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Foreword

The papers in this Record address a broad range of issues in aviation: airline operations and airport congestion, economic impacts, aviation system planning, modeling and forecasting, and airline safety.

Wheeler examines the profitability of airline hub-and-spoke operations and concludes that this type of route structure has enabled airlines to increase the efficiency of their operations and to provide increased service at lower cost.

Ozoka and Ashford apply disaggregate modeling techniques to determine the major factors influencing passengers' choice of airports in Nigeria. Unlike airline passengers in developed countries such as the United Kingdom or the United States where flight frequency and fare are predominant considerations, Nigerian airline passengers attach greatest importance to travel time for airport access.

Barol deals with the question of using the Regional Input-Output Modeling System (RIMS II) to estimate airport-dependent economic impacts.

Two papers by Brander et al. examine economic factors that affect airline competition. The first deals with the ability of dominant carriers to use slot pricing as a measure to exclude potential rivals or to force financially weaker competitors out of a market. The second paper takes up the related question of congestion, concentration, and contestability. Both papers reach similar conclusions: it is not feasible for dominant, financially stronger carriers to use slot auctions and airport access pricing as effective competitive weapons against weaker incumbents or potential new entrants.

Kanafani et al. explore using Service Difficulty Reports (SDR) as indicators of airline safety and find consistent evidence that the safety posture of an airline, as shown by SDRs, is correlated primarily with the scale of operations (stage length and the number of operations) and aircraft type (wide body versus narrow body). These conclusions hold true regardless of whether the airline is a new entrant or an established carrier.

McDougall and Cho describe a model to estimate average annual flight hours and project maximum practical flight hours over the service life of various types of general aviation aircraft. They conclude that the model provides useful information for aircraft manufacturers in developing marketing strategies and for aircraft operators in making purchase decisions and in planning fleet expansion.

Strategies for Maximizing the Profitability of Airline Hub-and-Spoke Networks

COLIN F. WHEELER

The use of hub-and-spoke networks by the U.S. airline industry is examined. The strengths and weaknesses of this type of route structure are assessed, and empirical and quantitative evidence is used to identify strategies for maximizing the economic success of an airline hub-and-spoke network. The hub location and network design process, as well as aircraft scheduling, is discussed. The author concludes that the use of hub-and-spoke networks has enabled airlines to provide increased operating efficiency and service at a lower cost to consumers of air transportation.

Since deregulation of the commercial aviation industry in 1978, many U.S. airlines have adopted a routing and scheduling strategy known as hub and spoke. The concept, named for the similarity of such a network to a wheel, involves the funneling of passengers from outlying cities via spoke routes to one or more centrally located hub airports at which—because of coordinated flight schedules—convenient connections to other cities in the network can be made. The operation of hub-and-spoke, or radial, networks has come under increasing scrutiny in recent years because of congestion from the large volume of and extreme peaks in arrivals and departures at hub airports. Despite the resulting strain on the air traffic control (ATC) system from using the hub-and-spoke strategy, its use nevertheless allows both airlines and passengers to realize a number of benefits.

By examining the success and failure of the hub-and-spoke networks that have emerged within the past decade, it is possible to draw some conclusions about how these networks should be designed and operated to maximize the profitability of the operating carrier. This paper identifies various methods for achieving maximum efficiency, beginning with discussion of the hub-and-spoke concept and followed by recommendations for optimizing carrier hub locations, network design, and flight schedules.

HUB-AND-SPOKE STRATEGY

With the hub-and-spoke strategy, an airline operates spoke routes from one or more hub airports. The convergence of flights on a hub at approximately the same time is referred to as a "bank," or "complex." Each bank lasts from the time the first inbound flight arrives at the hub until the last outbound flight has departed. Flight schedules are coordinated such that passengers can transfer between flights on a bank. After an adequate ground time to allow passengers and baggage to be exchanged, participating aircraft depart for their respective spoke cities. Flights are generally routed from one spoke to another in approximately the opposite direction from the hub. Banks are usually routed to serve traffic flows in a specific direction.

Advantages and Disadvantages

The main advantages of using hub and spoke are as follows:

- A hub-and-spoke network provides high-frequency service to a large number of low-density city pairs. A network allows a carrier to market many origin and destination (O and D) possibilities to each spoke city, thus allowing the carrier to compete in many markets and expend relatively few resources. High-frequency service is desirable because it is attractive to business passengers—who constitute approximately 50 percent of all airline traffic in the United States—and because it increases the carrier's chance of achieving top-line display in computer reservation systems (CRS) (*1*).
- The high demand for nonstop service allows a hub-and-spoke operator to realize higher-than-average fares on a nonstop route that it monopolizes.
- The large number of O-and-D markets served allows a hub-and-spoke operator to minimize its dependence on any particular market or group of markets and to reduce the risks involved in adding a new city to its system.
- A carrier with a hub-and-spoke system can market a large number of possible itineraries and thereby increase the rate at which passengers are retained on-line. On-line retention of passengers is desirable because the carrier keeps a connecting passenger's full fare, rather than only a portion allocated by proration.
- The large number of possible routings of aircraft and crew at hubs permits greater use of equipment and labor, as well as increased operational flexibility.

The main disadvantages of using hub and spoke are as follows:

Continental Airlines Corporation, P.O. Box 4607, Houston, Tex. 77019.

- A hub-and-spoke network contributes to congestion and delay at major hub airports and in the traffic sectors that serve these airports. Although these problems are largely the result of the narrowing gap between system capacity and volume of aircraft movements, they are exacerbated by the self-imposed delay that results from the "complexing" of flight schedules by hub carriers for connecting flights.
- The consolidation of operations at hubs results in overuse of terminal staff, gates, and equipment at a carrier's hub stations. A hub-and-spoke network consequently has higher departure costs—variable station and landing fee expenses—than do linear networks.
- Poor weather conditions at hub airports can result in increased costs because of reaccommodation of misconnected passengers, prevention of illegal crews, and other operational problems.

Economics of Complexing

Of the hundreds of thousands of airport pairs in the United States, only a small number are able to generate enough traffic to make scheduled nonstop service profitable. By operating a hub-and-spoke network, an airline can provide frequent service between a large number of airport pairs that do not generate enough passengers to support nonstop or direct (one or more stops, but no transfer to other aircraft) services. Although local traffic between a hub and its spoke cities may not be great enough for each route to make a profit, each spoke route also carries passengers traveling to and from other spoke cities behind the hub. Cross-feeding between spokes allows a hub-and-spoke operator to realize higher load factors than it would if each route were operated separately with no passenger interchange between routes

As the number of routes emanating from a hub increases, there is an exponential increase in the number of O-and-D markets served. For example, a hub with 10 spokes serves 55 O-and-D markets, but a hub with 20 spokes serves not 110, but 210 markets. [The number of O-and-D markets served by a hub is equal to $(N^2/N)/2$, where N equals the total number of cities in the network (including the hub).] The ability of hub-and-spoke networks to exponentially increase the number of possible itineraries as the number of routes increases is one reason for the recent consolidation of some airline carriers.

Table 1 illustrates the ability of a hub-and-spoke network to efficiently serve a large number of markets with a minimum expenditure of resources. Identified are the O-and-D volumes and average fares for Continental Airlines' Denver-Portland (DEN-PDX) route. For proprietary reasons, some of the values used in this example have been modified. Continental currently operates three round trip flights on the DEN-PDX sector and carries an average of 70 local and 154 flow passengers per day each way. As shown in the table, if Continental had to rely exclusively on local traffic, it would have an actual load factor lower than its break-even load factor and consequently would lose money on the route. However, if it were able to flow traffic to and from its other spokes leaving Denver, the number of added passengers and extra revenue would allow Continental to make a profit on the

TABLE 1 PRO FORMA PROFIT/LOSS FORECAST FOR DEN-PDX ROUTE

MARKET	MILES FROM DEN	MARKET SIZE - PAX PDEW INDY. 1/	MARKET SIZE - PAX PDEW CO 2/	AVG. OW FARE (O&D)	SEGMENT PRORATE FACTOR	AVG. OW FARE (DEN-PDX SEG.)	TTL CO REV. PDEW ON DEN-PDX SEG.	PROFIT/LOSS FORECAST
PDX-DEN	985	172	70	$150	1.00	$150	$10,500	1). IF CO HAS TO RELY ON LOCAL TRAFFIC:
CHI	901	206	9	198	0.54	107	962	
DFW	645	119	10	197	0.60	118	1,182	$25,500 TTL COST 3/
MSP	693	99	5	161	0.59	95	475	-------------------- = .06 CASM
BOS	1,767	89	7	216	0.36	78	544	431,430 ASM'S
NYC	1,632	204	19	213	0.38	81	1,538	
DTW	1,135	53	5	184	0.46	85	423	$10,500 TTL REV.
MCO	1,553	52	5	177	0.39	69	345	---------------- = .15 YIELD
PHL	1,569	50	4	214	0.39	83	334	68,950 RPM'S
MCI	543	46	9	170	0.64	109	979	
HOU	864	50	22	219	0.53	116	2,554	BELF = 40%
ABQ	339	33	6	146	0.74	108	648	ACTUAL L/F = 68,950 RPM'S/431,430 ASM'S = 16%
MSY	1,067	30	4	188	0.48	90	361	PDEW FULLY ALLOCATED P/L = ($15,000)
CLE	1,213	28	4	194	0.45	87	349	
OMA	485	28	6	162	0.67	109	651	2). IF CO IS ABLE TO CARRY FLOW TRAFFIC:
WAS	1,464	121	9	212	0.40	85	763	
MKE	908	23	3	160	0.54	86	259	$25,500 TTL COST 3/
OKC	500	23	4	148	0.65	96	385	-------------------- = .06 CASM
SAT	793	22	3	178	0.55	98	294	431,430 ASM'S
TUL	549	19	4	149	0.64	95	381	
ICT	428	18	7	150	0.70	105	735	$25,700 TTL REV.
COS	67	17	5	137	0.94	129	644	---------------- = .12 YIELD
ELP	556	9	1	159	0.64	102	102	220,640 RPM'S
BIS	527	8	3	149	0.65	97	291	
			---				-------	BELF = 51.7%
			224				$25,700	ACTUAL L/F = 220,640 RPM'S/431,430 ASM'S = 51.1%
								PDEW FULLY ALLOCATED P/L = $200

1/ SOURCE = DOT TABLE 8 YR. ENDING 2Q88.

2/ SOURCE = DOT TABLE 10 YR. ENDING 2Q88.

3/ THE FULLY ALLOCATED COST OF A 2 1/2 HOUR FLT. USING MD-80 EQUIP. = $8,500 X 3 RT'S = $25,500.

route. As demonstrated in this example, although local traffic is important because it is high yield [average revenue per passenger mile (RPM)], lower yield flow traffic is also important because the added RPM can result in greater total revenue.

Although an airline's ideal network should allow minimal travel time itineraries between any two cities in its system, in reality it is rarely possible for a carrier to competitively serve 100 percent of the potential O-and-D markets in its network. Some itineraries will invariably be too circuitous to successfully market to the public. Such a situation exists, for example, for airlines that primarily operate transcontinental service and those that operate spokes from one or more central hubs to western and eastern cities. (TWA and Braniff currently operate networks of this kind.) Connections can be made between aircraft operating on a route going in one direction from a hub and those going in the opposite direction, without dramatically increasing travel times. However, it is unlikely that itineraries between two cities in the same region would be able to attract many passengers. Passengers would be required to fly to a hub airport, change planes, and then fly to their destination.

Itineraries that require substantial circuity to a connecting hub often face competition from carriers offering shorter travel time between the spoke cities in that itinerary. It is undesirable for a carrier to market such itineraries because doing so would dilute its yield. The desire by airlines to minimize travel times of all or most of the traffic flows in their system is a main reason why the major carriers have recently acquired most of the national and regional airlines and created additional hubs. (Note that since 1981, airlines have been classified on the basis of annual revenues. "Major" carriers have annual revenues in excess of $1 billion; "national" carriers have annual revenues between $100 million and $1 billion; "regional" carriers have annual revenues between $10 and $100 million; and "commuter" carriers have annual revenues less than $10 million.)

Invariably there will be some circuitous flight connections in a carrier's network. The decision of which itineraries should be considered salable, and therefore identified in the carrier's CRS and system timetable, is subjective.

CONSIDERATIONS FOR HUB LOCATION

Although deregulation allows an airline the freedom to enter and exit cities at will and therefore the option to move hubs as markets and traffic flows change, the expense and difficulty of moving hubs severely limits an airline's ability to do so. Consequently, the decision of where to place a carrier's hubs is important.

Large Local Traffic Base

The most important consideration involved in the deciding on hub location is the volume of O-and-D traffic in the candidate hub city. Hubs located in cities that generate a large amount of local O-and-D traffic are desirable because they allow the carrier to compete effectively for high-yield local traffic and, consequently, to minimize dependence on lower-yield flow traffic. This is one reason for the success of United Airlines in Chicago, American Airlines in Dallas/Ft. Worth, and Continental Airlines in Houston. It is particularly desirable to have a hub located in a city with high O-and-D volumes and to achieve a high market share of passengers originating in, and destined for that city. Carriers that have achieved this ideal include USAir in Pittsburgh, TWA in St. Louis, and Northwest in Minneapolis/St. Paul. Each of these airlines carries close to 80 percent of the locally originating passengers at the hub city.

Central Location

Another important factor in determining hub placement is that it be centrally located. The hub should be at or near the midpoint of the cities it will be serving, weighted by the volume of traffic between each of these cities (i.e., it should be at the point of minimum aggregate travel). The importance of locating hubs at or near the weighted midpoint of the cities served by that hub stems from the desirability of minimizing network circuity and the total elapsed travel time of traffic flowing through a carrier's system. Minimizing network circuity results in lower fuel consumption and crew pay time, as well as higher yields.

