show the incidence of use of weather briefing services by flights involved in weather accident flights. The data show that multiengine airplanes evidence a higher use of weather briefing services than do single-engine piston airplanes. Weather briefings as counted in the accident record include both full and partial briefings which were delivered by telephone, by radio, or in person.

Comparable data for the use of weather briefing services by all flights are shown in Table 9. There are few comprehensive data about the relative use of weather briefing services by general aviation pilots under differing conditions. It must be recognized that the weather briefing frequency of use by general aviation aircraft depends on a number of factors in addition to the local and cross-country flying distinctions noted in Table 1. For example, the actual weather at the time of flight may influence a pilot's decision to obtain a weather briefing. The data in Table 9 were calculated on three bases to provide a lower bound estimate, a best estimate, and an upper bound estimate for the population use of weather briefing services.

The following factors serve to make the above estimates conservative:

- Weather briefing incidence in the records of fatal weather accident flights considers both preflight and in-flight weather information. In all three cases, the population proportions are based only on the use of preflight weather briefings.
- In the lower bound and best estimate cases, the population use of weather briefings was estimated from 1981 survey data which were collected after the onset of the PATCO air traffic controllers strike. Flight service station briefers at FAA did not strike; however, there was a significant reduction in IFR (instrument flight rules) flights due to air traffic control system constraints. A similar survey for 1978 showed a much higher incidence of use of weather briefing services and this was used for the upper bound case.
- Fatal weather accident flights occur largely in marginal or bad weather. The population proportion of use of weather briefings is based on flying in all weather conditions, which makes this estimate conservative.

TABLE 8 FREQUENCY OF WEATHER BRIEFINGS FOR WEATHER ACCIDENT FLIGHTS

	Multiengine Piston		Single-Engine Piston	
Type of Weather Briefing	Fatal	Nonfatal	Fatal	Nonfatal
No entry	37	154	238	2,937
National Weather Service	51	39	167	248
Flight service station	565	416	1,761	2,706
None	142	100	1,086	3,441
Other	37	58	143	550
Unknown	27	46	148	777
Total accidents	859	813	3,543	10,659
Accidents with known status	795	613	3,157	6,945
Percent briefed	82.1	83.7	65.6	49.5

SOURCE: NTSB Accident Record.

TABLE 9 ESTIMATED INCIDENCE OF USE OF PREFLIGHT WEATHER BRIEFINGS, POPULATION USE AND FATAL WEATHER ACCIDENT USE (*7, 8*)

	Lower Bound Estimate[a]	Best Estimate[b]	Upper Bound Estimate[c]
Single-engine piston	72.3	82.9	92.8
Multiengine piston	88.8	93.1	96.6

[a]The lower bound case was calculated from the *1981 General Aviation Pilot and Aircraft Activity Survey* (*7*) by weighting the percentage of local and cross-country flights that used no preflight weather briefing services by the incidence of such flying. The percentage of flights that used no services was subtracted from one to produce the percentage of flights that did use services.

[b]The best estimate of the population use of weather briefing services was made by applying the percentage of fatal weather accidents that were local and cross-country to the incidence of such flights in the *1981 General Aviation Pilot and Aircraft Activity Survey* (*7*). The result was subtracted from one to produce the percentage of flights that did use those services.

[c]The upper bound case was calculated from the *1978 General Aviation Pilot and Aircraft Activity Survey* (*8*). It shows the same percentage use of preflight weather briefings for local and cross-country flights.

SAFETY VALUE OF WEATHER BRIEFING

The methodology to evaluate the value of weather briefing (Methodology I) was developed using a Bayesian decision theory approach. The Bayesian approach uses information about prior probabilities and applies empirical evidence to yield posterior probabilities. It enables examining the relative difference in the probability of a fatal weather accident given that a pilot did or did not have a weather briefing. The principal assumption in the analysis is that the weather briefing information is a critical differentiator in safety performance for fatal weather accidents. The methodology to evaluate the value of weather briefing (Methodology I) follows:

Methodology I

given

$P(A)$ = probability of an accident

$P(B)$ = probability of a weather briefing

$P(A/B)$ = probability of an accident given a weather briefing

$P(A/\bar{B})$ = probability of an accident given no weather briefing

$P(B/A)$ = probability of a weather briefing given an accident

$P(\bar{B}/A)$ = probability of no weather briefing given an accident

and

$$P(A/B) = \frac{P(B/A)\,P(A)}{P(B)}$$

$$P(A/\bar{B}) = \frac{P(\bar{B}/A)\,P(A)}{P(\bar{B})}$$

then

$$\frac{P(A/\bar{B})}{P(A/B)} = \frac{P(\bar{B}/A)\,P(B)}{P(\bar{B})\,P(B/A)} = \frac{[1 - P(B/A)]\,P(B)}{[1 - P(B)]\,P(B/A)}$$

The results of the Bayesian analysis are shown in Table 10. For single-engine piston airplanes, the "best estimate" of the probability of a fatal weather accident is over 2.5 times as great if a flight did not have a weather briefing as if it did (lower bound: 1.4 times as great; upper bound: 6.8 times as great). For multiengine piston airplanes, the "best estimate" is that a flight without a weather briefing is almost three times as likely to have a fatal weather accident if it did not have a preflight weather briefing (lower bound: 1.7 times as likely; upper bound: 6.2 times as likely).

TABLE 10 ESTIMATED VALUE OF WEATHER BRIEFING, FATAL WEATHER ACCIDENTS

	Lower Bound Estimate	Best Estimate	Upper Bound Estimate
Single-engine piston	$P(B) = 72.3\%$ $P(B/A) = 65.6\%$ $\frac{P(A/\bar{B})}{P(A/B)} = 1.37$	$P(B) = 82.9\%$ $P(B/A) = 65.6\%$ $\frac{P(A/\bar{B})}{P(A/B)} = 2.54$	$P(B) = 92.8\%$ $P(B/A) = 65.6\%$ $\frac{P(A/\bar{B})}{P(A/B)} = 6.76$
Multiengine piston	$P(B) = 88.8\%$ $P(B/A) = 82.1\%$ $\frac{P(A/\bar{B})}{P(A/B)} = 1.73$	$P(B) = 93.1\%$ $P(B/A) = 82.1\%$ $\frac{P(A/\bar{B})}{P(A/B)} = 2.94$	$P(B) = 96.6\%$ $P(B/A) = 82.1\%$ $\frac{P(A/\bar{B})}{P(A/B)} = 6.19$

NOTE: $P(A/\bar{B})$ = probability of weather accident with no weather brief; $P(B)$ = probability of a weather accident with a weather brief.

SOURCE: Data from Table 8 and 9 evaluated using Methodology I.

METHODOLOGY TO EVALUATE CHANGES IN USE OF WEATHER BRIEFINGS

The methodology used to estimate the number of accidents with varying levels of use of weather briefing services (Methodology II) follows:

Methodology II

given

$N(A/\bar{B})$ = number of accidents—no flights briefed
$N(A/B)$ = number of accidents—all flights briefed
OA = observed annual average accidents
$P(B)$ = proportion of flights briefed
$N(A)$ = estimated number of accidents
$FLIGHTS$ = annual aircraft flights

and

$$N(A/\bar{B}) = P(A/\bar{B})\ FLIGHTS$$

$$N(A/B) = P(A/B)\ FLIGHTS$$

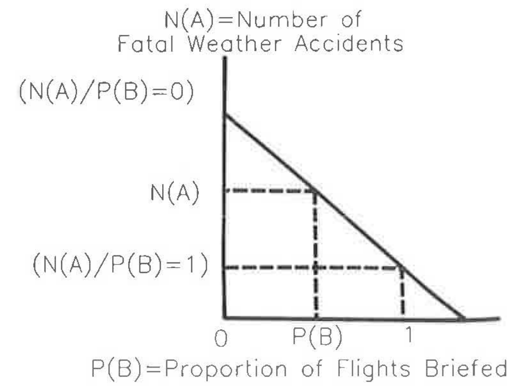
then

$$N(A) = P(A/B)P(B)\quad FLIGHTS + P(A/\bar{B})\,(1 - P(B)]\quad FLIGHTS$$

$$N(A) = N(A/B)\,P(B) + N(A/\bar{B})\,[1 - P(B)]$$

$$N(A) = N(A/\bar{B}) - [N(A/\bar{B}) - N(A/B)]\,P(B)$$

The accident flight use of weather briefing services (Table 8) and the population use (Table 9) (*7, 8*) are employed to estimate the probability of an accident if all flights are briefed and if no flights are briefed. This approach calculates the potential number of accidents in each case using the observed accidents. It should be noted that this approach is valid for a level of use of weather briefings that is not widely divergent from the actual use of weather briefings by the population. This is graphically portrayed in Figure 1. It also shows that even if all flights are briefed—$[N(A)/P(B) = 1]$—some weather accidents would still occur. This results from the fact that weather briefing information is only one factor in fatal weather accident flights.



N(A)=(N(A)/P(B)=0)–[N(A)/P(B)=0–N(A)/P(B)=1]P(B)

Source: Derived from Methodology II.

FIGURE 1 Graphical depiction of the change in fatal weather accidents from different levels of use of weather briefing information by U.S. general aviation pilots.

The data in Table 11 provide the basic values for use in calculating the number of fatal weather accidents estimated to occur under varying levels of use of weather briefing information. They are used in the next section to show how the number of fatal weather accidents could change if the proportion of flights using weather briefings was increased.