Minimal Competition

A third consideration in the hub placement decision is the competition present in each candidate city. The desirability of dominating hub cities encourages airlines to create hubs in cities not currently used as hubs. Hubs strategically situated in certain cities to serve a particular traffic flow but used as a hub by other carriers usually generate low yields on those carriers' mutual nonstop services. These low yields are a result of the intense competition that exists on such routes. An example of a strategically situated city that generates low yields is Denver. Continental and United both use Denver as a hub. The desirability of being the only hub operator in a city, combined with the intensity of competition in multicarrier hubs, is illustrated by the fact that there are currently no airports continually used as a hub by more than two major airlines.

An airline should also weigh the trade-off between carrying a high volume of true originating traffic—by locating hubs in densely populated cities that often have congested airports and airways—and the benefits of lower volume traffic—by locating hubs in smaller cities that are generally less congested. Although hubs located in heavily populated cities are attractive because they allow a carrier to market nonstop services to a larger population, it is easier for a carrier to dominate hubs located in smaller cities. The reduced level of congestion that exists in the vicinity of most smaller cities also allows a carrier to realize operating efficiencies as a result of improvement in on-time performance. Hubs located in smaller cities include Piedmont in Charlotte and Dayton, American in Raleigh/Durham and Nashville, and Braniff in Kansas City. Some carriers have attempted to achieve the best of both worlds by creating a hub in a less congested secondary airport in or near a major city. People Express's Newark hub (now a Continental hub) and Midway's Chicago Midway hub are examples of this strategy. The recent trend of locating hubs in smaller cities and in secondary airports not only allows a carrier to realize the preceding benefits, but also reduces congestion levels near major hub airports.

Multiple-Hub Networks

During the past decade, many carriers have developed multiple-hub networks that allow them to compete in several major traffic flows. The creation of additional hubs can allow a carrier to serve an increased percentage of the potential O-and-D markets in its network by better serving existing flows and tapping into markets that were previously served only with circuitous and therefore minimally salable itineraries. American Airlines' multi-hub network provides a good example of the strategic placement of hubs.

Each of American's five hubs is well situated to serve a particular traffic flow. American now serves all of the major traffic flows in the United States. The Chicago and Dallas/Ft.Worth hubs primarily serve east-west transcontinental traffic, with Chicago serving more northern flows and Dallas/Ft.Worth serving more southern flows; Nashville serves flows between the Northeast and the lower Mississippi region, as well as between the Midwest and the Southeast; Raleigh/Durham handles traffic between the Northeast and the Southeast; San Juan, Puerto Rico manages flows between the continental United States and the Caribbean; and San Jose fields intra-West Coast traffic. Table 2 identifies the current location of each of the major and national carriers' hubs.

NETWORK DESIGN CONSIDERATIONS

Once a carrier's hubs are in place, several fundamental principles of hub-and-spoke network design should be employed in laying out its route structure. These principles include:

- Operating spokes only on routes that will be able to make reasonably direct connections with other routes leaving a hub.
- Establishing service only on routes with block, or flight, times so aircraft use will be maximized.
- Inaugurating service only on routes that have minimum competition.

Although it is often difficult to meet each of these criteria in candidate spoke cities, they are the ideals toward which carriers creating or expanding a hub-and-spoke network should strive.

Delineation of Tributary Regions

Hub-and-spoke operators should attempt to lay out routes in such a way that circuitous connections between all or most of the routes leaving each hub are minimized. Although some strategically located hubs can be used to simultaneously serve several traffic flows (e.g., Atlanta, which is used by Delta to serve flows between five separate regions of the country), most hubs primarily serve only one traffic flow between two tributary regions leaving the hub in approximately opposite directions.

In an attempt to maximize the number of possible itineraries available for sale, carriers with hubs that primarily serve two

TABLE 2 DOMESTIC HUB LOCATIONS OF MAJOR AND NATIONAL U.S. PASSENGER AIRLINES

Airline	Hubs (as of May 1, 1989)	
Alaska	Seattle	
American	Dallas/Fort Worth	Chicago (O'Hare)
	San Juan, Puerto Rico	Nashville
	Raleigh - Durham	San Jose
America West	Phoenix	Las Vegas
Braniff	Kansas City	Orlando
Delta	Atlanta	Dallas/Fort Worth
	Cincinnati	Los Angeles
	Salt Lake City	Orlando
Midway	Chicago (Midway)	
Northwest	Minneapolis/St. Paul	Detroit
	Memphis	Milwaukee
Pan Am	New York (JFK)	Miami
Southwest	Dallas (Love)	Houston (Hobby)
	Phoenix	
Texas Air	Denver	Houston (Intercontinental)
Continental	New York (Newark)	Cleveland
	New Orleans	
TWA	St. Louis	New York (JFK)
United	Chicago (O'Hare)	Denver
	San Francisco	Washington D.C. (Dulles)
USAir	Pittsburgh	Philadelphia
	Cleveland	Indianapolis
	Los Angeles	San Francisco
Piedmont	Charlotte	Dayton
	Baltimore	Syracuse

regions in opposite directions from the hub should establish a network in which the amount of demand that exists on one side of the hub is approximately equal to that which exists in the opposite direction. Although a disparity in the number of routes or the capacity operated on each route may exist, carriers should try to balance the amount of demand generated by each region. If one region generates more traffic and consequently requires more capacity than another, the carrier will have to rely, in part, only on local traffic between the heavier demand region and the hub.

Ideally, each city within one region generates an amount of traffic equal to a corresponding city in another region. However, carriers with an equal amount of demand in two regions—but with a disparity in the number of spoke cities in each—can still operate an efficient hub-and-spoke network by operating high-capacity equipment on their heavier demand routes and low-capacity equipment on their lighter demand routes. Because preference is given to direct flights over connecting itineraries on CRS displays, a carrier with several low-density routes in one direction and a few high density routes in the other may, for marketing reasons, want to operate change-of-gauge through-flight service between its high-demand spoke cities in one region and its lower demand cities in the other (i.e., flights would operate between both regions but would involve a change of aircraft at a hub).

Aircraft Cycle Times

Another important consideration when designing a hub-and-spoke network is the round-trip block time between the hub, city and each candidate spoke city. Because of the desirability of maximizing aircraft use, a carrier should attempt to map its routes so that aircraft departing from a hub during one bank will be able to return to that hub as part of a later bank after having had a minimal turn time at a spoke city. Carriers should avoid scheduling aircraft to remain on the ground in spoke cities for longer than necessary. They should schedule the return flight to arrive at a hub during, rather than before, a bank arrival period. One way of accomplishing this is for carriers to operate spoke routes with an approximately equal stage length. Aircraft that depart from a hub together would therefore return to the hub at approximately the same time—assuming that the aircraft travel at approximately the same speed on each route. Another way of ensuring maximum aircraft use is to only operate routes with one of two or three approximate stage lengths. With such networks, the round-trip block times of the shorter routes should be a fraction of the round-trip times on the longer routes. For example, Continental Airlines aircraft operating between its Denver hub and Midwest cities such as Omaha and Kansas City return to Denver twice as fast as aircraft operating to central cities such as Chicago and Cleveland, and three times as fast as aircraft operating to East Coast cities such as Boston and New York. As is discussed in the following section on schedule and complex design, TWA's domestic network is a good example of the application of this principle.

Economics of Candidate Routes

Economic forecast must be made for all candidate spoke routes. It is possible to estimate the financial success or failure of a new route by evaluating the local and flow market sizes, their average fares, and the amount of competition. The Civil Aeronautics Board's (CAB) Quality of Service Index (QSI) can be used to estimate a carrier's share in a given market. (The CAB's QSI assigned a value of 1 to nonstop service, 0.55 to one-stop service, and 0.033 to connecting service.) After RPMs and yield have been estimated for a candidate route, the carrier can determine the route's economic viability by dividing the cost per ASM by the yield to get its break-even load factor, and then comparing this with the estimated actual load factor.

Carriers should attempt to serve city pair markets in which a minimal amount of competition exists or in which they can provide superior service. Although such markets may have relatively low traffic volumes, the lack of a substantial amount of competition allows carriers to realize higher yields than would otherwise be possible. Carriers can achieve such near monopolies by serving traffic flows in which competitors provide only highly circuitous connecting itineraries. The desirability of dominating a carrier's city pair markets is supported by Higgins and Toh (1985), who constructed a linear regression model using a profitability index (calculated by dividing a carrier's operating revenues by its operating costs and then multiplying by 100), and a monopoly index (the percentage of unduplicated nonstop flights operated) (*2*, p. 22). Higgins and Toh found that for every 1 percent increase in a carrier's monopoly index, there is likely to be a 17.7 percent increase in its profitability. The relationship between monopoly and profitability is a major reason for the post-deregulation success of USAir and Piedmont, both of which have been able to dominate many of their city pair markets.

SCHEDULING CONSIDERATIONS

This section describes the various components of the aircraft scheduling process, including such issues as how long banks should last, when they should occur, how they should be directionalized, and how the scheduling of individual aircraft through a hub-and-spoke network can be optimized.

Bank Length

A fundamental decision that needs to be made early in the scheduling process is how much time should elapse between the arrival of the last inbound flight forming a connecting bank at a hub and the departure of the first outbound flight from that bank (i.e., the period during which all flights participating in a bank are scheduled to be on the ground). The shorter a hub's connecting period, the less time passengers traversing the hub will have to spend on the ground, and the shorter the total elapsed time for itineraries with a stop at the hub. The benefit of having short connecting periods is offset by the increased likelihood that connections between flights will be missed as a result of late arrivals. Although carriers can hold departing flights so that important connections can be made, doing so is likely to cause aircraft departing late to fall behind schedule and, consequently, to miss connections with other flights later in the day. Holding departures can also prevent inbound aircraft from arriving at their gates on time. Carriers must therefore weigh the trade-off between minimizing travel times and maximizing the number of successfully completed connections. Although some airlines using smaller, less congested hubs schedule connecting periods of 20 min, most major carriers schedule at least 30 min.

To minimize the amount of time required for passenger transfer and to minimize passenger walking distances, carriers should assign flights that have a considerable amount of connecting traffic to dock at neighboring gates. Because it is often difficult if not impossible to do this, an easier and more commonly used way of minimizing passenger walking time is to assign the flights with the most passengers to the most centrally located gates. Carriers can also speed the flow of connecting passengers by placing flight status and gate location screens in the walkways adjacent to their gates and by stationing information personnel at several locations throughout the terminal.

In addition to deciding the duration of connecting periods at each of their hubs, carriers must also decide how much time should elapse between the first and last inbound flights, and between the first and last outbound flights. The length of a hub's arrival and departure periods is based on the number of inbound and outbound flights participating in each bank, as well as the constraints imposed by the hub airport and the ATC system. Most major carriers use 30-min arrival and departure periods—an average of 1.3 operations per minute per runway during visual flight rules, or 80 operations per hour per runway if 40 flights are scheduled to participate in each bank. Passengers transferring between flights when arrival and departure periods of this length are used in combination with 30-min connecting periods have a connecting time between 30 and 90 min. (Connecting time is the amount of time elapsed between the arrival of one flight and the departure of a connecting flight.) To balance out the amount of time each aircraft will spend on the ground, outbound flights are generally scheduled to depart in approximately the same order they arrived. Aircraft participating in a bank with 30-min arrival, connecting, and departure periods spend approximately 60 min on the ground—through times at hubs are generally closer to 45 min. Exceptions to this average ground time are flights arriving from abroad. International flights are typically scheduled to arrive well ahead of other inbound flights so passengers will be able to clear customs in time to make connections with outbound flights. Also, larger, wide-body aircraft, which require longer through times than smaller planes, are usually scheduled to arrive early in a bank and to leave late.

After a carrier has decided the length of a hub's arrival, connecting, and departure periods, it can calculate the maximum number of daily banks it will be able to hold at that hub by dividing the length of the hub airport's operating day by the amount of time elapsed between the beginning of the arrival period and the end of the departure period of each bank. The length of an airport's operating day is based on the desirability of only operating flights with attractive departure and arrival times, and on noise abatement curfew constraints at some airports. As an example of the calculation of the maximum number of daily banks a hub will be able to accommodate, an airport with a typical, 18-hr operating day would be able to accommodate 12 daily banks, assuming that 30-min arrival, connecting, and departure periods are used and that no cushion of time exists between the end of one bank and the beginning of another. Although some carriers such as Delta schedule their operations as tightly as this, most schedule at least 10 min between banks, resulting in the operation of only 10 daily banks at each hub. Other carriers that use shorter arrival, connecting, or departure periods operate more than 12 daily banks. Piedmont (now owned by USAir) currently operates 14 daily banks at its Charlotte hub.

Directionalization and Timing of Banks

The next step in the aircraft scheduling process is determining precisely when banks should occur at a carrier's hubs and how, if at all, the banks should be directionalized to best serve specific traffic flows. This decision is based primarily on the most attractive spoke city departure and arrival times for the traffic flows a hub is designed to serve. Additionally, a carrier should attempt to form complexes to maximize the use of its fleet. Passengers generally want to depart from their origin sometime during the 18-hr period between 7:00 a.m. and 1:00 a.m. Demand for departures peaks between approximately 7:00 a.m. and 8:00 a.m., and again in the afternoon between approximately 4:00 p.m. and 6:00 p.m. Similarly, passengers typically want to arrive at their destination sometime during the 18-hr period between 6:00 a.m. and midnight. Demand for arrivals grows shortly after noon, peaks in the late afternoon, and declines later in the evening. Although it is desirable to maximize the number of flights that have attractive spoke city departure and arrival times, it is often impossible for a carrier to achieve this ideal on all of its flights. Because banks are generally timed and directionalized to serve the heaviest traffic flows, departure or arrival times of flights that serve less important markets sometimes occur at unattractive times, such as departure between 1:00 a.m. and 7:00 a.m. or arrival between midnight and 6:00 a.m. This is primarily true for longer routes, but exists for short ones as well.