CHANGES IN ACCIDENTS RESULTING FROM CHANGES IN USE OF WEATHER BRIEFINGS

The data in Table 12 show the increase in safety associated with a hypothetical 3 percent increase in weather briefing use by the pilot population. Such a change could be achieved by a number of means:

- Increased availability and convenience of use;
- Increased FAA enforcement for nonuse of required weather briefings; and
- Incentives from insurance companies for pilots who agree to receive a weather briefing for all flights (i.e., reduced

TABLE 11 BASELINE VALUES FOR CALCULATIONS OF NUMBER OF FATAL WEATHER ACCIDENTS UNDER CHANGES IN USE OF WEATHER BRIEFINGS

	Lower Bound Estimate	Best Estimate	Upper Bound Estimate
Single-engine piston	$OA = 196.8$ $P(A/\bar{B}) = 1.24\ P(A)$ $P(A/B) = 0.91\ P(A)$ $N(A/\bar{B}) = 244.4$ $N(A/B) = 178.5$	$OA = 196.8$ $P(A/\bar{B}) = 2.01\ P(A)$ $P(A/B) = 0.79\ P(A)$ $N(A/\bar{B}) = 359.9$ $N(A/B) = 155.7$	$OA = 196.8$ $P(A/\bar{B}) = 4.78\ P(A)$ $P(A/B) = 0.71\ P(A)$ $N(A/\bar{B}) = 940.3$ $N(A/B) = 139.1$
Multiengine piston	$OA = 47.7$ $P(A/\bar{B}) = 1.60\ P(A)$ $P(A/B) = 0.93\ P(A)$ $N(A/\bar{B}) = 76.2$ $N(A/B) = 44.1$	$OA = 47.7$ $P(A/\bar{B}) = 2.59\ P(A)$ $P(A/B) = 0.88\ P(A)$ $N(A/\bar{B}) = 123.6$ $N(A/B) = 42.0$	$OA = 47.7$ $P(A/\bar{B}) = 5.27\ P(A)$ $P(A/B) = 0.85\ P(A)$ $N(A/\bar{B}) = 251.1$ $N(A/B) = 40.5$

SOURCE: Data from Tables 3 and 10 evaluated using Methodology II.

TABLE 12 ESTIMATED CHANGE IN FATAL WEATHER ACCIDENTS FROM INCREASE IN USE OF WEATHER BRIEFING SERVICES OF 3 PERCENT

	Lower Bound	Best Estimate	Upper Bound
Single-engine piston airplanes			
Probability of briefing: $P(B)$	.745	.854	.956
Estimated number of accidents: $N(A)^a$	195.3	190.8	174.4
Observed annual average accidents: OA	196.8	196.8	196.8
Change in accidents	−1.5	−6.0	−22.2
Multiengine piston airplanes			
Probability of briefing: $P(B)$	.915	959	.995
Estimated number of accidents: $N(A)^a$	46.8	45.3	41.6
Observed annual average accidents: OA	47.7	47.7	47.7
Change in accidents	−0.9	−2.4	−6.1

NOTE: Change in use of weather briefings = +3 percent.

[a]Using Methodology II.

premiums for weather-brief use, conditioned on reduced coverage if involved in accident without having received a weather briefing).

Any safety improvement would result from increased use of weather briefings by the overall pilot population; that is, accident flights cannot be selectively targeted. The Bayesian model allows an estimate of the reduction in accidents as a result of increased population use of weather briefings. For example, as shown in Table 12, a 3 percent increase in the population use of weather briefings is projected to reduce fatal weather accidents by about six accidents per year for single-engine piston airplanes (best estimate). Depending on the true population use of weather briefings, the reduction in accidents could range from 1.5 to 22.2 per year. If a high current level of weather briefing use is assumed, changes in the proportion of pilots briefed can have a significant effect on the number of accidents. However, the maximum reduction possible occurs when all flights are briefed (i.e., $P(B)$ = 100 percent). This level of use would reduce fatal weather accidents in multiengine piston airplanes by 7.2 in the upper-bound case. (For single-engine piston airplanes, 100 percent use of weather briefings is estimated to reduce fatal weather accidents by 57.7 per year.)

Decreases in the use of weather briefings were evaluated in a study of the effects of user fees on such services (*9*). Another study (*10*) examined how estimated changes in the level of use of weather briefings at various fee levels could be used to determine the value that aviators implicitly place on avoiding loss of life.

CONCLUSIONS

The most significant issue in the application of the results of this study is the uncertainty regarding the level of use of weather briefing by the pilot population. Changed assumptions about the present level of use of weather briefings have significantly different implications for the accident-reduction potential than increasing the population use of weather briefings. Nonetheless, the analysis shows that increases in the use of weather briefings can result in reducing the number of fatal weather accidents.

Future research into the role of weather briefings in fatal weather accidents is warranted. One approach would be to explore how accident rates differ for flights that received briefings from different sources (e.g., FAA, National Weather Service, private company, etc.). Another research topic of interest would be to study how differences between predicted conditions in a weather briefing and actual weather encountered affect safety. However, both of these topics are likely to require that additional information be developed on the performance of nonaccident flights.

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Defining the Philadelphia Regional Reliever Airport System

ROGER P. MOOG

This paper describes the federally funded procedure developed to identify the necessary "reliever" airports in the Delaware Valley Region. The resulting study is the product of regional planning with input from local aviation and business interests. In order to analyze noncommercial airports in the region to determine necessary level of reliever facilities, eight criteria were developed. These criteria are (a) airport capacity contrasted with current and future demand, (b) compatibility with surrounding land uses, (c) final destination of arriving passengers, (d) public and private development commitment, (e) status of airport in state's plans, (f) geographic density of airport's coverage, (g) instrument flight rule coverage, potential and airspace conflicts, and (h) pilot/user amenities. Each airport was evaluated and scored with respect to each criterion and available federal standards. Comparative rankings were assigned to each facility. Criteria scores were totaled for each airport and ranges of total scores established for existing relievers and existing general aviation facilities. The major findings of the study, which were adopted regionally and transmitted to FAA as the local priority reliever system, are (a) each of the 12 current reliever airports should retain its classification; (b) eight airports currently classified as general aviation facilities should remain so in the regional, state, and federal system plans; and (c) four general aviation reports have operating characteristics and demand estimates at higher levels than the other general aviation airports and they are within the range of reliever airport scores—these four facilities should be reclassified as reliever for state and federal funding purposes.

The Delaware Valley Regional Planning Commission (DVRPC) has, since 1980, participated with the FAA in the planning for development of the Aviation System in the Philadelphia area. The DVRPC planning area includes over 5,000 sq mi in four states surrounding Philadelphia. The 12 counties making up the planning area are Bucks, Chester, Montgomery, Delaware, and Philadelphia in Pennsylvania; Camden, Gloucester, Mercer, Burlington, and Salem in New Jersey; New Castle in Delaware; and Cecil in Maryland. In this vast area there are over 100 airports and heliports, both privately and publicly owned, in operation privately or for the public. Under FAA contract, DVRPC, between 1980 and 1982, developed the Regional Airport Systems Plan (RASP) which identified 37 existing and 8 proposed aviation facilities which were determined by DVRPC and FAA to be the critical aviation infrastructure in the region (*1*). This RASP document has been maintained by DVRPC in a dynamic state since 1982 and is incorporated in the National Plan of Integrated Airport Systems (NPIAS) as the principal source of local input to FAA aviation funding priorities (*2*).

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Inclusion of airport facilities into the NPIAS is a necessary ingredient for public sector funding of certain capital improvements at both private and public airports in the region. FAA does not guarantee federal funding, which can be as high as 90 percent of project cost to NPIAS facilities, nor does it necessarily adopt into the NPIAS the facilities from the RASP automatically. Inclusion in the RASP, however, is the major channel through which federal and related states' funds flow to airports in the DVRPC region.

In order to distribute FAA development funds in a manner that supports the needs of diverse aviation functions in the region, all of the DVRPC RASP airports also contained in the NPIAS are classified in one of three service level categories. These categories, Primary and Other Commercial (C), Reliever (RL), and General Aviation (GA), correspond to percentage allocations of the annual federal grant funding under the Airport and Airway Improvement Act applicable through Federal FY1987. Airports in similar service level categories, other than commercial, within each federal region and state, compete with each other for these scarce allocations, on the basis of relative local need and impact of potential improvements. Introduction of new reliever airports will heighten the competitive atmosphere surrounding the grant program in the Delaware Valley Region. The purpose of this paper is for the 12-county region to develop a technical rationale and identify which airports, of the acknowledged RASP/NPIAS facilities, should be considered as relievers as opposed to general aviation facilities. Funding opportunities and potential development ramifications, based on FAA adoption of this study's conclusions, may be significant to certain local airport facilities.

Eligible airports for FAA Airport Improvement Program (AIP) funding must be open to public/corporate use and may be either publicly or privately owned. These airports fall into one of the three categories listed in the previous paragraph, which are described as follows:

- Primary Commercial—having .01 percent of U. S. annual total of passenger enplanements per year. Other Commercial—having 2,500 or more enplanements per year and scheduled service.
- Reliever Airport—General aviation airports that divert general aviation traffic from commercial airports, as well as serve a high level of local general aviation operations and based aircraft. The airport must also have instrument landing potential.
- General Aviation Airport—local airports intended to serve smaller craft used for a variety of business, personal, and training functions (*2*).

Given the future scarcity of public airport improvement funding, reliever airports represent, from a systems viewpoint, a funding mechanism that aids in the preservation of that portion of the regional airport system that is in private ownership. These private facilities may experience financial pressure to close because of operating losses or attractive nonaviation development buy-out. This is demonstrated by the closing sale, in recent years, of six privately owned public-use facilities in the RASP. Reliever status must, therefore, be considered for its impact to maintain the system as well as to operationally relieve demand during peak aircraft use periods.