A carrier can determine the optimal timing of a hub's banks by experimenting with different combinations of aircraft flows in an attempt to serve the greatest amount of traffic with the least amount of resources. This is usually done by first identifying when individual flows serving the peaks of demand are needed, and then determining when these aircraft pass through the hub on previous or later flights. Additional aircraft flows can then be added to fill any gaps in service. A carrier must be careful to not schedule more than one flow to pass through a hub at a time, and must sometimes schedule a group of aircraft to remain in spoke cities for longer than necessary so that a hub will be vacant upon the aircraft's arrival. Flows with very attractive departure or arrival times are generally composed of flights from all or most spoke cities in a particular direction from a hub. A carrier must avoid creating flows with aircraft volumes exceeding the capacity of its hub airports or the ATC system, particularly when one or more competitors will be converging a group of flights on the same airport at or close to the same time.

A carrier operating hubs with spokes in many directions generally does not try to directionalize each bank because to do so would usually require the operation of more daily banks than the airport is able to accommodate. Instead, banks occurring at hubs serving multiple traffic flows usually serve all directions simultaneously. Flights arriving from one region thus make connections with flights destined to all other regions served by that hub. To provide a competitive but not excessive amount of service on each route, and to prevent the number of aircraft docked at the hub from exceeding the number of gates, a carrier operating hubs of this type typically includes each route in only every second or third bank. This results in the operation of an average of six or four daily round trip flights on each route, respectively, if 12 daily banks are operated at the hub.

A carrier with hubs that have spokes in opposite directions usually schedules aircraft flows to pass through the hub in one direction at a time. Because passengers arriving from one region generally do not transfer to flights destined for the same region, banks at this type of hub do not have to serve both directions simultaneously. By alternating the direction served by each bank, a carrier can minimize the peaking of operations at a hub, thereby minimizing the quantity of terminal staff and facilities required and maximizing their use. Also, because of the effect of block times and time zone changes, it is unlikely that aircraft serving traffic flows in opposite directions will always pass through a hub at the same time. As with hubs serving multiple traffic flows, a carrier with single traffic flow hubs generally do not include every route in each bank. Although hubs where 12 daily banks are operated would result in the operation of six daily round-trip flights on each route if all routes participated in each bank, most carriers operate an average of only four daily round-trip flights on routes leaving hubs of this kind. The trend appears to be toward the adoption of less peaked, directionalized banks, and away from the operation of very peaked banks in all direction. Most of the newer hubs have directionalized banks, and some of the older hubs have been rescheduled to reflect this trend. Northwest Airlines, for example, recently rescheduled its Memphis hub from four 40-departure "omni-direction" banks to six 25-departure directionalized banks.

In scheduling aircraft, it is desirable for a carrier to include an inbound group of flights in the first bank of the day and an outbound group of flights in the last bank of the day. Although hotel costs for crew could be reduced by originating and terminating aircraft only at hubs, the operation of complete banks is necessary so that a carrier will not have to rely exclusively on local traffic during each hub's first and last bank.

Table 3 describes two common transcontinental aircraft flows that serve different spoke cities but pass through a hub together. The first of these flows consists of aircraft that begin their daily flight sequence, or line of flow, on the West Coast with a morning departure. This flow arrives at a midcontinent hub shortly after noon and arrives on the East Coast during the late afternoon. These aircraft then depart for the West Coast in late afternoon or early evening, pass through a hub during the early evening, and arrive on the West Coast during the late evening. Some carriers then send the aircraft back to the East Coast as "red-eyes," but for simplicity aircraft in this example terminate on the West Coast. The itinerary for such a flow is identified in Table 3 as Aircraft Flow Number 1. Aircraft Flow Number 2 operates on the opposite schedule with aircraft departing from the East Coast in the morning, arriving at a midcontinent hub during mid-morning, and arriving on the West Coast during the late morning. The flow then returns to the East Coast, departing at approximately noon, passing through a hub during the late afternoon, and terminating during the late evening.

As a carrier's aircraft flows begin to fall into place, the scheduler starts to get an idea of when each hub's banks will occur and how, if appropriate, they will be directionalized. As can be seen in Table 3, the two aircraft flows create eastbound banks beginning in the vicinity of 12:45 p.m. and 5:30 p.m., and westbound banks beginning in the vicinity of 8:00 a.m. and 6:45 p.m. TWA's St. Louis hub provides a good example of the outcome of creating carefully arranged aircraft flows. As can be seen in Table 4, TWA's second, fifth, eighth, and ninth banks in St. Louis are formed by aircraft flows with itineraries very similar to those illustrated in Table 3. Each of TWA's flows are carefully arranged so that nearly all flights have attractive spoke city departure and arrival times. Additionally, TWA's route structure and St. Louis bank times allow it to make intensive use of its fleet. Because most of TWA's domestic routes leaving St. Louis have one of two approximate stage lengths—the longer routes radiate out to coastal cities on both sides of the continent and the shorter routes serve inland cities located closer to St. Louis—aircraft departing from each bank onto routes of either length return

TABLE 3 EXAMPLE OF TWO COMMON TRANSCONTINENTAL AIRCRAFT FLOWS

		Aircraft Flow No. 1 (Eastb'd Flight Followed By a Westb'd Flight)		Aircraft Flow No. 2 (Westb'd Flight Followed By an Eastb'd Flight)
Dep.	WCC	O 0700		1145
Arr.	HUB	1245	Eastbound	1730
Dep.	HUB	1345	Complexes	1830
Arr.	ECC	1645		2130 T
Dep.	ECC	1745		O 0700
Arr.	HUB	1845	Westbound	0800
Dep.	HUB	1945	Complexes	0900
Arr.	WCC	2130 T		1045

WCC = West Coast City
ECC = East Coast City
HUB = Connecting Hub City
O = Originate
T = Terminate

TABLE 4 TWA'S COMPLEX TIMES, VOLUMES, AND DIRECTIONS AT ST. LOUIS HUB

Complex Number	Remarks	Direction	Arrival Period	Number of Inb'd Flights	Departure Period	Number of Outb'd Flights
1	Arrivals are returning from sixth complex the day before	Eastb'd	0520 - 0535	6	0620 - 0710	13
2	First westb'd flights from eastern cities	Westb'd	0730 - 0800	29	0830 - 0900	24
3	Flights are from interior western cities only	Eastb'd	0900 - 0930	25	0945 - 1015	35
4	Returning from first complex	Westb'd	1000 - 1030	37	1100 - 1140	33
5	First eastb'd flights from extreme West Coast cities	Eastb'd	1150 - 1225	37	1300 - 1330	41
6	Returning from first and third complexes	Westb'd	1330 - 1400	26	1430 - 1500	25
7	Returning from second complex	Eastb'd	1415 - 1445	18	1515 - 1530	15
8	Returning from second complex	Eastb'd	1540 - 1610	21	1630 - 1700	23
9	Returning from fifth complex	Westb'd	1700 - 1800	48	1830 - 1900	40
10	Returning from fourth and sixth complexes; become first westb'd flights the next day (second complex)	Eastb'd	1900 - 1930	39	2000 - 2045	41
11	Returning from seventh complex	Westb'd	2050 - 2120	22	2200 -2220	15

Source: This table compiled from a TWA station activity report for St. Louis.

to the hub during the formation period of a later bank after having had minimal turn times in their spoke cities. Although some banks are composed of aircraft that pass through St. Louis at the same time throughout the day (e.g., the ninth bank consists almost exclusively of aircraft that began service on the extreme West Coast), most banks are composed of aircraft with different repeating patterns (e.g., the sixth bank consists of aircraft from the first bank, which were routed onto longer routes, as well as aircraft from the third bank, which were routed onto shorter routes). A comparison of the bank times and directions at other midcontinent hubs reveals that the timing and directionalizing of TWA's St. Louis hub are similar to that of other carriers' hubs, particularly Northwest's Minneapolis/St. Paul hub and Delta's Dallas/Ft. Worth hub.

Creation of Lines of Flow

After a carrier has decided what its aircraft flows will be and how many flights will be participating in each flow, it is ready to schedule the individual aircraft in its fleet. At this point the carrier will know the approximate departure and arrival times of all or most of the flights in its system but will not have connected these flights together into lines of flow (i.e., consecutive sequences of flights that are operated by a specific aircraft on a particular day). The overriding concern at this point is that the capacity operated on each flight match demand as closely as possible. Although some hub-and-spoke operators use a single type of aircraft, most carriers with hub-and-spoke networks have gradually acquired diverse fleets that allow them to allocate appropriately sized equipment to each flight. In determining the type of aircraft to be operated on each flight, a carrier tries to assign equipment that is well suited to the logistical requirements of the flight and that will, on average, be able to achieve greater than break-even load factors. Although capacity should match demand as closely as possible, it is sometimes necessary to operate excess capacity on flights departing from a hub so that the next inbound flight operated by that aircraft will have adequate capacity. Another concern in the creation of lines of flow is that because certain connecting markets will generate substantially more traffic than others, direct, one-stop, through plane service should be operated between city pairs with dense traffic volumes when possible.

The result of this hooking together, or blocking, of flights is that each line of flow should consist of a series of flights that, if operated by a particular type of aircraft, will generate revenues in excess of operating costs. Because the originating and terminating cities of lines of flow are rarely the same and ferrying aircraft between cities is undesirable, individual aircraft are usually scheduled to operate different lines each day. Individual aircraft are generally rotated through several lines and undergo several maintenance checks before the pattern is repeated. Other aircraft, usually of the same type, cycle through the pattern in the same order of lines. The number of aircraft that share a pattern is always equal to the number of days required to complete one circuit of the loop.

Because hub-and-spoke networks rely so heavily on connecting itineraries, it is critical that hub-and-spoke operators maintain a high degree of schedule integrity. Although it may be tempting for carriers to advertise unrealistically short block times, such an action increases the likelihood that connections will be missed as a result of late arrivals. Consequently, it is important that block times be as accurate as possible and that through, turn, and connecting times be adequate. Operations personnel should also endeavor to get flights in and out of stations as close to schedule as possible.

CONCLUSION

It has been a decade since the U.S. commercial aviation industry was deregulated. In an effort to survive and prosper in a highly competitive environment, airlines have sought to maximize the efficiency of their operations. The adoption of hub-and-spoke networks has been one strategy used by airlines to provide the most service at the least cost. The increase in the quantity of service supplied, and the decline in average air fares enjoyed by the nation's air travelers have, in part, been made possible by the widespread use of hub-and-spoke networks. In response to the growth in congestion levels of recent years and a perceived decline in the quality of service provided by the airline industry, many now advocate a total or partial return to regulation. It is the author's hope that instead of restricting the ability of airlines to respond to the needs of the marketplace, local and federal governments will accommodate the industry's growth by expanding the nation's landside and airside capacities, as well as adopting pricing mechanisms that will encourage a more efficient and equitable use of available capacity.

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Application of Disaggregate Modeling in Aviation Systems Planning in Nigeria: A Case Study

ANGUS IFEANYI OZOKA AND NORMAN ASHFORD

This paper deals with the application of disaggregate modeling in airport choice by domestic air travelers in Nigeria. The major factors influencing passengers' choice of airports in a developing country such as Nigeria are discussed. Knowledge of these factors will greatly assist in the planning of aviation systems on a more reliable basis. A travel survey was conducted in August 1987 in Nigerian airports to collect disaggregate data on air travelers for use in model calibration using the multinomial logit model (MNL). The results of the analysis suggest that the travel time of access is the major determinant of airport choice in Nigeria and that variables such as flight frequency and air fare, which were found to be significant in previous studies in the United Kingdom and the United States, were not significant in the Nigerian context.

Nigeria, a developing country on the west coast of Africa, has 16 major airports; many more are either planned or under construction. The Nigerian government's goals is to establish airports in all state capitals and important commercial centers and to foster air travel, social mobility, national integration, and commercial and industrial development. However, a challenge has been inadvertently put to airport planners and managers. They must provide facilities that serve the social and economic needs of Nigerians and yet are economically justifiable by matching investments with returns. Another reason for building a large number of domestic airports is the general belief that each airport will serve a particular territory or "catchment area." Airports are centers for modal change between air and ground transportation, therefore there is bound to be competition between airports. The concept of catchment areas is invalidated because people do choose between airports (*1–3*). Figure 1 shows the 16 major airports in Nigeria. Figure 2 shows the trip generation zones for the two competing airports considered in this research.

The aims and objectives of this work are to:

- Determine the traffic distribution among airports in Nigeria, with special focus on two selected airports that are possible competitors.
- Give insight into the major determining factors of airport choice by Nigerian domestic air travelers and to compare the findings with earlier research, particularly in the United States and the United Kingdom.
- Use the model as a predictive tool to determine the effect of building a new Nigerian airport in Onitsha, to serve that city and its environs.

An important consideration in deciding the scope of this project was that no prior research existed on airport choice in Nigeria. Therefore, such research would likely add significant knowledge about air transportation in Nigeria. Other developing countries with a similar structure of commercial aviation would also benefit from the research. Ultimately, aviation systems planning in Nigeria will be enhanced, because, planning will be done on a more reliable basis through clearer understanding of how demand is shared among the components of a multiple airport system.

DATA REQUIREMENTS AND PREPARATION

Demand is treated in a micro context, specifying the consumption, choice patterns, and behavior of the individual consumer (the air traveler). The model is disaggregate and requires data at the personal level for calibration. Such data are not routinely available in Nigeria and had to be obtained through a survey of air travelers at the two regional airports in Enugu and Benin.

These airports were selected because:

- They are situated near each other;
- They attract air travelers from nearby regions;
- They offer the promise of competition, should competition exist;
- They have relatively high aeronautical activity in terms of aircraft and passenger movements; and
- They each have two commercial air carriers providing service to Lagos.

To calibrate successfully the airport choice model, it is important that the destination city have only one major airport; otherwise, the choice of departure airport may be influenced by the options of the destination airport. This requirement was satisfied because Lagos has one airport that serves all domestic traffic.

A. I. Ozoka, Federal Ministry of Transport and Aviation, Lagos, Nigeria. N. Ashford, Loughborough University of Technology, United Kingdom.

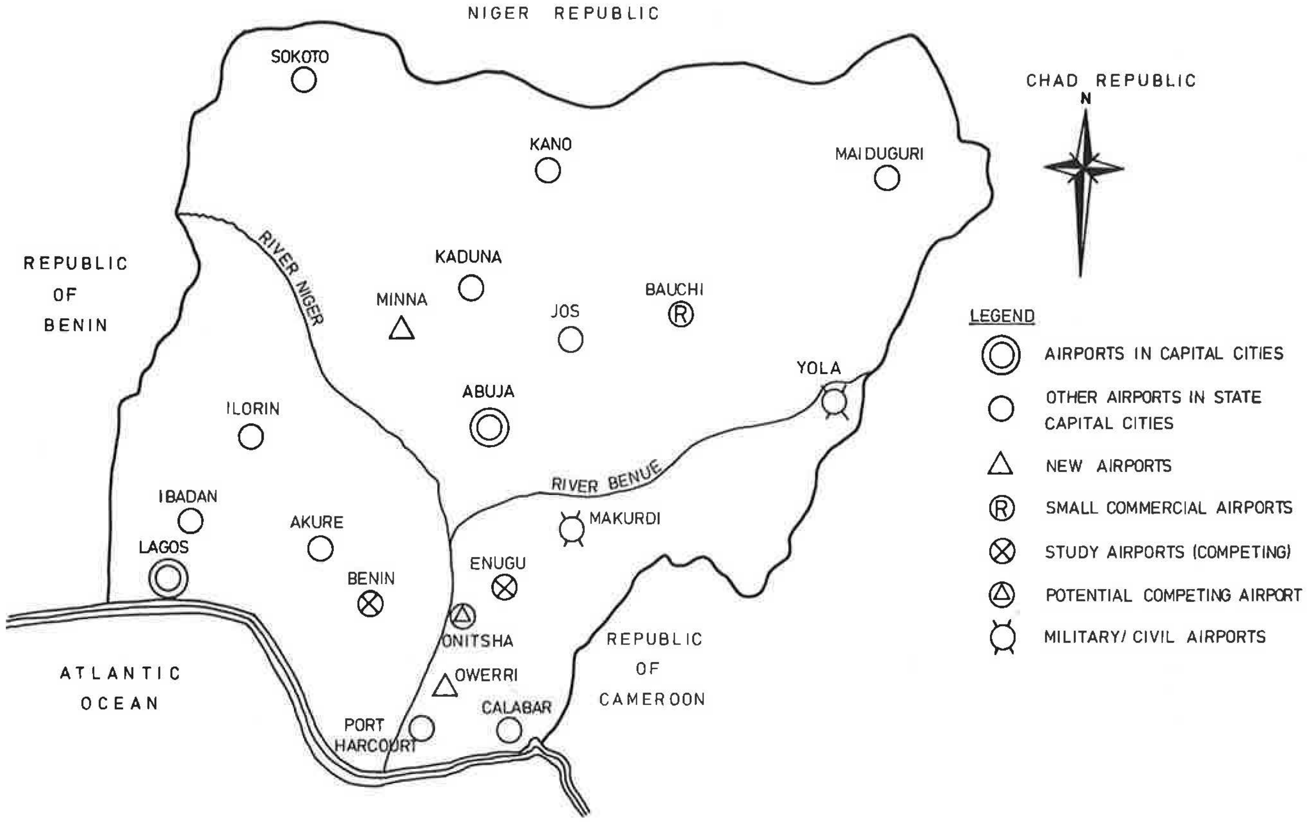


FIGURE 1 Main Nigerian airports.

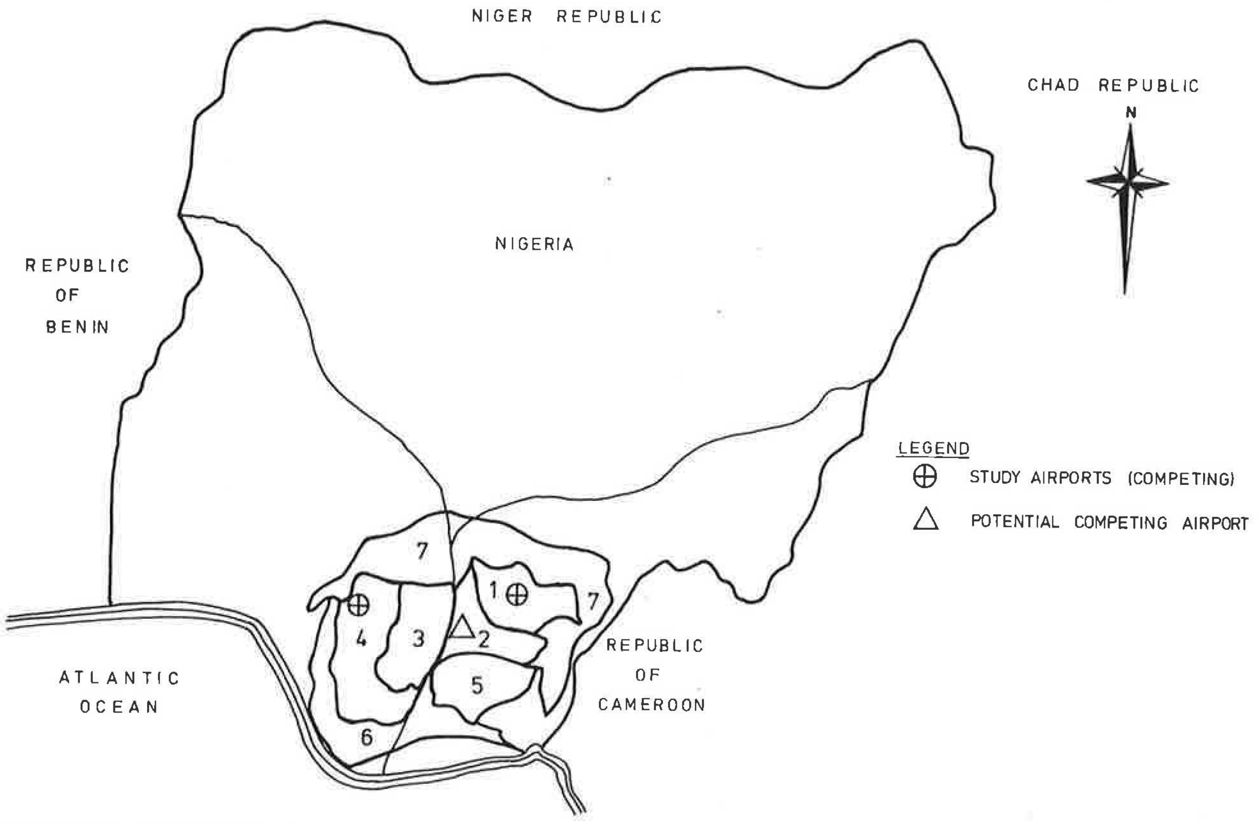


FIGURE 2 Nigerian zone map.

Questionnaires were designed as stipulated by Oppenheim (*4*). The questions were largely in line with the United Kingdom's Civil Aviation Authority format (*5*) but were greatly modified to suit the purposes of this study. Low levels of literacy and the lack of complexity of air travel—there are no connecting flights and each flight is a complete journey in its own right—were taken into account. The survey was conducted during a 2-week period in August–September 1987 and completed inflight by travelers en route to Lagos—all flights from the departure airports terminated in Lagos.

The format of the questionnaire shown in Figure 3. For each traveler, the following data were collected or computed from both survey and nonsurvey sources:

- place of residence in Nigeria,
- surface origin of the traveler,
- sex,
- age,
- occupation and education,
- day of the week,
- trip purpose,
- selected airport or nonselected airport,
- access travel time from surface origin,
- number of flights from the competing airports to the destination (Lagos) for that particular day of the week,
- air fare from the competing airports to the destination,
- airline used for the journey, and
- reasons for choosing the airport.

Not all the data collected were found to be relevant to the study. Irrelevant data included income, occupation, age, sex, and education. These data were not cited by the air travelers surveyed as the reasons for their airport choice. They were included in the questionnaire because leisure and recreational travel is largely undertaken by educated men and women in the top economic group. (*6*). Tardiff concluded that a socioeconomic indicator such as occupation was superior to income in explaining travel behavior (*7*).

Data relevant to the study were the air passenger trip records (local origin, destination, airport used, flight number, trip purpose, and day of the travel), passenger access travel time, air fares, and flight frequencies to the destination airport. These were necessary data both in terms of the choice made and the choice rejected.

Values of the access travel times used in the research are

- Reported access travel time, which is the time reported by the passenger in the questionnaire, and
- Computed access travel time, which is the time computed from passenger's origin to the airport not chosen for the flight.

More than 85 percent of the survey respondents used family cars or taxis to travel to the airport. The time needed to travel to the airport usually depended on drivers' characteristics, road quality, and vehicle performance.

Because road quality from the observed zones to both airports was similar, identical estimated network access speeds were used. Another reason for calculating travel times for each passenger is that both Harvey (*2*) and Benchemam (*8*) suggested this procedure in the U.S. and U.K. studies. However, they did not use the procedure in their study because values of individual travel times to the airports not chosen were not accurately available to them.

Air fare and flight frequency were obtained from those airlines operating at the airport (Nigeria Airways and Okada Airways). Economy air fares were used in the research and the frequency variable included was the total of the round-trip weekly frequency between the individual airports and Lagos. The data were organized and edited into the form acceptable to the model. A total of 1,002 observations were used for the study.

Each observation described the airport choice made, characteristics of the chosen alternative, and characteristics of the unchosen alternative. Table 1 indicates how data were arranged. It was determined that three factors were cited more frequently than any others as reasons for airport selection: access time, flight frequency, and air fare. For each record (observed passenger), the airport chosen was indicated, then the values of these variables for the airport chosen, followed by the values for the airport not chosen.

AIRPORT CHOICE MODEL

Discrete choice models can be developed based upon the hypothesis of random utility maximization. The form of the model used in this research was the multinomial logit model (MNL). The MNL was selected because the airports were perceived to have different, mutually exclusive attributes. The MNL also has numerous advantages (*9*), including easy mathematical manipulation; easy parameter estimation; and easier application than the other forms of choice models, notably the multinomial probit model (MPL).

The mathematical expression of the MNL is written as follows:

$$P_{gk} = \frac{e^{V_{gk}}}{\sum_{r=1}^{G} e^{V_{rk}}}$$

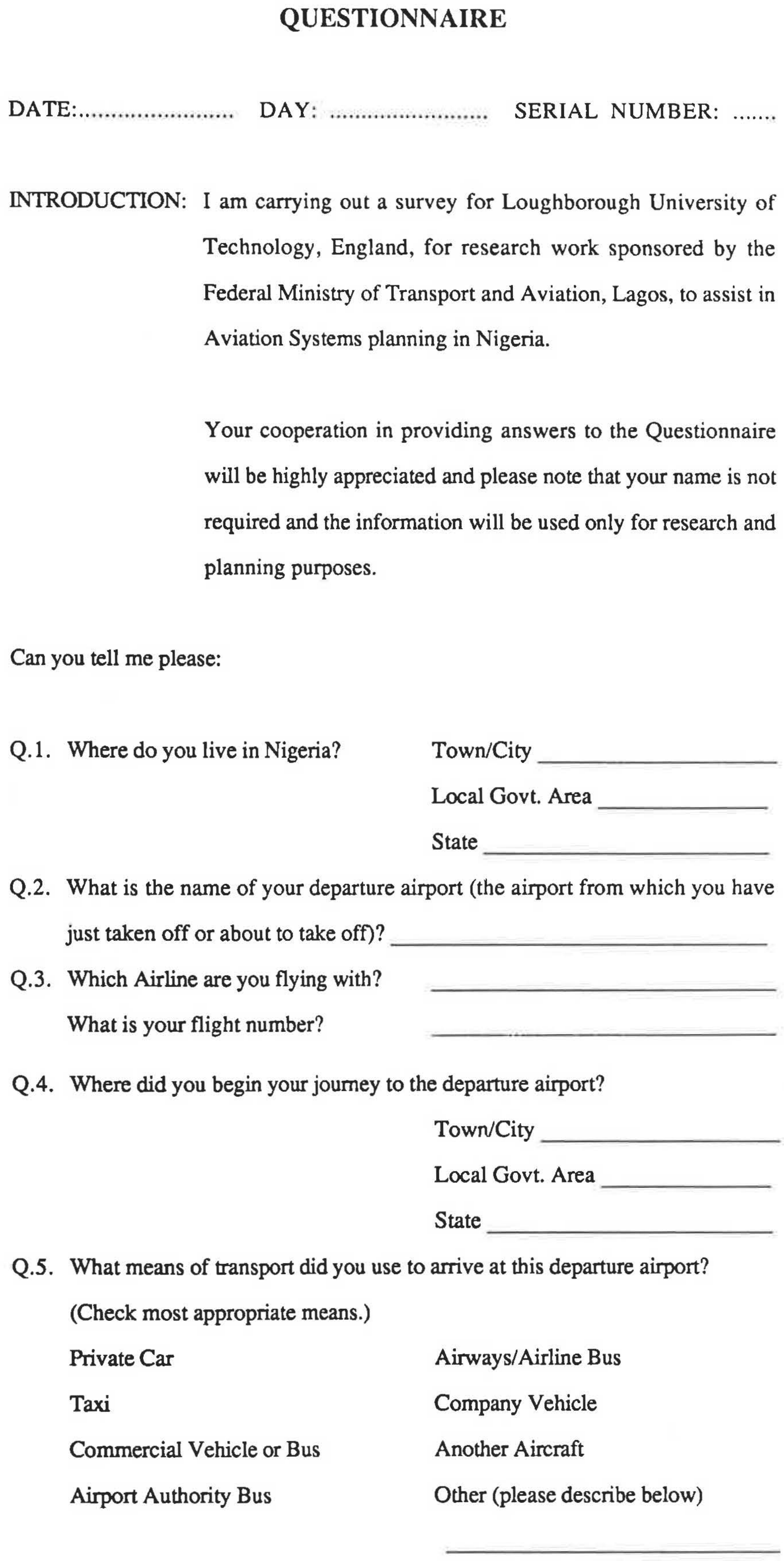
where

P_{gk} = probability that alternative g will be chosen by individual k,
V_{rk} = $a_0 + a_1 \cdot X_1 + a_2 \cdot X_2 + \ldots a_n \cdot X_n$,
= utility function assumed to be a linear combination of the explanatory variables (X),
a_1 = parameters of the equation to be determined by calibration ($i = 1, 2, \ldots n$), and
G = number of alternatives available.