STUDY OBJECTIVES AND METHODOLOGY

Legislatively, FAA funding for the commercial airports in the DVRPC RASP—Philadelphia International, Mercer County, and Wilmington—is established on a formula basis and directly related to passenger enplanements. These airports are publicly owned, are heavily supported by the investments of the air carriers based there, and form the backbone of the regional aviation system. However, the general aviation support subsystem embodied by the 23 reliever and general aviation airports in the RASP and the NPIAS have a far less definite future, because of indefinite public and private capital funding and economic developmental pressures. At the same time, the local need for these facilities increases to divert general aviation traffic from Philadelphia International, which is experiencing rapid growth in commercial operations.

The objectives of this study are to examine current RASP system general aviation facilities' demand and capacity and development trends in service areas, determine the potential of facilities to be expanded physically and enhanced operationally, and then to identify deficiencies and arrive at an updated recommended plan of reliever airports for the DVRPC system. This plan, after review input from local aviation interests, will be presented to FAA for potential amendment of the NPIAS.

The methodology used to accomplish this analysis is the following:

1. Identify RASP general aviation facilities.
2. Define regional criteria/priorities for reliever status (expanded and quantified from FAA criteria through input from local aviation operators, air traffic control, government agencies, and others.)
3. Gather demographic and operations data describing the 24 study airports with regard to the above criteria, the airport's operation relation to the regional system, and relation to ground market area services.
4. Rank study airports on the basis of each criterion and summarize rankings for each airport.
5. Determine suggested relievers and general aviation classifications on the basis of rankings.

DESCRIPTION OF STUDY AIRPORTS

Since the RASP process, between 1980 and 1982, developed the regional plan of critical facilities considering location, public access, and operator commitment, this study assumes that any warranted additional relievers would be chosen from the RASP group of general aviation airports, of which 21 have been incorporated into the NPIAS. Given the active local political involvement in public transportation projects planning, the scarce supply of available land for new facilities, the excess storage capacity at some existing RASP airports, and the limited nature of public and private funds for airport development, the likelihood of implementation and advantage of proposing new facilities are not significant. Figure 1 locates each facility in the regional overview with detail given concerning geographic orientation of the runway or runways. Next to each airport are the letters GA or RL indicating its current status in the NPIAS. Figure 2 is an outline of information gathered from telephone interviews, published materials, and site visits for each facility (*3*). The data form the basis of the evaluation of each airport relative to its reliever potential, according to the eight criteria described later.

Study Airport Inventory (General Aviation Facilities) (*1*)

- Privately Owned Public Use: 19 (11 in Pennsylvania, 6 in New Jersey, 1 in Delaware, and 1 in Maryland). These are all in suburban counties, have no precision instrument approaches, are single runway (one airport has a crosswind runway in bad repair), have limited maintenance and repair facilities, and are usually owned by an individual or privately held corporation.
- Publicly Owned Public Use: 5 (all in Pennsylvania). These are all in suburban counties—except Northeast Philadelphia Airport. Two have precision approaches, more complete repair and storage facilities, and are owned and operated by county or city where they are located.

CRITERIA FOR RELIEVER AIRPORT EVALUATION

Which physical, financial, economic, demographic, and geographic attributes of local airport facilities qualify a general aviation airport for reliever status in the RASP was a subject addressed by the Aviation Technical Advisory Committee (ATAC) with input from FAA, local operators, and local government. Initially, it was realized that the importance, functions, and impacts of reliever airports to a regional aviation system were much more diverse than just taking general aviation overflow from Philadelphia International Airport. Therefore, a set of eight criteria was proposed by DVRPC to the ATAC in November 1985, discussed by that group subsequently, revised, and again reviewed by the ATAC in February 1986 before being finalized. The criteria and tests used in this study area are summarized in Table 1 and discussed in the following subsections.

1. *Reliever capacity for operations and storage.* Reliever airports provide operating and storage locations more convenient and less costly than those found at PHL. Thus, the capacity of our general aviation and reliever airports becomes critical to their role as satellites for basing of local aircraft necessary for local business development and, thereby, as a means of decreasing the operations and storage pressure of PHL by those general aviation aircraft. This criterion rates the 24 airports by capacity in dimensions. First, runway configuration will be examined, using FAA guidelines to establish operations capacity based on mix of aircraft using the facility (*4*). Second, and

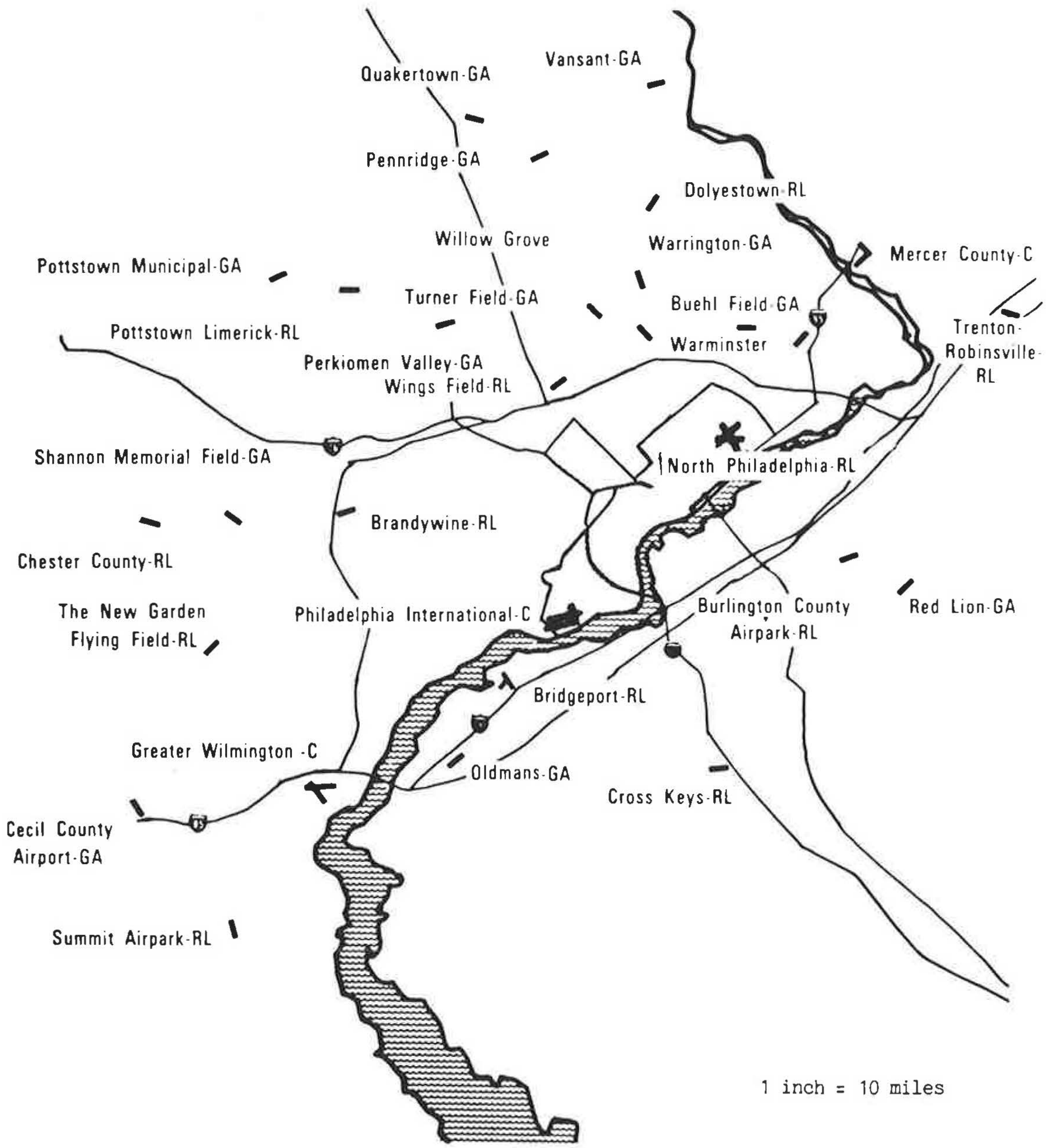

FIGURE 1 Delaware Valley airports, including runway orientations and designations as reliever or general airports.

more critical to potential operations levels, is the rating of each airport by storage capacity in hangars and outside tie-down slots. In conjunction with the capacity indicators in the above criterion is a ranking of the facilities on the basis of demand indicators quantified in the study. These include based aircraft, types of aircraft (single engine or twin jets, helicopter) as reported by each operator, level of scheduled service, if any, and annual operations as estimated in 1982 in the RASP. Excesses or deficiencies in capacity are then noted.

2. *Compatibility with local land uses.* Perhaps the most significant constraint to suburban airport facilities and operations growth is conflicts with neighbors and local governments. This conflict may result from noise, aircraft accidents or fear of such an occurrence; developmental, economic, and political pressures on local governing bodies; airport owners; traffic congestion; or any number of other issues. To rank the 24 study airports with regard to this criterion, three data parameters will be examined. These are total contiguous acreage of the airport, existence of local airport zoning to protect against developmental or natural obstructions, and type of adjacent land uses, if any (*5*). From these parameters a ranking of the facility will be established that estimates the relatively local operating environment of each airport.