The equation implies that the ratio of the probabilities of choosing alternative i over alternative g, that is, P_{ik}/P_{gk}, is independent of the presence or absence of any other alternative in the system, thus satisfying the equation

$$\ln\left(\frac{P_{ik}}{P_{gk}}\right) = V_{ik} - V_{gk}$$

This property is called the independence of irrelevant alternatives (IIA). IIA is a strength of the MNL because it allows new alternatives to be introduced into the model without reestimating the model once a numerical functional form of V is established. The IIA property was useful in this research when a new airport was introduced into the system to deter-



QUESTIONNAIRE

DATE:........................ DAY: .... SERIAL NUMBER: ....

INTRODUCTION: I am carrying out a survey for Loughborough University of Technology, England, for research work sponsored by the Federal Ministry of Transport and Aviation, Lagos, to assist in Aviation Systems planning in Nigeria.

Your cooperation in providing answers to the Questionnaire will be highly appreciated and please note that your name is not required and the information will be used only for research and planning purposes.

Can you tell me please:

Q.1. Where do you live in Nigeria?
Town/City ____________________
Local Govt. Area ______________
State ________________________

Q.2. What is the name of your departure airport (the airport from which you have just taken off or about to take off)? ________________________________

Q.3. Which Airline are you flying with? ____________________________
What is your flight number? ____________________________

Q.4. Where did you begin your journey to the departure airport?
Town/City ____________________
Local Govt. Area ______________
State ________________________

Q.5. What means of transport did you use to arrive at this departure airport?
(Check most appropriate means.)

Private Car
Taxi
Commercial Vehicle or Bus
Airport Authority Bus
Airways/Airline Bus
Company Vehicle
Another Aircraft
Other (please describe below)

____

FIGURE 3 Inflight questionnaire.

Q.6. Why did you choose the particular means of transport, e.g. taxi, bus, car to the airport? (Mark one answer below.)

The only means available	Cheapest means	Fastest means	Free ride or family car	Company vehicle	Other (please specify) ____________

Q.7.a. How long did it take you to reach the airport from your home or the place where you started the journey today? __________ (hours and minutes)

7.b. How much did it cost you to get to the airport today? (by taxi, bus, car petrol) ____________

Q.8. How far away from the departure airport did you start this journey today? ________ km (approx)

Q.9. Why did you choose this particular airport for your journey? (mark one answer below)

Nearest to place I stayed last night	Most convenient and has many flights	In my state, or affiliated to airline	Cheaper air fares	Recommended by company or agent	Convenient and cheap parking

Other (specify) ______________________________

Q.10. Which airport are you travelling to from here? ________________________

Q.11. Are you travelling to that airport just to change flight? (yes/no) ____________

If "yes", which airline are you continuing your flight with? ____________

Q.12. What is your final destination airport? ______________________________

(airport you are really travelling to)

Q.13. What is your final destination city/town? ________________________

State ________________________

Q.14. By what means will you travel to your final destination city/town from that airport? (car, bus, taxi, train, etc.) ________________________

Q.15. What is the chief purpose of your journey?

(please check one box only)

Official - Government duties/armed forces/civil servant

Business/trading/private consultant

School/leisure/holidays/personal reasons/visiting

Q.16. What is your profession/occupation? ______________________________

Q.17. Where is your usual place of work or business? ________________________

FIGURE 3 (*continued*).

Q.18. What is your age group? (please mark group only)

Under 21 20-29 30-39 40-49 50-59 60-69 Over 70

Q.19. What is your sex? Male Female

Q.20. What annual salary/business income range do you belong in Naira?

(check one box only)
0 - 4,999 p.a.
5,000 - 9,999 p.a.
10,000 - 14,999 p.a.
15,000 - 19,999 p.a.
20,000 and over p.a.

Q.21. How often do you travel from the departure airport?

Occasionally Regularly

Please give approx. number of times per week,
per month, etc. ____________________

Q.22. What suggestion would you give to the following, concerning the improvement of Aviation services?

a. Airport Authority ____________________

b. The Airways or Airline ____________________

c. The Government/Ministry of Transport & Aviation

What is the air fare on your ticket? (1st Class or Normal) ____________

Q.23. If all the items listed below are available, which one best serves your interest? (check only ONE answer please)

a. More flights + night flights
b. More airlines for competition
c. Direct flights to your destination
d. Punctuality of departures, and seat numbers on boarding passes
e. Cheaper air fares
f. Better road, less congestion and cheaper cost to the airport

Q.24. a. Are you a Nigerian Non-Nigerian (check box)

b. Where is your permanent residence? Country ____________

Q.25. Finally, how many people saw you off at the airport? 1 2 3+

FIGURE 3 ***(continued).***

TABLE 1 ARRANGEMENT OF DATA FOR MODEL CALIBRATION

Obs No	Alternative Chosen	TT_1	FF_1	AF_1	TT_2	FF_2	AF_2
0001	2	141	66	69	90	86	48
0002	2	131	.	.	15	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
1002	1	15	.	.	138	.	.

The number of alternatives = 2 (codes 1 and 2)

TT_1 = Travel Time to airport 1 by an observation

TT_2 = Travel Time to airport 2 by same observation (calculated)

FF_1 = Flight Frequency from airport 1

FF_2 = Flight Frequency from airport 2

AF_1 = Air Fare from airport 1 to destination

AF_2 = Air Fare from airport 2 to destination.

NB: If the observation chose airport 2, then TT_2 is the travel time to airport 2 which was reported, while TT_1 is then calculated for that observation for the unchosen airport (which is airport 1).

TABLE 2 RESULTS OF INITIAL MODEL CALIBRATION

Initial likelihood function value	-692.4606
Final likelihood value	-146.1230
"Rho-squared" (ρ^2) wrt zero	0.7986
"Rho-squared" (ρ^2) wrt constants	0.7847

	Travel Time	*Frequency*	*Fare*
Estimated Coefficient	-.4789E-01	.7547E-01	.8013E-01
Standard Error	.373E-02	2.36	2.25
"t" Ratio	-12.8	0.03	0.03

mine its effects on these two airports within the existing airport system. The model was calibrated using the ALOGIT Maximum Likelihood Method of Estimation (MLE) because the choice model is nonlinear and requires a more complex estimation procedure than simple linearized demand models such as regression techniques and least-squares estimation methods.

A number of variables, namely travel time (*TT*), flight frequency (*FF*), and air fare (*AF*), were used for the initial calibration of the model to determine whether they were significant in airport choice in the airports studied. These variables were used because they were cited most frequently by the air travelers surveyed as the reasons for choosing an airport. They were also found to be pertinent in the previous studies in developed countries (*2,3*). Other variables were rejected by inspection because they were so infrequently cited.

Results of the initial calibration given in Table 2 showed that of the three variables tested, only the travel time variable had a "t" ratio significantly different from zero, with a value of −12.8. The flight frequency and air fare variables were not significant and were therefore dropped from the model.

Final Structure of Model

The model was recalibrated using the only significant variable—access travel time. The utility function could now be written as

$$U = \beta \cdot TT$$

where TT is access travel time to the airport, and β is the coefficient to be estimated.

The final model calibration output is given in Table 3. The output of the model shows that the rho-squared values of 0.8 and the standard error for travel time (β_1) = 0.0038 both indicate a high degree of fit.

Results of Calibration

Comparison of Observed and Forecast Data

The theoretical probabilities of choice are calculated for a number of observations as follows:

$$P(X_1/E) = \frac{1}{1 + \beta^* \exp[\beta_1 (X_2 - X_1)]}$$

where

β_1 = −0.048 (from model calibration),
β^* = exp (−β_0) = exp (−0.1729) from calibration = 0.84122,
X_1 = access travel time to Airport 1 (Enugu airport),
X_2 = access travel time to Airport 2 (Benin airport), and
$P(X_1/E)$ = probability of choosing Enugu airport given knowledge of its access travel time.

Values of the theoretical probabilities obtained are plotted against the differences in travel times for the observations (see Figure 4). The shape of the resulting logistic curve is in close agreement with those found in standard texts. As demonstrated by the curve, the slope is greatest at the midpoint where the probability (P) = ½ which means that changes in independent variables will have their greatest impact on the probability of choosing an alternative at the midpoint of the distribution. Additionally, the gentle slopes near the ends of the curve imply that large changes in X are necessary to bring about a small change in probability (*10*).

Goodness-of-Fit

The same goodness of fit is shown in Table 4, which is a tabular comparison (in percentages) of the observed and forecast shares of the two airport choice. Similarly a χ^2 test indicated a very high level of significance to the fit.

EFFECT OF INTRODUCING A THIRD AIRPORT

The model was used to forecast the effect of introducing a third airport into the system (the Onitsha airport, now under construction). The forecast shares are shown in Table 5, where the redistributions from a two- to a three-airport system are shown. Table 6 indicates the predicted losses at Benin and Enugu engendered by the introduction of the Onitsha airport to the system.

Overall, the introduction of the third airport reduced the share of Lagos-bound traffic from the region for Enugu from 58.8 percent to 41.2 percent and for Benin from 42.8 percent to 33.0 percent. Using the available 1985 annual traffic volumes 295,992 for Enugu and 364,996 for Benin—figures provided by the Nigerian Airports Authority—the traffic for Enugu would drop to 207,396 and traffic for Benin would drop to 255,838. Onitsha would pick up these losses, which amount to a total of 197,754 passengers, and would also be expected to generate its own traffic. These results indicate model capability for forecasting the choice made in the event of the construction and operation of the third airport.

DISCUSSION OF RESULTS

Results of the model suggest several implications regarding the role of the variables in airport choice in Nigeria.

First of all, flight frequency and air fare are not important variables at the levels investigated. This conclusion implies that reasonable changes in both frequency and air fare will have very little effect on airport choice.

Second, travel time is the major determinant in choosing an airport in Nigeria. This implies that shares of air travel could be increased by improving the general ground accessibility of the airport; however, this is likely to be a useful policy tool in only a few instances. Travel time factor also implies that the introduction of additional airports into a region will cause a predictable redistribution of airport passenger traffic. This implication has important locational considerations when additional facilities are being considered.

Third, at the outset of this study, it was felt that tribal origin could have an effect on airport choice—that passengers might travel from airports and make a choice of airport within their own tribal districts or region. This was not found to be a significant factor in airport choice.

Additionally, the results imply that the level of service and the level of investment in each airport can be based in part on the accessibility to population in each airport region, because airports will be expected to serve the demand of nearby areas. Harvey (*2*) found travel time and flight frequency to be important determinants of airport choice in the San Francisco Bay Area airports (air fare was not introduced in the model and its effect was not determined), whereas Benchemam found that travel time, flight frequency, and air fare were important determinants of airport choice in the UK airports studied (*8*).