3. *Final destination of arriving passengers.* The location of satellite airports, from the viewpoint of PHL Air Traffic Control (ATC), with regard to their proximity to employment and residential centers, is a critical indicator of an airport's value in the regional aviation system. Business and personal use, and potential future use of facilities, is directly related to ground access time, assuming some conformity between airports with regard to operations ease and ground amenities. To determine the relative market areas of the study airports and the growth of

Airport	Market Area (by airport - 5-mile radius)
Owner Operator (FBO) Address	
DIMENSIONS	GEOGRAPHIC
Runway Configuration Runway Lengths Storage Capacity (aircraft) - Tee Hangar - Hangar - Paved tiedown - Non-paved tiedown Facility Total Area (acres) Clearance (principal runway ends) Surrounding Uses	Townships States DEMOGRAPHIC Population - 1980-2000 Employment - 1980-2000 Population - % change Employment - % change
LOCAL DEMAND	
Based Aircraft Customers, Corporations, etc. Mix of Aircraft by Engine Type Annual Operations (estimates) Scheduled Service-enplanements Planned Annual Growth in % operations	
RECENT CAPITAL INVESTMENTS	
Funding Source - Federal Assurances? Types of Improvements Master Planning Studies	
AMENITIES	
Operating Times Fuel Availability Security Navaids Ground Transportation Food, Rest Rooms, Training School Maintenance & Repair Facilities	

FIGURE 2 Airport and market data used in the nontowered facility reliever study.

each market area, data on employment and residential levels for 1980 and 2000 are summarized for the municipalities containing and surrounding each airport. These numbers represent a level of "gravity" or attraction to each airport, and the trend from 1980 to 2000 gives an indication of the change in each airport's critical role in the future regional aviation system.

4. *Private/public development commitment.* In order to expand operations and business as well as improve safety and levels of service and amenities, all 24 airports have periodically had capital improvements. In the case of publicly owned facilities, these improvements were funded predominantly by FAA AIP funds with the 10 percent local share coming from a mix of state or local government resources. Private reliever airports have also received public funding through AIP, but usually a portion of the local share comes from the private resources of the owner/operator. Privately owned general aviation airports have, to date, relied on private funds for all improvements. Typically, in the 1980–1985 period, improvements funded through the FAA include runway extensions, taxiway paving, runway lighting, and other safety and capacity improvements. Privately funded projects at publicly owned airports include revenue generating improvements such as hangars, repair shops, passenger lounges, and so on. At privately owned general aviation airports, all improvements, whether safety related or not, are the responsibility of the operator. With regard to current private relievers, either FAA funded planning studies leading to capital improvement grants, or actual grants themselves, been executed at several airports. In order to receive the federal assistance, the facilities have obligated themselves to continue operating for up to 20 years. In many cases, these private airports have also spent considerable private improvement funds without federal match. It is, therefore, expected that most current private relievers will remain so in the NPIAS for the foreseeable future. However, as a strategy to maximize federal funding to the region, public relievers could be reclassified to general aviation where they would qualify for federal funding in that category, and thereby potentially create reliever status for a current private general aviation facility.

TABLE 1 EVALUATION CRITERIA AND DATA TESTS

Criterion	Category	Data Tests Used in Ranking
1	Reliever capacity for operations and storage contrasted with demand	Level of based aircraft Based aircraft storage availability Estimated operations in comparison to runway capacity
2	Compatibility with local land uses	Size of airport property in acres Level of municipal zoning protecting airport Compatibility of adjacent uses—resident, open farmland
3	Final destination of arriving passengers	Magnitude of 1980 population Magnitude of 1980 employment Percentage of population growth in 2000 Percentage of employment growth to 2000
4	Private/public development commitment	Degree of ongoing planning Level of public funding support Level of private investment in facility
5	Status of facilities in respective state plans	Funding classification of facility in state plan (none to commercial service) Service level in state plan (basic utility to transport)
6	Local geographic airport coverage	Distance to nearest general aviation facility Distance to nearest reliever facility
7	Instrument flight rules coverage, potential and approach conflicts	Runway length (existing) Runway expandability Percentage of based aircraft other than single engine Approach conflicts with other airports Proximity to 4,200-ft runway
8	Pilot/passenger/tenant amenities	Level of navigational aids, VFR to IFR Number of operating services (fuels, avionic shop, etc.) Degree of operations features and passenger/pilot amenities

To evaluate this criterion, operating commitment in the form of recent capital improvements, both private and public, as well as ongoing planning studies, will be identified for each facility. These data as reported to DVRPC during the winter of 1985–1986 are indicative of the ongoing private or local economic basis of the facility as well as the federal/state determination of local importance of the facility.

5. *Status of facilities in respective state plans.* New Jersey, Delaware, and Pennsylvania maintain state aviation plans as a guide for the expenditure of state funds for airport improvements. Status in those plans directly influences the potential of general aviation airports, in each state, to receive state match for federal funds, as well as for direct single-source grants. Each state maintains criteria and minimum standards for entry into the state plan. Status of each study airport in its respective state plan, including functional classification, will be noted and ranked in this criterion (*6*).

6. *Local geographic airport coverage.* Of the 23 functioning general aviation airports and 3 towered nonprimary airports in the RASP, FAA has designated 12 as reliever airports in the NPIAS; 10 of these airports are privately owned and would therefore not qualify for FAA capital grant funding without reliever status. These current reliever facilities are located, with relation to Philadelphia International Airport (PHL), as shown on Figure 1. According to Philadelphia International Air Traffic Control, approach and departure routes to PHL are interchangeable with traffic loads and weather conditions. Therefore, airport location, as a corridor alternative to PHL approaches during congested periods, is not a critical criterion for reliever designation. Air traffic control indicates that airport location in relation to ground destination for general aviation traffic is the critical selection criterion for traffic passing through the traffic control area and landing at satellite facilities to PHL. This criterion will examine airports in relation to their location to one another with rankings given to areas with lower concentration of satellite airport options.

7. *Instrument flight rules coverage, potential and approach conflicts.* In order for suburban airports to handle the increasing general aviation traffic, in the form of single, twin, and jet engine aircraft oriented towards the suburbs, these airports must develop flexibility to accommodate takeoffs and landings in adverse IFR weather conditions. Most RASP relievers and general aviation facilities currently have FAA approved nonprecision approaches directed by PHL tower to certain minimum elevations. Of the noncommercial airports, only Chester County and Northeast Philadelphia airports currently have precision ILS approaches with adequate runway length and approach clearance. Pottstown-Limerick, also a private reliever, is in the process of FAA installation of an instrument landing system to be completed in mid-1987. In order to thoroughly serve the IFR demand for relievers, it is desirable to establish these ILS approaches in major quadrants of the study area. This criterion ranks the study airports by their potential for upgrading to full IFR operation. This potential is established here by examining data that are indicative of runway length and expandability, airspace conflicts, and availability of other potential ILS facilities in the area.

8. *Pilot/passenger/tenant amenities.* Most nontowered airports in the RASP are operated by one or more Fixed Base Operators (FBOs) who provide a variety of services for pilots, aircraft, and passengers. These services contribute to the pilots decisions to choose a facility for itinerant operations and as a location to base their aircraft. The study airports have been surveyed with regard to quantifiable services and features and each airport has been given according to the diversity of amenities available. Operationally, fueling services, maintenance and repair, hours of operations and navigational aids

were considered. Customer services including availability of aircraft security, ground transportation, restaurant, and restrooms were surveyed.

EVALUATION OF AIRPORTS AND FINDINGS

Using the data gathered in this analysis, each of the 24 study airports was ranked in eight categories corresponding to the study criteria just described. Each airport was assigned qualitative rankings of high, medium, or low, based on the determination of its relative standing compared to all other airports. Each airport's rankings were then totaled for all criteria and a systemwide determination of the most significant current and future facilities was made.

According to the FAA criteria, a general aviation airport can qualify for reliever status by having 50 or more based aircraft, or annual operations of 25,000 itinerant or 35,000 local (2). Using that standard, 23 of the 24 study facilities would qualify as relievers if only the federal criteria were used. However, geographic redundance of reliever service without local demand to warrant reliever status probably will not be accepted by FAA in the NPIAS. Also, FAA capital grant funds may be reduced from FY1985 to FY1986 and FY1987 while costs of projects are increasing, thereby suggesting fewer FAA-funded projects in the future. Therefore, locally developed criteria were introduced in this study in order to more selectively identify critical reliever airports from the local perspective. With a more thorough analysis locally of the necessary reliever system, the regional recommendations contained in this report are more useful by the FAA in shaping the NPIAS and upcoming funding programs.

To achieve a more definitive analysis of reliever needs, the locally developed criteria were incorporated with existing FAA criteria. Equal weighting was given to all study criteria, partly because of the qualitative nature of the rankings and the recommendatory nature of the study conclusion from the perspective of the FAA in the NPIAS. However, certain criteria analyses contain more variables from which airports are ranked than other criteria. Consequently, the significance of those criteria will be greater in each airport's total ranking. Specifically, criteria 3 and 7 evaluating final ground destination of air travelers and IFR potential, respectively, can be said to have the most influence due to their higher number of tests.

A draft version of the completed analysis, including individual scores in all criteria, was reviewed by the Aviation Technical Advisory Committee and certain scores were revised based on that input. Table 2 summarizes the qualitative scores for all eight criteria analyzed by assigning a numerical grade of 3, 2, or 1 to each high, medium, and low, respectively, and totaling the ratings for each criterion. The far-right column presents the additive total score for each airport based on all 25 ratings in the eight criteria.

Table 3 compares scores and ranges for airports classified as reliever in the NPIAS with those classified general aviation

TABLE 2 SUMMARY OF CRITERIA RATINGS

Airport	(1) Three Tests	(2) Three Tests	(3) Four Tests	(4) Three Tests	(5) Two Tests	(6) Two Tests	(7) Five Tests	(8) Three Tests	Overall
Bucks County									
Buehl	6	7	11	2	4	4	12	6	52
Vansant	6	8	4	3	4	5	10	5	45
Quakertown	6	6	4	4	5	4	8	8	45
Pennridge	7	8	4	4	4	3	13	9	52
Doylestown	7	6	7	4	6	5	9	7	51
Warrington	6	6	12	2	4	4	7	3	45
Montgomery County									
Turner	8	6	12	4	4	3	7	6	50
Wings	7	6	10	5	6	4	13	8	59
Perkiomen Valley	6	5	8	5	4	4	11	7	50
Pottstown Limerick	6	7	7	9	6	5	13	6	59
Pottstown Municipal	5	6	6	5	4	3	13	8	50
Chester County									
Brandywine	6	7	8	8	6	4	13	4	50
Shannon	6	6	8	4	4	3	9	6	46
Chester County	7	9	6	6	6	4	14	8	60
New Garden	5	6	4	7	6	5	13	5	51
Mercer County									
Trenton-Robbinsville	7	9	9	3	6	6	13	7	60
Burlington County									
Burlington County	8	8	9	2	6	4	14	6	57
Red Lion	6	7	8	3	4	3	11	6	48
Gloucester County									
Cross Keys	8	8	10	5	6	5	12	6	61
Bridgeport	7	6	6	4	6	5	10	6	50
Salem County									
Oldmans	6	8	4	3	3	4	11	4	42
New Castle County									
Summit	7	6	4	8	6	6	15	9	61
Cecil County									
Cecil County	6	5	8	2	4	5	11	6	47
Philadelphia									
Philadelphia Northeast	8	8	10	6	6	5	15	9	67

TABLE 3 COMPARISON OF SCORES, STUDY RECOMMENDATIONS

Airport	Scores: Current Reliever Airports	Scores: Current General Aviation Airports	Not Recommended as Reliever	Recommended as Reliever
Bucks County				
Buehl		52		X[a]
Vansant		45	X	
Quakertown		45	X	
Pennridge		52		X[a]
Doylestown	51			X
Warrington		45	X	
Montgomery County				
Turner		50		X[a]
Wings	59			X
Perkiomen Valley		50		X[a]
Pottstown Limerick	59			X
Pottstown Municipal		50	X	
Chester County				
Brandywine	56			X
Shannon		46	X	
Chester County	60			X
New Garden	51			X
Mercer County				
Trenton-Robbinsville	60			X
Burlington County				
Burlington County	57			X
Red Lion		48	X	
Gloucester County				
Cross Keys	61			X
Bridgeport	50			X
Salem County				
Oldmans		42	X	
New Castle County				
Summit	61			X
Cecil County				
Cecil County		47	X	
Philadelphia				
Philadelphia Northeast	67			X

[a]New recommended reliever airport requires modification to RASP and NPIAS.

airports. Existing relievers have an average of 57.6 points with a range of 50 to 67 while general aviation airports average 47.6 points with a range of 42 to 52. Based on the overlap of general aviation airport scores into the reliever range and the individual situations of specific airports, the last column in Table 3 identifies those airports that DVRPC recommends qualify to be relievers, according to the criteria of this study.

Specifically, several RASP general aviation airports—Vansant, Quakertown, Warrington, Shannon, Red Lion, Oldmans, and Cecil County—score under the reliever average and out of the reliever range and therefore are considered not to qualify for reliever classification. Publicly owned Pottstown Municipal Airport, a general aviation facility in the NPIAS, scored in the reliever range but is recommended to remain general aviation. Pottstown Municipal was classified reliever in the original DVRPC reliever system recommendation to FAA in March 1983, but subsequently was reclassified by FAA to general aviation in the NPIAS, where it can receive developmental AIP funds as a publicly owned airport.

Buehl, Pennridge, Turner, and Perkiomen Valley airports, all privately owned and operated, had total scores that equaled or exceeded the lower end of the reliever range. The study finds that, from a local service and development perspective, these airports should be classified reliever, while all existing relievers also retain reliever classification.

CONCLUSIONS

Several conclusions can be made from the process and results documented in the study:

- The study process, by which technical criteria are generated in a committee structure of aviation interests from both the private and public sector, proved to be objective and functional. Results of evaluation were acceptable to the local aviation community and elected officials represented on the Regional Planning Agency Board. FAA participation ensures the validity of the results as the local priority position for federal consideration. FAA indicates it is considering changes in the NPIAS with regard to the DVRPC region, based on the findings of this study, and notes similar infrastructure trends and needs affecting other urbanized areas. This may precipitate modification of national policies and programs.
- Since all existing reliever airports (1982 RASP adoption) achieved relatively high scores, the study process confirmed those selections as critical facilities, while identifying four additional airports which, by comparison, now warrant reliever status on the basis of intensifying demand or diminishing alternatives.
- The study findings have infrastructure ramifications which make them appropriate input to the update of the Regional

Airport Systems Plan which occurs every 10 years and has a planning horizon of 20 years.

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Estimation of Aircraft Operations at Nontowered Airports in the Delaware Valley Region

THABET ZAKARIA

Described are the development and application of a statistical model for estimating aircraft operations at nontowered airports in the Delaware Valley Region. The model produces daily, seasonal, and annual operations based on a sample of 8 weeks of counts at each airport. A stratified cluster sample of departure counts by type of aircraft, such as single and multiengine, jet, and helicopter, was obtained from a survey that sampled 11 airports for 2 weeks in each of the 1986 seasons. The traffic demand counts were collected by means of an acoustical activity counter, which records aircraft noise at takeoffs or other activities. The model was tested with actual count data for two towered airports. The sensitivity tests indicated that the model produces good results based on survey data obtained from an 8-week sample selected at random at each airport. The margins of error in the estimates of annual operations at the airports surveyed are generally small, ranging from 9 to 21 percent of the estimated operations. These estimates are being used for managerial and operational decisions, and for long-range traffic demand projections to update the Regional Airport System Plan for the Delaware Valley Region.

Past, present, and projected traffic trends for airports are required for the planning and programming of airport improvements. To be useful for planning facilities, traffic demand data should include all airport operations (departures and arrivals), including commercial air carrier and commuter services, business, flight schools, recreation, and cargo. The data should be classified by day, season, and year and by type of aircraft (*1*). The number of operations is also needed for airport management and provision of daily services and for forecasting future activities. Such traffic demand information is generally available at towered airports with air traffic controllers. At nontowered airports, however, traffic data are usually estimated. Such facilities are generally classified as reliever or general aviation airports (Figure 1).

Since the present information on annual operations at nontowered airports in the region is not reliable, the Delaware Valley Regional Planning Commission (DVRPC) recently developed a model to estimate aircraft operations at 21 nontowered airports (*2*). In consideration of practicality, administration, and cost, a sampling plan which identifies the days and weeks of aircraft counting at each airport was also developed. The DVRPC model provided estimates of annual operations at a reasonable level of sampling error (*3*).

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The purpose of this paper is to describe briefly the DVRPC aircraft counting program for nontowered airports, with particular emphasis on sample design, model structure, data collection, and analysis of the estimated operations at 11 airports surveyed in Calendar Year 1986.

SAMPLING METHODOLOGY AND MODEL DEVELOPMENT

Analysis of aircraft activities at towered airports indicates that airport operations vary by hour, day, and season as a result of flight characteristics and changes in weather conditions (*4*). Traffic operations usually increase during good weather [Visual Flight Rules Conditions—Modified Visual Flight Rules (MVFR) and Visual Flight Rules (VFR)] and decrease during bad weather [Instrument Flight Rules Conditions—Limited Instrument Flight Rules (LIFR) and Instrument Flight Rules (IFR)]. Daily airport operations also depend on the purpose of flying; they increase on the weekend, if the airport is used predominantly for pleasure.

In order to determine variations in airport operations, the sample must include counts by hour of the day for at least 7 consecutive days. This should be repeated four times, one for each of the four seasons of the year.

Sample Size

The sample size depends on the desired accuracy and the funds available for the survey (DVRPC budget for the FY 1986 counting program was about $50,000). Statistical inference methods indicate that the greater the precision desired in the estimate, the larger the sample size and cost (*5–7*). In addition, the greater the variation in aircraft operations during the days of the week and seasons of the year, the larger the sample size needed for estimating seasonal or annual airport operations. Finally, the larger the number of airport operations, the smaller the percentage sample size needed for achieving a specific precision in the estimate of airport operations.

Based on the experience of the Oregon and Utah Departments of Transportation, and the Southwestern Pennsylvania Regional Planning Commission, DVRPC selected a stratified cluster sample for each airport consisting of a total of eight weeklong samples, two in each season (*8–10*). As will be discussed in the sections of this paper, this sample resulted in a reasonable sampling error (± 9 to 21 percent) in the estimate of annual airport operations. The eight weekly samples at each