Air fare and flight frequency were insignificant to the study for two reasons. First, the study involved domestic travel of less than 1 hr duration, and there are no significant variations in both fare and frequency for the two airports. The number

TABLE 3 FINAL MODEL CALIBRATION OUTPUT

Initial likelihood function value	- 694.5402	
Final likelihood value	- 146.1283	
Likelihood	- 146.1283	
Rho-squared (ρ^2) wrt zero	0.7986	
Rho-squared (ρ^2) wrt constraints	0.7847	
	K-Enugu (β_0)	K-Travel Time (β_1)
Estimates (coefficients)	0.1729	- 0.04845
Standard Error	0.151	0.00381
"t" Ratio	1.1	- 12.7
No. of iterations	7	

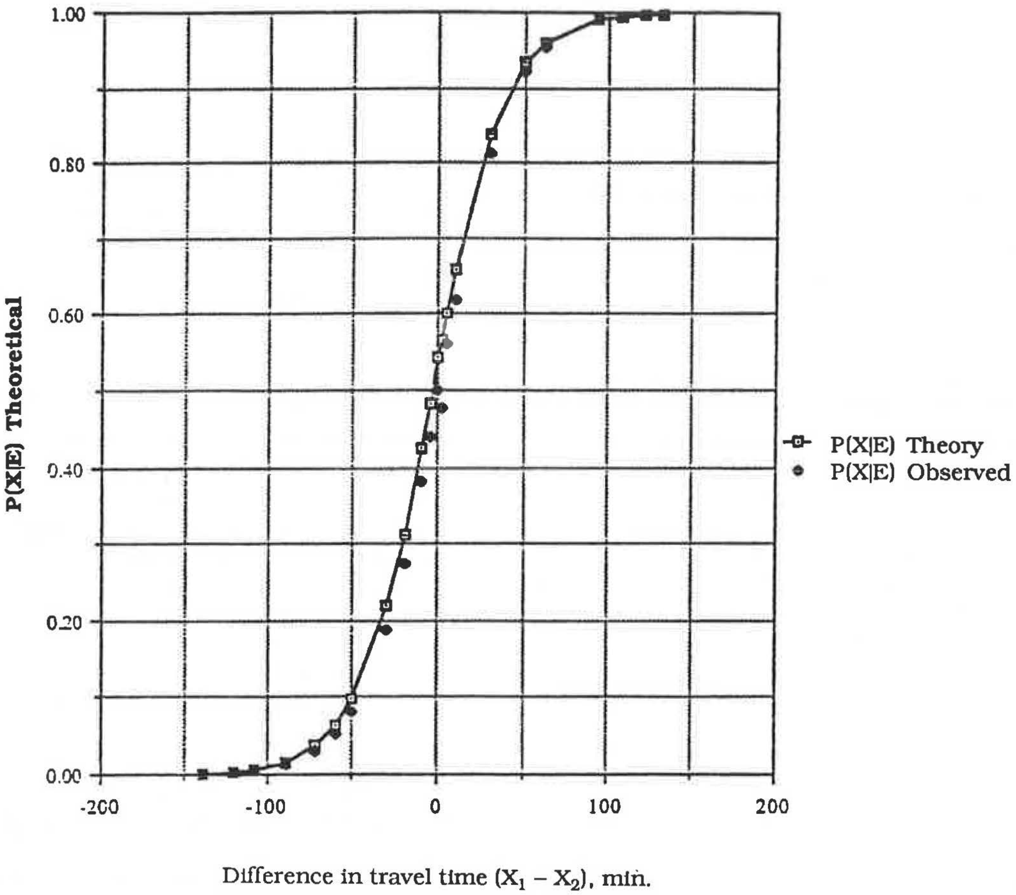


FIGURE 4 Probability versus difference in travel time.

TABLE 4 ZONE COMPARISON OF OBSERVED AND FORECAST SHARES FOR TWO AIRPORTS FOR THE 1,002 OBSERVATIONS

ZONES	*OBSERVED SHARE OF TRIPS*	*FORECAST SHARE OF TRIPS*	*OBSERVED %*	*FORECAST %*
1E	282	281	0.28	0.28
1B	3	4	0.00	0.00
2E	99	105	0.10	0.10
2B	40	34	0.04	0.03
3E	2	1	0.00	0.00
3B	36	37	0.04	0.04
4E	4	5	0.00	0.00
4B	190	189	0.19	0.19
5E	28	25	0.03	0.02
5B	2	5	0.00	0.00
6E	0	0	0.00	0.00
6B	2	2	0.00	0.00
7E	174	180	0.17	0.18
7B	140	134	0.14	0.13
TOTAL TRIPS	1002	1002		

TABLE 5 FORECAST SHARES FOR THREE-AIRPORT-CHOICE SITUATION

	FORECAST *(based on sample of 1002 passengers)*			*FORECAST SHARE (%)*		
ZONE	ENUGU (A 1)	BENIN (A 2)	ONITSHA (A 3)	A 1	A 2	A 3
1	256	2	27	89.8	0.7	9.5
2	25	8	106	18.0	5.8	76.2
3	1	16	21	2.6	42.1	55.3
4	4	181	9	2.1	93.3	4.6
5	7	1	22	23.4	3.3	73.3
6	0	2	0	0	100	0
7	136	121	57	43.3	38.5	18.2

TABLE 6 ZONAL LOSS FROM TWO- TO THREE-AIRPORT SYSTEM (%)

Zone	Enugu	Benin
1	9.1	0.4
2	53.2	23.0
3	2.7	52.6
4	0	4.5
5	69.9	3.4
6	0	0
7	12.1	6.1

of daily direct flights from Enugu to Lagos is five, and from Benin to Lagos is seven. Air fares are noncompetitive and are effectively controlled by the government. It should be noted that access to the airports is mainly by private car and taxi, because there is no rapid transit, rail service, or bus service as observed in previous studies in the developed countries (United Kingdom and United States). Passengers appear not to have found the small differences in air fare and frequency sufficient attraction to choose an airport that is farther away from their trip origin because of increased access time and access cost. Total travel time and cost (air and ground) would also increase.

Second, air fare and flight frequency are, to a large extent, outside the control of the airlines and airports; these factors are influenced and controlled by the Nigerian government. The government's intent is to balance regional with national needs, which are not necessarily economic. In effect, there is no strict competition between the airports and airlines. The advertising and promotional fares used as market strategies in the United Kingdom and the United States are not used in Nigeria.

The differences in the three case studies are that the Nigerian study involved journeys of less than 1 hr and that passengers may not have found it necessary to choose an airport with a longer access travel time, because total trip time would certainly increase. On the other hand, the airport studies in the United States and the United Kingdom involved both domestic and international passengers. Passengers in those studies were stratified into business and nonbusiness passengers (and international leisure passengers in the UK study). Thus travelers had to consider the flight frequencies and air fares available at each airport because of the long-haul nature of their journey.

CONCLUSIONS

Disaggregate behavioral airport choice models can provide an important policy tool for airport planners, managers, and decision-makers. Although relatively new, the advantages of such models over other models in forecasting ability and accuracy make them more suitable in airport choice modeling to help ensure the balance of the economic equation between travel demand and supply.

Because of the high level of investment characterizing the civil aviation industry, and because the industry is highly susceptible to political, economic, and other external influences, air traffic forecasting is a useful tool in airport planning. It can be used to determine airport shares, levels of service, and consequent desirable levels of investments—especially in a developing country such as Nigeria. Finally, this research has demonstrated that the catchment area concept is not valid in Nigeria. Airports do in fact compete. This supports the findings in the United States and the United Kingdom in separate studies by both Harvey (*2*) and Benchemam (*8*). However, the results suggest that the regional populations should be considered when deciding on the level of investment and level of service because airports will, in most cases, be expected to serve "local" demands, at least in the short run.

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Measuring Secondary Economic Impacts Using Regional Input-Output Modeling System

DAVID BAROL

Public decision makers use economic impact studies to justify the existence or expansion of airports and other infrastructure. The studies demonstrate that the airport produces an economic benefit that offsets its perceived environmental, social, or financial costs. Unfortunately, informed policy making has suffered because these studies have differed greatly in their methodologies. The studies have relied on assumptions and have used terms that render a comparison of competing projects impossible. Although there have been some attempts at creating standards for these studies, their complexity—and the competitiveness of the practitioners—has made agreement difficult. This paper attempts to provide a standard for estimating secondary airport-dependent economic impacts using the Regional Input-Output Modeling System (RIMS II) multipliers.

An airport provides a wide range of economic benefits to a region. Some of these benefits are more apparent than others. An airport "brings the world closer" to residents of a region, adding value to a community. An airport encourages tourism, and tourism increases regional revenues. An airport also reaches beyond its role as part of the transportation network, and provides on- and off-site employment opportunities, generating more economic activity throughout the region.

Airport operation requires the services of numerous vendors, including passenger and cargo airlines, airport gift shops, and airline caterers. Goods and services purchased by airline passengers from these sectors constitute the *primary impact* of an airport.

For example, an airline's catering generates demand for food items, such as fruit and meat and disposable products such as plastic cups. Providing food service aboard an aircraft requires inputs produced by other companies. These inputs, which are used to produce the goods and services that represent the primary impact, constitute the *secondary impact* of an airport. These inputs and outputs represent successive rounds of spending. In this way, an initial expenditure "multiplies" into a much larger impact as the money circulates throughout the economy.

Although several methodologies have been developed to measure secondary impacts, this paper deals exclusively with the Regional Input-Output Modeling System (RIMS II) available for purchase from the U.S. Department of Commerce. [To obtain tables and additional information on RIMS II multipliers, contact the Regional Economic Analysis Division, Bureau of Economic Analysis, BE-61, U.S. Department of Commerce, Washington, D.C. 20230, (202) 523-0594.]

The examples used in this paper come from the author's research using RIMS II multipliers as part of economic impact studies (EIS) of Dallas/Ft. Worth Airport (1989), Baltimore/Washington International Airport (1986), Washington Dulles Airport (1985), Washington National Airport (1985), and Hong Kong's Kai Tak Airport (1988).

ECONOMIC IMPACT STUDIES

An EIS study looks at current situations and calculates future trends. The EIS shows how an airport affects a region's economy during a year designated as the base year. As passenger and cargo activity and facility operation increase over time, the EIS shows how the economic impact on the region also rises. Because no airport can handle unlimited increases in activity, the EIS demonstrates how future limitations on airport capacity will limit the future economic impact on the region. The EIS then calculates the present value of this loss to the local economy from the inability of the airport to satisfy potential demand.

An EIS estimates impacts that depend on activities occurring on site, such as baggage handling, and those occurring off site, such as car rentals. These impacts can be divided into primary, secondary, and total impacts. Primary impacts are found using data collection and data analysis. Detailed EISs show these impacts by changes in employment, payrolls, tax revenues, final demand, and total output, as well as in local purchases and in leakages of money from the region. Table 1 shows a representative table of on-site impacts from an EIS.

To determine these impacts, the study team collects as much data as possible from each of the different airport sectors and, using statistical and econometric techniques, extrapolates from a sample to a survey population. The study team estimates secondary impacts using RIMS II.

RIMS II

Since 1758, when French economist François Quesnay published *Tableau Economique*, the input-output nature of the

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Gellman Research Associates, Inc., 115 West Avenue, Suite 201, Jenkintown, Pa. 19046.

TABLE 1 ON-AIRPORT ECONOMIC IMPACT SUMMARY FOR THE YEAR 2000

Sectors: Impact	Psngr. Aviation	Cargo Aviation	Airline Suppliers	Airport Concess.	Gov't. Agen.	Total On-Airport
Employment						
Primary	14,570	1,607	4,881	2,405	2,151	25,614
Secondary	4,818	2,243	5,917	4,436	3,680	21,095
Total	19,388	3,851	10,798	6,841	5,832	46,709
Output ($000)						
Primary	$935	$205	$393	$252	$251	$2,038
Secondary	$1,374	$302	$398	$375	$362	$2,814
Total	$2,309	$507	$791	$627	$613	$4,852
Earnings ($000)						
Primary	$420	$64	$124	$36	$60	$707
Secondary	$113	$52	$139	$104	$86	$497
Total	$533	$116	$263	$140	$146	$1,204
Loc Purch ($000)	$130	$56	$115	$116	$91	$510
Leakages ($000)	$347	$76	$139	$89	$92	$745
Tax Revenues ($000)						
Corporate	$8	$1	$2	$1	$0	$12
Personal	$3	$.5	$1	$1	$1	$6.5
Secondary	$1	$.5	$1	$1	$1	$4.5
Total	$12	$2	$4	$3	$2	$21

economy has been recognized. However, it was not until the 1930s that the analytical framework of the Leontief Inversion led to the creation of a national input-output matrix that could actually measure these interindustry transactions.

During the mid-1970s, the Regional Economic Analysis Division of the Bureau of Economic Analysis (BEA), U.S. Department of Commerce, designed the Regional Industrial Multiplier System (RIMS). Later, an improved version, RIMS II, extended the national input-output multiplier concept to regional uses and concerns. Essentially, RIMS II consists of the same technical coefficients as the national model but accommodates varying flows of imports to and exports from regions consisting of one or more contiguous counties within the United States. BEA updates the national model every 5 years and recalibrates the regional models every year using local data.

EISs have used RIMS II multipliers to show the change in total regional output, total earnings, and total employment from a change in final demand that may arise from a new investment or policy change. Final demand includes sales to government, industry, and other regions as well as capital formation. Unlike an input, final demand requires consumption for its own sake and not for the sake of producing some other kind of good.

As with most other fields of economics, real-world application of these multipliers requires as much artistic skill as scientific knowledge. Generating total impacts requires measuring the final demand of each industrial sector dependent on the airport and then multiplying that value by the appropriate RIMS II multiplier. The difficulties lie in determining which multiplier to use for what purpose and, more important, in determining the airport-dependent final demand for each relevant industrial sector.

USING RIMS II

RIMS II employs the same structure used in the national input-output matrix, listing 39 inputs for over 500 industries. The RIMS II matrices come in three varieties (plus a new employment multiplier table not discussed here). The matrices provide the following multipliers:

- Total output multiplier—helps estimate the total impact within the study area from primary final demand. Consisting of sales to final demand, sales to other firms, and wage payments within the study area, the total output multiplier represents a total of primary and secondary final demand. Total output measures the sum of transactions and thus constitutes double calculations. Some researchers are attracted to this multiplier because of the "big numbers," not because it discloses important data.

- Earnings multiplier—estimates the total, primary, and secondary earnings created by primary final demand expenditures within the study area. Earnings consists of wage and payroll payments to the household sector of the economy. Total earnings constitutes the sum of primary and secondary earnings.
- Direct impact multiplier—represents the proportion of primary final demand created by wage payments and purchases by firms from within the study area. The 39th row of the direct multiplier is called the *household multiplier*, which represents the percentage of final demand paid to households in the form of wage payments within the study area. If data on wages are not available from primary sources, the household multiplier may be used to create an estimate of wages.

Selecting Airport-Dependent Industrial Sectors

Although the RIMS II matrices do not include the "airport" industry per se, they do contain multipliers of those industries that provide goods and services necessary to meet the needs of airline passengers. As shown in Table 2, these industries include the goods and services a traveler might require when leaving home, passing through the airport onto an airline, flying to the destination airport, and reaching a final destination via some form of ground transportation. Each of the industries represented in this trip synopsis has a corresponding RIMS II industry number. The hundreds of columns in the RIMS II matrix are listed in numerical order by industry number.

Table 2 shows various airport-related services with their associated RIMS II and standard industrial classification (SIC) numbers. The terms used here are those found in the SIC manual. The table shows that RIMS II may treat different types of enterprises similarly even though they may have different SIC numbers. It helps to identify an industry in the SIC manual, which is more specific, and then use the four-digit SIC number to find the corresponding RIMS II industry number.

After initially grouping firms with the same RIMS II industry number, the EIS estimates airport-dependent final demand for each industry. This process requires extensive surveying and econometric analysis as well as an understanding of the nature of airports, aviation, and other transportation-related services.

Determining Final Demand

The relevant measurement for analyzing the primary or first-round impact of an airport is final demand. Final demand consists of

- net earnings of labor and proprietors,
- purchases of inputs into the production of the transportation-related service [including inputs produced locally (local purchases) and those imported into the region (leakages)], and
- payments to the owners of land, capital, and equipment.

TABLE 2 INDUSTRIAL SECTORS FOR AIRPORT ECONOMIC IMPACT STUDIES

Industry Title	SIC Number	RIMS II Industry Number
Certificated Airlines	4511	65.0500
Uncertificated Airlines	4521	65.0500
Airline Caterers	5812	74.0000
Aircraft Cleaners	4582	65.0500
Baggage Handlers	4583	65.0500
Snack Bars	5812	74.0000
News Stands	5994	69.0200
Novelty Shops	5947	69.0200
Flight Insurance Stands	6411	70.0500
Ground Transit	4111	65.0200
Car Rentals	7512	75.0001
Hotels	7011	72.0100
Restaurants	5812	74.0000
Travel Agents	4722	65.0702
Freight Forwarders	4712	65.0701
Foreign Exchange	6052	70.0100
Airport Security	7393	73.0106

Source: Standard Industrial Classification Manual and Industry Classification of the Input-Output Tables.

The measurement of final demand comes from adding together sales (to the final consumer and not to another producer of airport-dependent services), organizational budgets, and commissions.

Under no circumstances should the EIS use *revenues* to determine the final demand of an airline. Revenues flow to the corporate headquarters that budget each airline station for local purchases, wages, fees, and so on. Similarly, revenues cannot measure final demand for travel agents and freight forwarders. These suppliers must pass roughly 90 percent of their revenues to the transportation or service providers. Commissions, rather than sales, are the relevant measure of final demand for these industries.

Organizing Primary Data

A major airport may have 20 or more airlines serving it and hundreds of travel agents, hotels, and freight forwarders that receive a portion of their revenues as a consequence of the airport. Table 3 shows several key aggregations of airport-dependent sectors along with their corresponding RIMS II multipliers (for a particular impact region).

TABLE 3 KEY RIMS II MULTIPLIERS

Sector	Output Multiplier	Earning Multiplier	Direct Multiplier	Household Multiplier
Passngr Airline	2.4696	0.5709	0.5895	0.3046
Cargo Airline	2.4696	0.5709	0.5895	0.3046
Suppliers	2.0127	0.6788	0.6890	0.3115
Concessions	2.4874	0.5618	1.9461	0.2929
Grnd Trnsprt	2.7793	0.7876	0.7066	0.4861
Hotels	2.7290	0.6680	0.7029	0.3533
Travel Agent	3.0383	0.9196	0.8263	0.5826
Freight Fwrd	3.0003	0.8249	0.7903	0.4561

Source: The Dallas Economic Impact Region Multipliers, Bureau of Economic Analysis, U.S. DOC, 1987.

Cargo and passenger airlines have the same RIMS II multipliers since they have the same RIMS II industry numbers. Their separation in an analysis or a presentation would not, therefore, depend on RIMS II but on other factors, among them the different airport activity variables used to forecast future impacts.

Creating Multipliers

This section describes creating a set of multipliers for an industry not covered in RIMS II when such an industry is, in reality, an agglomeration of several industries. Airline suppliers such as aircraft cleaners, baggage handlers, and caterers provide inputs into the airline production process. Because they are often located on-site, many EISs include them as a final demand sector. Because these services represent a number of different industries, the RIMS II multipliers in Table 3 represent a weighted average of an individual industry's RIMS II multipliers. Most studies measure the impact of airline suppliers separately from that of airlines and treat the suppliers as just another airport concession. But concessions sell to a traveler whereas suppliers sell to an airline. If airline suppliers are to be considered as a separate sector, then their total final demand must be subtracted from the total airline station budgets. This subtraction is necessary in order to avoid counting the value of the payment from airlines to suppliers twice. Similarly, the payments of all on-site suppliers to the airport authority must be subtracted from their budgets or sales before adding the budget for the airport authority to the total impact results.

Table 4 shows how the total earnings multiplier for the supplier sector would be developed for a hypothetical airport. A supplier data base would contain the names of each of the companies that fit the general classification of supplier. These companies would be sorted according to their RIMS II industry number. In the example shown in Table 4, the supplier sector has been sorted by baggage handling, building services, airport security, and airline caterers. Each of these four industries has a total earnings multiplier associated with it found in the earnings matrix. (Similarly, the industry would have each of the other types of multipliers shown in Table 3.)

The airport-dependent final demand for each firm must be found by using data collection and analysis techniques. The total earnings for baggage handling ($59,142) is found by multiplying the earnings multiplier (0.6877) by airport-dependent final demand ($86,000). After finding total earnings for the other categories, divide the sum of the total earnings ($483,233) by the sum of the total airport-dependent final demand ($668,000) to find the weighted multiplier for the supplier sector (0.7234). This procedure creates multipliers for broad industry classifications not covered by the RIMS II industry classifications.

Other multipliers that also produce useful information can be derived by combining the RIMS II multipliers and other data. For example, a local purchase multiplier would be constructed to determine what part of the primary impact consists of purchases of local goods and services. A leakage multiplier would be constructed to determine how much of the final demand leaves the region from imports of goods or services from outside. Derivation of the local purchase multiplier and the leakage multiplier is as follows:

$$\text{Local purchases} = \text{direct multiplier} - \text{household multiplier}$$

$$\text{Leakage multiplier} = 1 - \text{direct multiplier} - \text{profit multiplier}$$

The profit multiplier is the specific profit rate for a given industrial sector, found from secondary source material such as U.S. Department of Commerce publications that show the profit-to-sales ratio for various industrial sectors.

ESTIMATING IMPACTS

Table 5 provides a detailed example of how the RIMS II multipliers found in Table 2 can be applied to the airline

TABLE 4 DERIVATION OF SUPPLIER SECTOR MULTIPLIERS: TOTAL EARNINGS

Companies	Airport* Dependent Final Demand	RIMS II Industry Number	Total Earnings Multiplier	Total Earnings
Baggage Handling		65.0500	0.6877	
Airline Services Unlimited	$86,000			$59,142
Building Services		73.0102	0.8140	
World Service Company	$78,000			$63,492
Airport Security		73.0106	0.9303	
Globe Security	$120,000			$111,636
Smith Security, Inc.	$56,000			$52,097
Airline Caterers		74.000	0.6002	
Dobbs Int'l Services	$78,000			$46,816
Marriott In-Flite	$140,000			$84,028
Sky Chefs In-Flight	$110,000			$66,022
Total	$668,000			$483,233
Weighted Multiplier			*0.7234*	

*All values are hypothetical.

TABLE 5 APPLICATION OF RIMS II TO THE AIRLINE SECTOR

Total Airline Station Budget		$125,000,000
Total Suppliers Budgets		$25,000,000
Total Airline Final Demand		$100,000,000
Total Earnings	$57,090,000	
Primary	$30,460,000	
Secondary	$26,630,000	
Total Output	$246,960,000	
Primary	$100,000,000	
Secondary	$146,960,000	
Local Purchases	$28,490,000	
Leakages	$41,050,000	

sector. In this example, the airline sector of an airport with total airline station budgets of $125 million spent $25 million on airline suppliers, including fees to the airport authority. The remaining $100 million constitutes the airline final demand.

The airline sector was responsible for generating $57,090,000 in total earnings within the region, which is the sum of primary and secondary earnings. Primary earnings is the same as wages found either through data collection or by using the household multiplier (Wages = Final Demand × Household Multiplier). Total earnings was found by multiplying final demand by the total earnings multiplier. Secondary earnings, then, is the difference between total and primary earnings. Total earnings is the most important measure of value in terms of benefits to the people of the region.

The airline sector generated $246,960,000 in total output, which is the sum of primary output (final demand) and secondary output. Secondary output is sales, revenues, and budgets created from the subsequent rounds of spending after, and as a result of, the primary round of spending. Since output adds the total value of all transactions, it counts the same inputs over and over again. The more self-contained an economy, the greater the total output multiplier. Consequently, the total output multiplier does not present a true picture of the airport's value. A region that imports most of its products would have a low total output multiplier.

The airlines would have spent $28,490,000 for local purchases of goods and services. This was found by multiplying final demand by the local purchase multiplier created in the derivation of other multipliers given earlier. They would have spent $41,050,000 on leakages. The leakage multiplier was also derived in this calculation.

CONCLUSION

RIMS II is not a difficult tool to use if approached systematically. The two key concerns for the user are:

- Appropriate selection of a RIMS II multiplier for the given industry, and
- Correct and accurate estimation of final demand for that industry.

With the three RIMS II matrices, plus additional publicly available data, the user can employ a wide variety of multipliers that will help convey important information regarding the impact of an airport. RIMS II multipliers enable the estimation of secondary and total impacts. These impacts, along with both primary impacts and qualitative information describing the benefit of the airport, build the case that an airport has an intrinsic value to a region.

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Entry, Exclusion, and Expulsion in a Single Hub Airport System

JOHN R. G. BRANDER, B. A. COOK, AND JOHN E. ROWCROFT

Airport congestion is best handled by peak period pricing. The most efficient means of implementing such a scheme is via some type of slot auction mechanism. This paper addresses the questions of what happens to slot prices when the number of competitors increases, as well as whether or not a financially strong firm can use the auctions to overpower its weaker rivals. Slot prices rise with the number of air carriers competing in the market. The paper also demonstrates that it is not feasible for financially strong carriers to attempt to use the auction process to either exclude potential rivals or to expel them from the market.

Perhaps one inevitable consequence of the deregulation of an air transportation system is increasing airport congestion. Although congestion has existed at certain airports for many years, the onset of deregulation has exacerbated the problem because of the entry of new air carriers into the market and the desire to increase the number of flights on particular links in the system. In a series of earlier papers, the authors have argued that the only viable long-term solution is a system of peak-load pricing, ideally implemented through periodic auction of the available capacity. Although this study is limited to the question of airport runway landing slots, its approach is valid for other forms of airport congestion as well.

One study (*1*) presented a simulation model of passenger traffic along individual links into a congested hub airport. This model permitted estimation of auction prices for runway slots at the hub at both peak and off-peak periods. The auction proposal raised a number of concerns, the most important being the possibility of collusion among incumbents aimed at excluding potential competitors.

This paper extends that analysis and focuses on some of the criticisms of the authors' earlier work. Initially, the focus is on the impact of increasing the number of carriers in the market. Of interest here is the effect of the number of carriers on auction prices, airport revenues, and passenger welfare. Attention is then turned to the possibility of financially powerful, established firms using the auction mechanism as a competitive tool to preclude the emergence of new carriers through excessively high bids. Closely related is another question of whether or not it is possible for strong firms to (in effect) expel their financially weaker rivals from specific markets.

The paper begins with an overview of both the auction mechanism and the underlying structure of the single hub model. Measures of system performance are examined in the next section, particularly the assumptions underlying the measurement of airport revenue from the slot auctions. This examination leads directly to a discussion of the conditions under which new entrants might be barred from the market. As a corollary, the possibility of an attempt by existing carriers to expel one or more of their competitors from the market is considered. The data used in the simulations and then the results are discussed. Finally, some concluding observations are presented.

AUCTION METHOD OF ALLOCATION REVISITED

Slot auctions are seen as the most efficient means to implement the practice of peak-load pricing. This is the case because each profit-maximizing airline in a system can easily estimate the expected value of profit attached to each landing slot it might acquire. This is because the airline possesses detailed knowledge of the market structure of its routes and its cost structure. Thus, it can estimate the direct costs of participating in that route as well as the opportunity costs of reallocating aircraft from one route to another. It is anticipated that different airlines would submit different bids because of their differing perceptions of the market and because of their differing cost structures.

How would the auction process function? The initial step in the process would be for each airline to develop a draft schedule and to submit bids for the landing slots it wants to acquire. Each airline would, of course, operate in isolation. The airport authorities would receive the bids and place them in rank order. The airline submitting the highest bid would be awarded the property right to the slot for some predetermined period (i.e., two years). Should an airline be successful in all of its bids, it would then finalize its schedule. Otherwise, the airline could modify its draft schedule, or enter a slot aftermarket in the search for additional slots. The auction might be carried on twice yearly, with 25 percent of the slots available each time—if they were awarded for a 2-year period. Other combinations of frequency and the length of slot control are also possible.