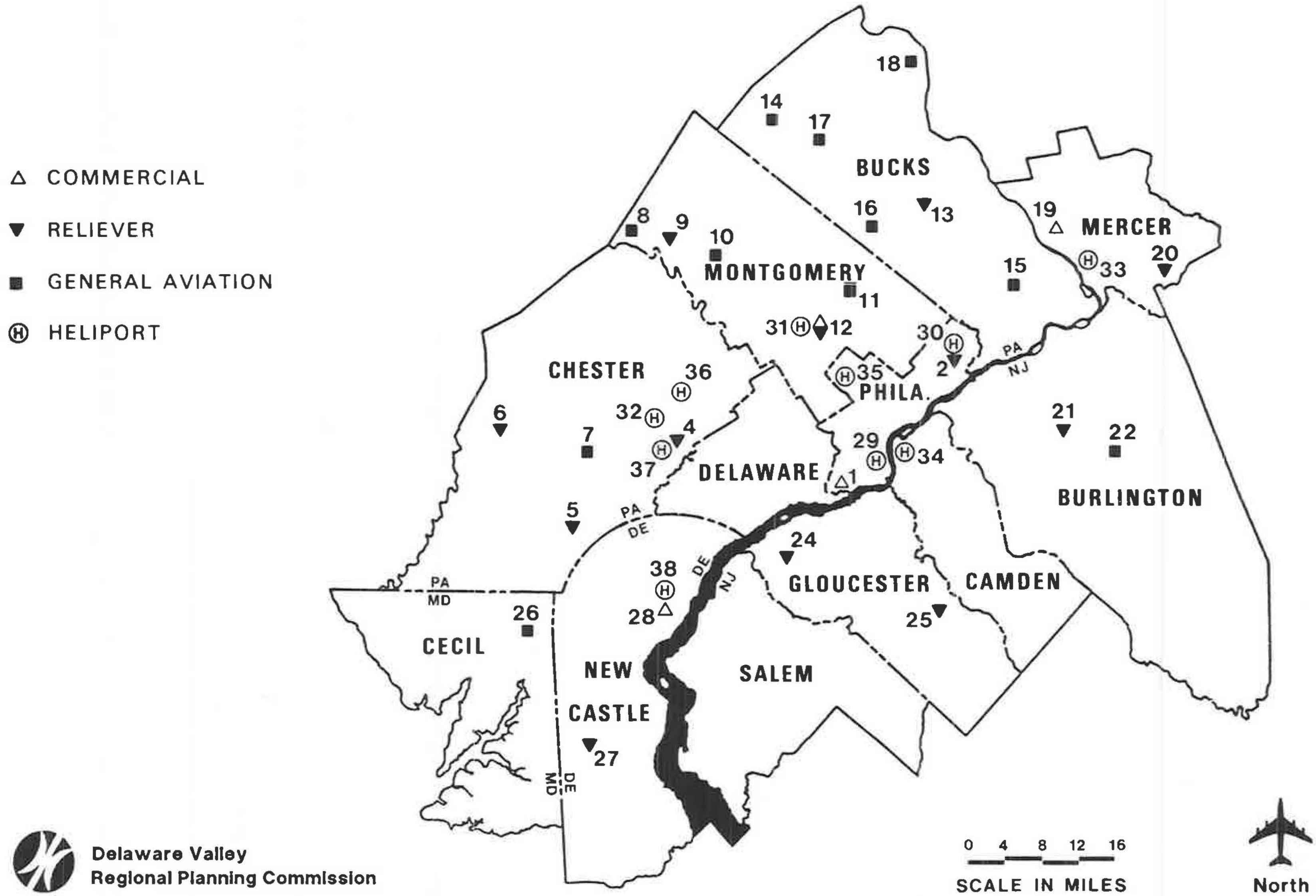

FIGURE 1 Regional airport system plan.

airport were selected at random with a sampling interval of about 6 weeks (52 weeks/9) (*3*), with the first cycle of airports being counted chosen arbitrarily in January or February 1986 in order to maximize the utilization of DVRPC's two acoustical counters during the year. This selection ensured a proportional sample at approximately equal intervals throughout the year.

Estimation of Annual Airport Operations and Sampling Error

Seven steps were used by DVRPC to estimate airport operations and compute the sampling error at 95 percent confidence interval in the estimate of annual operations for each airport counted in 1986. The following model equations are a simplified version of the standard statistical equations for the analysis of variance for the stratified cluster sample (*5, 6*).

1. Given the total daily aircraft counts (X_i) collected during each of the 2 weeks sampled in each season, the average daily counts for each of the 2 weeks were computed by dividing the total weekly counts ($\Sigma_1^7 X_i$) by 7. The average counts were labeled $\bar{X}_1$ and $\bar{X}_2$. Eight values were thus computed for the 8 weeks sampled during the year, two for each season.

2. The average daily counts for the week were subtracted from the daily counts (7 days in each of the 2 weeks of counting) sampled in each season and the differences were squared and summed. The sum was called L.

$$L = \left[\sum_1^7 (\bar{X}_1 - \bar{X}_1)^2 + \sum_1^7 (\bar{X}_2 - \bar{X}_2)^2\right]$$

Four values for L were produced, one for each season, L_w, L_s, L_r, and L_f for winter, spring, summer, and fall, respectively.

3. The average seasonal daily counts ($\bar{X}$) were calculated as follows:

$$X = \frac{\bar{X}_1 + \bar{X}_2}{2}$$

The average daily estimate for the season was subtracted from the average daily counts for the week and the differences were squared and summed for each season. This value was called F. For example, the value of F_w for the winter season is

$$F_w = (\bar{X}_{1w} - \bar{X}_w)^2 + (\bar{X}_{2w} - \bar{X}_w)^2$$

where

$\bar{X}_{1w}$ = average daily counts for the first week sampled in winter,
$\bar{X}_{2w}$ = average daily counts for the second week sampled in winter, and
$\bar{X}_w$ = average daily estimate for the winter season.

4. The variation (V) and parameters for each season and the variance of the annual operations (P) were computed as follows:

$$V = \frac{12F + 6.5L}{90}$$

Four values, V_w, V_s, V_r, and V_f, were computed for the four seasons of the year based on the number of weeks in a season, weeks sampled, and days in the week. The constants in this equation are 13 weeks in a season − 1 = 12, [13 weeks × (7 days in a week − 1)] ÷ [2 weeks sampled × (7 days in a week − 1)] = 6.5, and 13 weeks × 7 days − 1 = 90.

$$P = 476.79\ V_w + 524.81\ V_s + 537.17\ V_r + 476.79\ V_f$$

The coefficients in this equation were estimated for the Calendar Year 1986 based on the number of days in each season and the number of days sampled. For example, 476.79 for the winter season equals

$$\frac{(89)^2}{14} \times \left(1 - \frac{14}{89}\right)$$

5. The total annual operations (J) was computed as follows:

$$J = 89\ \bar{X}_w + 93\ \bar{X}_s + 94\ \bar{X}_r + 89\ \bar{X}_f$$

The coefficients in this equation represent the number of days in the winter, spring, summer, and fall of 1986, respectively.

6. The percentage of annual operations in each season was estimated as follows:

$89\ \bar{X}_w/J$, $93\ \bar{X}_s/J$, $\bar{X}_r/J$, and $89\ \bar{X}f/J$

7. Finally, the sampling error expressed in percentage terms (h) at the 95 percent confidence level was computed as follows:

$$h = \frac{216\ (P)^{1/2}}{J}$$

The t-value assumed in this equation (2.16) corresponds to 13 (14 − 1) degrees of freedom. It was based on the number of days sampled in each season of the year (*5*).

DATA COLLECTION

DVRPC aircraft counting was made by means of two acoustical activity counters purchased from the RENS company. The counter consists of a microphone, an electronic digital master counter, a tape recorder, and a digital clock that automatically sounds an hourly tone. It is activated by aircraft noise at takeoffs, landings, or other sources. The Oregon Department of Transportation, which pioneered in the use of the RENS counters, provided DVRPC with a special training tape for analysis and audit of tapes. Several types of activities are recorded on the tape, including takeoff, landing, fly by, and taxi, as well as other activity. The tape also includes information on aircraft activities by type of engine (single engine, multiengine, jet, helicopter or other), time of day (24 hours per day), and total daily activities.

In order to minimize the number of activity counters needed, the equipment was installed at an appropriate location near the runway where it can record all aircraft departures. These recorded departures were doubled to account for total operations (departures and arrivals) assuming that the number of departures is equal to that of arrivals. Nondeparture sounds recorded on the tape were not included in the estimation of seasonal or annual airport operations.

Activity Counter Rotation Cycle

Figure 2 shows the 8 weeks selected for counting at Airports A and B. Two weeks were selected for sampling in each of the four seasons of the year, which approximately correspond to the four calendar quarters. DVRPC started aircraft counting at two airports (A and B) on Monday, December 30, 1985. On the following Monday, the counters were picked up from these airports and installed at Airports C and D to start the first of eight weeks of counting at those facilities. As indicated in Figure 2, the second week of counting at Airports A and B began on February 13, 1986, and the eighth week began on December 1, 1986.

By using two counters, it was possible to sample airport activities at 11 airports during 1986. The remaining 10 nontowered airports in the region are being sampled according to this procedure during 1987.

The counters were installed or removed from airports only on working weekdays in order to decrease the cost of counting. This condition sometimes resulted in more counts than required according to the sampling methodology. However, only required data were considered for processing and running the model. It should be noted that the DVRPC staff has experienced some problems with the counters during the 1986 winter season, and one machine had to be returned to the manufacturer for repair.

Activity Counter Field and Office Sheets

An aircraft activity counter field sheet was designed to include information on airport name, observer name, weather conditions, counter placement in reference to the airport runway layout, and any pertinent remarks by the DVRPC observer responsible for installing the counters. Weather conditions were recorded for the first and last day of the week of aircraft counts, when counters were installed or removed. Cloud cover, precipitation, and wind speed were thus collected in the field for those 2 days in each sample. Other weather data such as cloud ceiling and visibility were recorded for every day of the week. These data were obtained from the National Weather Service and it was determined by DVRPC staff which of the four standard flight rules (LIFR, IFR, MVFR, VFR) was in effect.

An office sheet (Figure 3) was also designed for coding all data collected, including airport name, date of count, and season of the year. Each item was assigned a code number for ease of entry into the computer. The code numbers used are shown in Figure 4. Flight rules or categories were coded based on ceiling and visibility conditions as specified in the table.

Transcription of Airport Operation Tapes

Although the counter accurately records aircraft noise, the correct interpretation of the recordings is necessary to ensure accurate counts of activities. Transcribing the tape and identifying the various sounds are dependent on the skills and experience of the transcriber.

On a weekly basis, airport operation cassette tapes were brought into the office for identifying airport activities by type

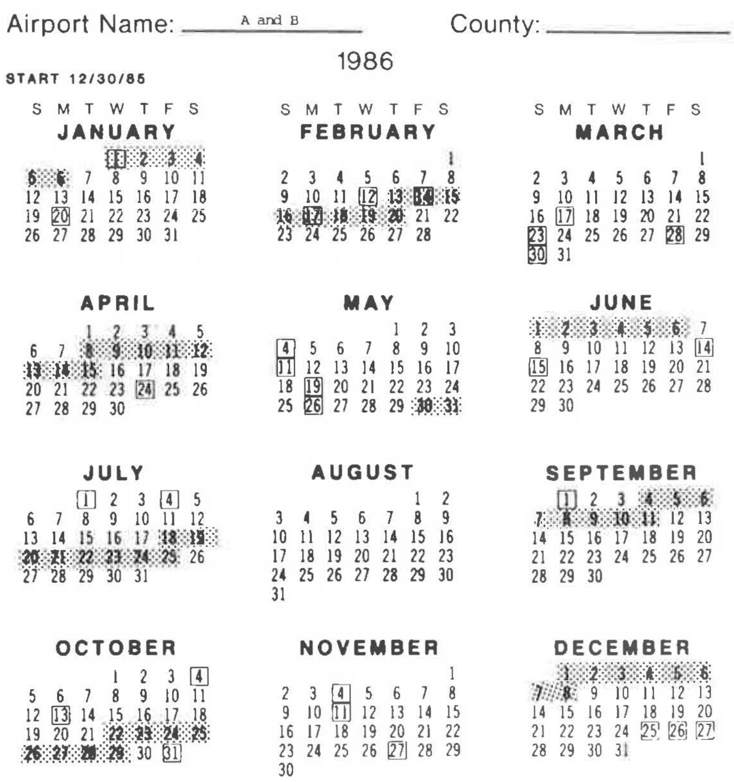

FIGURE 2 Delaware Valley Regional Planning Commission aircraft activity counter rotation cycle.

Airport Name: ____________ ( ) 1 - 28 County: ____________ ( ) 1 - 12

Date of Count: __/__/__ Day: ____________ ( ) 1 - 7 Holiday: ____________ ( ) 1 - 2

Week of: __/__/__ Season: ____________ ( ) 1 - 4

AIRPORT OPERATION BY TYPE OF ENGINE AND HOUR OF DAY

Hour	Single Engine (S)	Multi-Engine (M)	Jet (J)	Heli-copter (H)	Other (O)	S (1)	M (2)	J (3)	H (4)	O (5)	Total (6)	Hour
Midnight												Midnight
01												01
02												02
03												03
04												04
05												05
06												06
07												07
08												08
09												09
10												10
11												11
Noon												Noon
01												01
02												02
03												03
04												04
05												05
06												06
07												07
08												08
09												09
10												10
11												11
Total Counts												Total Counts

WEATHER CONDITIONS AND FLIGHT RULES

REMARKS

A. Field Observation

Time of Observation: ________

Cloud Cover: ( ) 1 - 3

Precipitation: ( ) 1 - 3

Wind Speed: ________ MPH

B. Weather Forecast

Cloud Ceiling: ( ) 1 - 4

Visibility: ( ) 1 - 4

C. Flight Rules ( ) 1 - 4

FIGURE 3 Delaware Valley Regional Planning Commission hourly and daily counts of aircraft operations.

of engine, hour of day, and type of activity. The number of takeoffs by engine type and all other types of activities that occurred in each day during the sample week were determined and recorded on the office sheets (Figure 3). After transcribing the complete tape for the weekly sample period, each category was totaled and the totals entered on the office sheets. The daily totals were then added and compared to the independent weekly count that was taken from the recorder by the field person. In almost all cases, the transcribed counts were equal to the recorded count.

Several difficulties were experienced during the transcription process. It was found that the placement of the microphone with respect to the runway had a significant impact on the quality of the sounds recorded. In some instances, it was necessary to relocate microphones to improve quality of recording or eliminate unwanted activities such as taxiing and

I. AIRPORT CODE

01. Philadelphia International
02. Northeast Philadelphia
03. Oxford
04. Brandywine
05. New Garden
06. Chester County
07. Shannon
08. Pottstown Municipal
09. Pottstown-Limerick
10. Perkiomen Valley
11. Turner
12. Wings
13. Doylestown
14. Quakertown
15. Buehl
16. Warrington
17. Pennridge
18. VanSant
19. Mercer County
20. Trenton-Robbinsville
21. Burlington
22. Red Lion
23. Camden-Burlington
24. Bridgeport
25. Cross Keys
26. Cecil
27. Summit
28. Wilmington

II. COUNTY CODE

01. Bucks
02. Chester
03. Delaware
04. Montgomery
05. Philadelphia
06. Burlington
07. Camden
08. Gloucester
09. Mercer
10. Salem
11. New Castle
12. Cecil

III. DAY CODE

1. Monday
2. Tuesday
3. Wednesday

(DAY CODE Continued)

4. Thursday
5. Friday
6. Saturday
7. Sunday

V. HOLIDAY/NON-HOLIDAY CODE

1. Non-holiday
2. Holiday

V. SEASON CODE

1. Winter
2. Spring
3. Summer
4. Fall

VI. WEATHER FORECAST CODE

Cloud Ceiling
1. Less than 500 feet
2. 500 - 1,000 feet
3. 1,000 - 3,000 feet
4. More than 3,000 feet

Visibility
1. Less than 1 mile
2. 1 - 3 miles
3. 3 - 5 miles
4. More than 5 miles

VII. FLIGHT RULES

1. LIFR - Limited Instrument Flight Rules (if ceiling and/or visibility is coded 1)
2. IFR - Instrument Flight Rules (if ceiling and/or visibility is coded 2)
3. MVFR - Modified Visual Flight Rules (if ceiling and/or visibility is coded 3)
4. VFR - Visual Flight Rules (if ceiling and visibility are coded 4)

FIGURE 4 Delaware Valley Regional Planning Commission aircraft counting program instructions.

flyovers. Sometimes, the sensitivity level of the machine was adjusted to obtain the best audio results.

At the beginning of the process, it was difficult to distinguish helicopters from taxiing or idling single-engine aircraft. Normally, the helicopter has a special sound which helps in identification, but this depends on the helicopter's activity at the time of recording. It was almost impossible to determine the helicopter-specific type of activity, such as landing and hovering. Also, single-engine aircraft presented some problems in determining whether the aircraft was taking off or executing a flyover past the microphone. Normally, the sound of the aircraft engine enables the transcriber to make a decision, but it does require exercising judgment.

Finally, the "other" category on the form (Figure 3) was used to record those sounds which were not aircraft departures. Fire trucks, motorcycles, mowers, thunderstorms, animal sounds, and various indistinguishable sounds were observed. In a severe thunderstorm, it was not unusual to find many consecutive observations in this category.

DATA PROCESSING AND MODEL TESTING

All office sheets were reviewed individually and those with apparent error were corrected. The data were then entered into an IBM AT personal computer for processing.

Computer Programming and Generation of Output Tables

A LOTUS-123 spreadsheet template was created for each airport. The templates include input areas for the hourly data of all 7 days from both weeks in each of the four seasons. Other areas of the template contain the seasonal and annual summaries. The templates have a built-in menu system to aid the user in data entry, computation, and display of seasonal and annual operations, printing reports, and filing.

Three tables were designed to display the computer output by hour of day, day of week and season, and season of year and total annual operations. Tables 1, 2, 3, and 4 are examples produced for Wings Field Airport in Montgomery County. Table 1 shows the daily counts (departures only) by type of aircraft and hour of day. Weather conditions and flight rules are also indicated for the day. The information in Table 1 is identical to that coded on the office sheet. Fifty-six sheets of this form were produced for displaying departure data collected in 8 weeks at each airport.

Table 2 shows the daily and weekly counts (departures and arrivals) at Wings Field Airport for the spring season. Four sheets of this form were produced for the four seasons of the year. The average daily operations in a season were estimated based on the data collected in 2 weeks during the season. As stated before, the estimates of seasonal operations by type of engine were obtained by multiplying the average daily operations in a season by the number of days in that season.

Table 3 indicates the seasonal and annual operations at Wings Field Airport. One sheet of this form was prepared for each airport. The total annual airport operations was obtained by adding the four season estimates for the year. As shown in Table 3, the seasonal operations are also expressed as a percentage of annual operations. Finally, the sampling error was computed by the model according to the statistical equations and assumptions described previously. The actual annual operations at this airport could be any number between 36,470 and 43,684 (40,077 ± 9 percent). It should be noted, however, that the model was designed to compute the margin of error in the annual estimates of airport operations. The error in the daily or seasonal estimates could be smaller than, equal to, or larger than the sampling error in the annual estimates.

Model Testing with Actual Counts

The model was tested four times using actual counts from the towered Greater Wilmington and Mercer County Airports (*4*), where departure and arrival information is recorded for every day of the year. The annual operations at each airport were estimated twice (Tests 1 and 2) by using two different 8-week samples chosen at random. None of the weeks selected for Test 1 overlapped with the weeks for Test 2. The estimated annual operations in each test were compared to the actual counts, along with the margins of error in the model estimates.

TABLE 1 DAILY DEPARTURE COUNTS BY HOUR OF DAY

DVRPC AIRCRAFT COUNTING PROGRAM - DAILY COUNT DATA Screen 1
AIRPORT: WINGS FIELD COUNTY: MONTGOMERY
DATE OF COUNT: 5/12/86 DAY: MON HOLIDAY: NO
WEEK OF: 5/6/86 SEASON: SPRING WEEK #1 DAY 7

	SinEng	MultiEng	Jet	Helcptr	Other	Total
MIDNIGHT	0	0	0	0	0	0
1 AM	0	0	0	0	0	0
2 AM	0	0	0	0	0	0
3 AM	0	0	0	0	0	0
4 AM	0	0	0	0	0	0
5 AM	0	0	0	0	0	0
6 AM	0	4	0	1	0	5
7 AM	1	3	0	1	1	6
8 AM	1	5	0	0	0	6
9 AM	2	3	0	0	0	5
10 AM	0	2	0	0	1	3
11 AM	0	2	0	1	2	5
12 NOON	2	2	0	0	1	5
1 PM	1	3	0	0	1	5
2 PM	0	3	0	0	1	4
3 PM	2	1	0	0	0	3
4 PM	0	4	0	0	2	6
5 PM	1	3	0	0	0	4
6 PM	1	3	0	0	1	5
7 PM	0	2	0	0	0	2
8 PM	0	3	0	0	0	3
9 PM	0	3	0	0	0	3
10 PM	0	0	0	0	0	0
11 PM	0	0	0	0	0	0
TOTAL	11	46	0	3	10	70

FIELD OBS TIME: CLOUDS: PRECIP:
FORECAST CEILING: 4 VISIBLTY: 4 FLT-RULE: 4
WIND:

TABLE 2 AVERAGE DAILY AND SEASONAL OPERATIONS FOR SPRING

DVRPC AIRCRAFT COUNTING PROGRAM — SEASON SUMMARY: SPRING
AIRPORT: WINGS FIELD — COUNTY: MONTGOMERY

Date of Count	Day of Week	Single	Multi	Jet	Helicptr	Total
		AIRCRAFT OPERATIONS BY TYPE OF ENGINE				
Week #1						
5/6/86	TUES	18	98	6	14	136
5/7/86	WED	20	92	4	14	130
5/8/86	THUR	30	90	6	12	138
5/9/86	FRI	54	92	8	8	162
5/10/86	SAT	52	50	2	4	108
5/11/86	SUN	84	60	0	2	146
5/12/86	MON	22	92	0	6	120
Total Operations:		280	574	26	60	940
Daily Average:		40.0	82.0	3.7	8.6	134.3
Week #2						
6/27/86	FRI	64	82	20	14	180
6/28/86	SAT	22	30	4	0	56
6/29/86	SUN	70	42	0	2	114
6/30/86	MON	50	90	4	16	160
7/1/86	TUES	38	78	10	16	142
7/2/86	WED	10	52	6	6	74
7/3/86	THUR	52	90	6	12	160
Total Operations:		306	464	50	66	886
Daily Average:		43.7	66.3	7.1	9.4	126.6
Season Estimates						
Daily Average:		41.9	74.1	5.4	9.0	130.4
Total Operations:		3893	6895	505	837	12130

TABLE 3 SEASONAL AND ANNUAL OPERATIONS

DVRPC AIRCRAFT COUNTING PROGRAM — ANNUAL SUMMARY
AIRPORT: WINGS FIELD — COUNTY: MONTGOMERY

Season & Year		Average Daily Operations	Total Seasonal Operations	Percent of Annual Operations
WINTER	1986	88.0	7,832	20%
SPRING	1986	130.4	12,130	30%
SUMMER	1986	122.3	11,495	29%
FALL	1986	96.9	8,620	22%
Total Annual Operations:			40,077	100%
Margin of Error:			± 9 Percent	

Table 4 compares the actual counts to the estimated operations at Greater Wilmington Airport for the two tests. As shown in this table, the differences between the counts and estimated annual operations are very small—4.4 and 0.3 percent for Tests 1 and 2, respectively. The differences are also smaller than the margins of error in the estimates (±10 and ±11 percent). Table 4 also indicates that the differences between the actual and estimated seasonal operations are generally small, ranging from −14.4 percent for the winter season in Test 2 to 8.6 percent for the spring in Test 1.

According to the 1986 official air traffic records, there were 184,780 operations at Mercer County Airport. The annual operations estimated by the model for this airport were 176,663 and 198,415 for Tests 1 and 2, respectively. The margins of error in

TABLE 4 COMPARISON OF ACTUAL AND ESTIMATED AIRCRAFT OPERATIONS AT GREATER WILMINGTON AIRPORT

		Test 1			Test 2		
			Difference from Acutal Operations			Difference from Actual Operations	
Season	Actual Operations	Estimated Operations	Absolute	Percent	Estimated Operations	Absolute	Percent
Winter 1986	38,280	37,622	(658)	−1.7	32,752	(5,528)	−14.4
Spring 1986	49,422	53,661	4,239	8.6	52,890	3,468	7.0
Summer 1986	46,577	40,930	(5,647)	−12.1	48,437	1,860	4.0
Fall 1986	49,015	42,987	(6,028)	−12.3	49,802	787	1.6
Total 1986	183,294	175,200	(8,094)	−4.4	183,881	587	0.3

NOTE: Margin of error at 95 percent confidence level—Estimated operations is ±10 percent for Test 1; ±11 percent for Test 2.

these estimates were ±10 and ±11 percent. The differences between the actual counts and estimated annual operations were −4.4 and 7.4 percent for Tests 1 and 2. In addition, the differences between the actual and estimated seasonal operations for Test 1 were −3.0, −3.3, −6.6, and −4.8 percent for winter, spring, summer, and fall, respectively. Similarly, Test 2 resulted in −1.7, 14.8, 15.0, and 1.6 percent difference between the actual and estimated seasonal operations. These sensitivity tests indicate clearly that the 8-week sample counts selected according to the DVRPC methodology produce good estimates for seasonal and annual airport operations within small margins of error.

ANALYSIS AND USE OF THE RESULTS

Table 5 presents estimated annual operations for the 11 nontowered airports surveyed in 1986. The margins of error in these estimates are expressed in percentage terms and shown in parentheses. They range from 9 percent for Wings Field in Montgomery County to 21 percent for Pennridge Airport in Bucks County. The estimated annual operations range from 16,947 at Burlington to 68,200 at Cross Keys.

Table 5 also compares the estimated operations produced by the model based on the 1986 survey to those estimated for 1985 according to the DVRPC Regional Airport System Plan (RASP) adopted in 1982 (2). In all cases, the plan numbers are higher than the survey figures. At 8 of 11 airports, the differences between the survey and plan numbers are very significant, ranging from 60 to over 1,000 percent of the 1986 estimated annual operations.

The survey results appear to be quite good, both in terms of airport capacity and current flight operations. The annual estimates are consistent with the level of operations according to aircraft records and observations by airport managers or owners. In 1984, for example, the DVRPC staff made an independent estimate of flight operations at Perkiomen Valley Airport by using airport records and logs and by interviewing airport operations personnel (*11*). The DVRPC estimate of annual operation at this airport was much lower than included in the RASP (16,000 versus 51,000). The 1986 annual operations estimated by the model were 26,091 compared to 58,000 estimated in the RASP for 1985 (Table 5).

If taken at face value, the RASP numbers imply a drastic decline in general aviation in recent years. However, there was no such trend of this magnitude and it is much more likely that the RASP traffic demand figures were overestimated. Essentially, these figures were estimated by multiplying the number of based aircraft by a factor ranging from 400 to 600 operations per year, which seems to be on the high side (*12*). Probably, a factor ranging between 250 and 400 would have been much more reasonable for most nontowered airports in the Delaware Valley Region.

TABLE 5 COMPARISON OF 1986 SURVEY AND 1985 PLAN, ESTIMATED ANNUAL OPERATIONS

Airport			Estimated Annual Operations			Difference	
No.	Name	County	1986 Survey	Margin of Error[a] (%)	1985 Plan[b]	Absolute	Percent
4	Brandywine	Chester	18,108	15	38,000	19,892	110
24	Bridgeport	Gloucester	23,026	17	71,000	47,974	208
21	Burlington	Burlington	16,947	17	193,000	176,053	1,039
25	Cross Keys	Gloucester	68,200	15	109,000	40,800	60
13	Doylestown	Bucks	32,743	15	81,000	48,257	147
17	Pennridge	Bucks	34,598	21	35,000	402	1
10	Perkiomen Valley	Montgomery	26,091	20	58,000	31,909	122
9	Pottstown-Limerick	Montgomery	28,502	14	34,000	5,498	19
14	Quakertown	Bucks	22,603	19	55,000	32,397	143
27	Summit	New Castle	40,371	16	42,000	1,623	4
12	Wings Field	Montgomery	40,077	9	188,000	147,923	369

[a] For example, the actual annual operations at Brandywine Airport could range between 15,392 and 20,824 (18,108 ± 15 percent).
[b] Regional Airport System Plan for the Delaware Valley Region, adopted in 1982 (2).

The 1986 survey results have been mailed to individual airport managers or owners for use in management, planning, and capital investment decisions. They will also be used as a basis for long-range traffic demand projections to update the RASP. The future aviation demand will be greatly influenced by airport improvements, the competitive aviation market, and conversion of some airports to more profitable land uses such as commercial or residential real estate development. The latter is likely in the growing suburban and rural areas of the region. Therefore, annual operations at each airport will be closely monitored by DVRPC to determine a factual trend line based on traffic counts taken over several years.

CONCLUSIONS

The DVRPC model for estimating aircraft activities at non-towered airports has produced good estimates for annual operations at all 11 airports sampled in 1986. It also produced estimates with small sampling or margin of error, ranging from 9 percent for Wings Field Airport to 21 percent for Pennridge. Such errors are acceptable for all planning purposes.

The model was tested with actual data recorded at two towered airports. In all tests, the differences between the actual and estimated annual operations were very small, ranging from 0.3 to 7.4 percent of the actual observations recorded. These figures indicate that an 8-week stratified cluster sample of departure counts during the year, two in each season, is sufficient for producing adequate estimates for airport operations.

Except for some repair problems, the two acoustical activity counters, purchased from the RENS company, were operating adequately throughout the year. Each machine was used for more than 44 weeks in 1986 to record count data specified in the sample design.

The total cost for estimating aircraft operations was about $5,000 per airport. This included the cost of collecting sample data in 8 weeks, transcribing the tapes, coding input data, entering data into the computer, running the model, and tabulating the estimated daily, seasonal, and annual operations output.

The estimates produced are essential for regional planning and programming of airport improvements, and for long-range traffic demand projections. They are being used by airport owners and managers, and by the DVRPC staff for updating the Delaware Valley Regional Airport System Plan.

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