In the absence of such auctions for airport capacity, it is necessary to simulate the process. This was done for a single hub system (*1*) and for a larger system as well (*2*). Only the single hub case is considered here. That simulation was solved both analytically and iteratively. The former solution produced some difficulties, the most fundamental being that the initial solution did not necessarily assign whole numbers of

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Department of Economics, University of New Brunswick, P.O. Box 4400, Fredericton, N.B., Canada E3B JA3.

flights to each route and to each carrier. To ensure such an outcome, an iterative scheme was developed. Slots were distributed one at a time to the carrier and route that could earn the most extra contribution from one more flight. In a sense, the process may be regarded as an auction of each successive slot to the highest bidder, although no fee is necessarily collected.

Each airline is seen as facing two distinct markets—a time sensitive business market and a fare sensitive recreational market. Carriers operate within a peak period—the combination of a morning peak and a late afternoon peak—and an off-peak period consisting of the rest of the day. There are then, in principle, four distinct demand curves, all of which have been assumed linear for the sake of convenience. There are initially four airlines in the market each operating a different sized aircraft. Linear cost relationships have been assumed to simplify the analysis. Each airline seeks to maximize its contribution to overhead, that is, to maximixe the difference between its passenger revenue and its flight costs.

Let each airline currently operate a variety of flights, Q^*_{ij} on each of the n routes and within the capacity of the airport, N. Thus:

$$\begin{aligned} &Q_{ij} + Q_{ij+n} = Q^*_{ij} \\ &\quad \Sigma_i / \Sigma_j \, Q_{ij} < N \end{aligned} \qquad (1)$$

Only the Q^*_{ij} need be integers since Q_{ij} and Q_{ij+n} represent the portions of the flights that are drawn from the business and recreational markets, respectively. Temporarily treating Q^*_{ij} as the maximum number of flights available, each expression in Equation 1 becomes a "less-than-or-equal-to" constraint. A new optimizing solution will generate a set of shadow prices, m_{ij}, one for each airline on each of the n routes.

The Kuhn-Tucker conditions for this problem are:

$$\begin{aligned} &W_{ij} = V_{ij} - m_{ij} < 0\text{: } Q_{ij} W_{ij} = 0 \\ &M = {}_{i\,j}(Q^*_{ij} - Q_{ij} - Q_{ij+n}) > 0\text{: } m_{ij} M = 0 \qquad (2) \\ &m_{ij+n} = m_{ij} \qquad i = 1, \ldots, m \,;\, j = 1, \ldots, 2n \end{aligned}$$

For most cases, solution is by a similar iterative procedure to the initial solution algorithm. However, if some, but not all, airlines supply a market on a particular route, the m_{ij} equation itself must be solved iteratively. A modified Newton-Raphson method was adopted and found to converge rapidly for the values considered.

The m_{ij} represent the value to each airline of an extra flight on the corresponding route. If additional runway capacity is available then the next slot is "awarded" to the carrier-route combination with the highest positive m. If no capacity remains, or if all shadow prices are zero, the solution is final. The last value for the maximum m_{ij} provides a second measure of the value of an extra unit of airport capacity.

It remains to provide a starting point for the solution routine. In principle the iteration procedure can start with all the Q^*_{ij} equal to zero. Slots could then be allocated one at a time. However, for a problem of any size, the computational time required is considerable. Each new m solution requires a lengthy iterative procedure of its own that is repeated for each additional slot. A more computationally efficient approach is to use the initial continuous solution as a starting point. Each noninteger volume Q^*_{ij} is rounded down, freeing up a small number of slots ($\leq 2nm$), which are allocated by means of the "m auction solution." Starting from zero remains an available method if the initial solution technique fails, or to mimic a particular auction procedure.

MEASURES OF PERFORMANCE

The behavior of the airport system may be evaluated differently by the airport, the carriers, the passengers, and by society as a whole. Hence, a number of performance measures are appropriate. Following directly from the solution process, various estimates of the slot auction prices are available.

Slot Prices

In a competitive bidding situation, the final bid does not represent the maximum price that any carrier will pay, but the highest price that would be paid by an unsuccessful bidder. This situation follows from the recognition that the successful firm will not bid against itself. It remains true for a variety of auction types including English, Dutch, sealed bid first price and sealed bid second price (*3*). Because all the m_{ij} are calculated, the actual price at auction can be extracted automatically during the solution process.

Various auction methods can be simulated by making small modifications to the algorithm. Thus, if the initial values of the Q^*_{ij} are set equal to zero, prices are generated that correspond to a slot-by-slot auction. If slots are auctioned in batches, then the solution method is readily modified to generate the corresponding prices and allocation.

Airport Revenue

As shown in other research (*2*) airport revenue depends on the form of the slot auction, particularly the size of the lots in which slots are sold. To preserve generality in the present analysis, all slots are deemed to be sold at the auction price for the final slot. Because the demand curves are downward sloping, the highest price paid by an unsuccessful bidder for the last slot provides a lower bound on the auction price of airport runway capacity. Thus airport revenue is the product of capacity and the appropriate m.

Revenue and Profit

The total contribution to total carriers' profit may be calculated by summing the individual carrier's contribution from each route and each period and subtracting the total revenue received by the airport. Because airport revenue is a lower bound, total contribution represents the maximum retained by the carriers.

Social Welfare

Within the model and the auction, the slot prices are determined by the profit maximization of the individual carriers. However, the performance of an air transportation system is normally considered in the broader context of how it serves society as a whole, or, at least, that part of society involved directly with air travel.

In this context an appropriate and widely used measure of social welfare is the sum of consumers' and producers' economic surplus. The relevant calculations for the present model are as follows:

For a single linear demand curve, $q = a - bp$, consumer surplus at quantity q is given by $q^2/2b$. The number of passengers using carrier i on route j is $g_{ij}Q_{ij}$ where g is the capacity of the relevant aircraft. Hence the total number of passengers on this route in this period is gQ, and total consumer surplus (CS) for the system is given by

$$CS = \Sigma_j (\Sigma_i g_{ij} Q_{ij})^2/2b_{ij} \text{ summed over both periods.} \qquad (3)$$

For each aircraft size and route, cost per passenger is constant. Therefore, producer surplus for each carrier is simply the contribution to fixed cost, Π_k, and total producer surplus (PS) including payment to the airport is given by

$$PS = \Sigma_{ij} \Pi_{ij} \text{ summed over both periods.} \qquad (4)$$

Consumer and producer surplus added together equals total surplus. It provides a useful means of gaging the impact on social welfare of market expansion.

Passenger Revenue

A more direct measure of the level of operations is provided by the total passenger revenue generated by flights to and from the hub. Revenue here is a reflection of total passenger revenue miles and the fares for the different routes, both of which may be expected to respond to changes in the number of carriers.

BARRIERS TO ENTRY

In principle, the slot auction may be used to influence competition in two ways. Existing carriers may attempt to discourage potential entrants, or to drive an established carrier from the market. Because the periods are distinct, if the slots are auctioned separately, exclusion or expulsion may be attempted in peak, off-peak, or both periods.

It is assumed that all carriers operate with full and accurate knowledge of the effects of entry and exit. Thus an entry-preventing slot price is one that would reduce the potential entrant's contribution to zero. Specifically, if the market is served currently by m carriers, the entry-preventing price is found by resolving the system for $m+1$ carriers and dividing the last firm's contribution by the number of flights that it operates in the relevant period. Entry prevention is worthwhile if the profits of the m carriers, net of entry-preventing slot fees, exceed those that they would earn in the market with $m+1$ carriers and normal auction payments.

The slot fee necessary to exclude the m^{th} carrier is calculated in a similar way by dividing its contribution by the number of slots used. Exclusion will be worthwhile if reducing the system to $m-1$ carriers enables the remaining carriers to increase their own profits by an amount sufficient to pay the increased slot fees.

Raising slot fees above the marginal price calculated in the model would normally lead to a reduction in the number of slots actually used by the carriers to maximize their contributions to profit. However, exclusion and expulsion require that all slots be purchased at the appropriate price. This raises the question of how the purchase costs are apportioned by the carriers concerned. In the present analysis, carriers are assumed to optimize their operations, neglecting the larger fee and then paying for the slots used at the higher exclusion or expulsion price. In this way, the exclusion or expulsion "premium" is treated as a form of sunk cost. Because collectively they must buy all the slots, the carriers will continue to use them all if they would have done so without the extra fee.

THE DATA

The decision to examine the behavior of the model data was made in order to reflect, in a general way, part of a network in the North American context. No identification with a specific location is intended at this stage.

Carriers, Routes, and Markets

Computation focused on four or more carriers operating on some or all of eight "spokes" to the hub airport. Each of the routes differed in length from a short haul of 250 mi, increasing in increments of 250 mi, to a stage length of 2,000 mi. Demand on each route came from two markets: a relatively high-priced business market and the larger lower-priced recreational demand. To avoid generating results from peculiarities of demand, a "white noise" approach was adopted to the two types of market. Thus, basic demand for seats on route j was given by

business demand:

$$q_j = 6{,}400 - (5{,}000/d_j)p_j \quad j = 1, \ldots, n \qquad (5)$$

recreational demand:

$$q_{j+n} = 20{,}000 - (160{,}000/d_j)p_{j+n}$$

d_j is the length of route j as before. In a sense demand price is simply "scaled up" as d_j increases.

Aircraft Size

Throughout the analysis, g was assumed to represent both the capacity of an aircraft and the number of fare-paying passengers actually onboard. This is for convenience only, and altering the load factor to less than 100 percent would simply shift the profit functions downward.

In general, each carrier might be expected to operate a mixed fleet of aircraft using different sizes on different routes. Aircraft capacity might also be varied between peak and off-peak services. However a distinction has yet to be drawn between each carrier. To avoid too many interacting effects, each carrier was identified with a particular size of aircraft. Carriers were deemed to have a sufficient number of aircraft of the designated capacity to operate as many flights as they wished. Fleet size does not appear as a constraint.

For investigatory purposes, four sizes of aircraft broadly appropriate to the route distances were selected. Thus the initial configuration consisted of four carriers operating single type fleets of 50, 100, 150, and 200 passenger aircraft.

Operating Cost

The linear cost function in Equation 2 permits considerable flexibility in terms of cost variation between routes and carriers. However, for the present analysis, the following simplified version was used:

$$\text{cost of flight by carrier } i \text{ on route } j = c + d_j\,(f + hg_{ij}) \qquad (6)$$

To obtain "reasonable" values for f and h, two steps were involved. Canadian Transport Commission data (*4*) provided operating costs per mile for 11 medium and large aircraft types. Representative passenger capacities for each of these types were obtained from *Aviation Week and Space Technology* (August 19 and September 9, 1985). Linear regression provided values for f and h as follows:

$$\text{cost of flight by carrier } i \text{ on route } j = d_j\,(2.2031 + 0.0247g_{ij}) \qquad (7)$$

Support for this straight line form is good with an R^2 of 0.97. However, costs for small aircraft may be understated because none were included in the original estimation.

Parameter c was set equal to zero in the basic cost Equation in 6 and remained available to introduce a landing/take-off fee as required. Other costs not sensitive to either stage length or aircraft size could be incorporated into this constant term as well.

Airport Size

Following Borins (*5*), a single runway fully used and with a full complement of airport services is able to support 40 aircraft movements per hour. Each peak period is considered to last 2 hr and therefore, a single runway represents a peak capacity of 80 slots if it is fully supported. Consolidating the two peak periods produces a total peak capacity of 160 slots. If the airport is closed between midnight and 7:00 a.m., there are 13 hr (or 520 slots)for off-peak traffic.

RESULTS

As noted previously, the basic configuration consisted of four carriers each operating aircraft of a different size. With the demand specified, these carriers were found to use all the available capacity in the off-peak as well as the peak period. However, the auction price for an off-peak slot was about 5 percent of the peak price.

Increasing the Number of Carriers

To assess the impact of increased competition for landing slots, the number of carriers was increased by adding successive carriers with aircraft of a particular size. The effects of the expansion on the various measures of performance mentioned earlier are summarized in Table 1. The first line of data in the table indicates the basic four-carrier configuration, and the entry in the second column indicates that the fourth carrier uses 200-seat aircraft. For convenience, a number of

TABLE 1 IMPACT ON SLOT PRICES AND CERTAIN WELFARE MEASURES OF ADDITIONAL FIRMS

Firms		Slot	Price	TAR	TFP	ratio TAR /	$CS	$TS	$TPR	TPRM
#	cty	peak	off-p	x$10,000		TAR+TFP	x 10,000			
4	200	47327	2587	892	2789	0.2423	1787	5468	2572	12499
5	50	47327	2887	907	2765	0.2471	1788	5460	2559	12321
6	50	47327	3108	919	2747	0.2506	1789	5455	2551	12216
7	50	47327	3334	931	2729	0.2543	1792	5452	2545	12174
8	50	47327	3479	938	2720	0.2565	1791	5449	2541	12102
5	100	54822	3067	1037	2599	0.2851	1811	5446	2545	12426
6	100	58654	3250	1107	2480	0.3087	1841	5428	2516	12413
7	100	59159	3477	1127	2402	0.3194	1872	5402	2481	12327
8	100	60490	3548	1152	2374	0.3268	1881	5407	2475	12337
5	150	53072	2854	998	2566	0.2799	1894	5458	2507	12992
6	150	58428	3104	1096	2338	0.3192	1988	5423	2437	13289
7	150	60796	3387	1149	2209	0.3421	2045	5403	2393	13469
8	150	64592	3661	1224	2070	0.3715	2085	5379	2356	13496
5	200	48214	2125	882	2554	0.2567	2026	5462	2433	13747
6	200	52214	2004	940	2261	0.2936	2209	5410	2306	14529
7	200	51643	1739	917	2136	0.3003	2324	5376	2224	15020
8	200	52428	1904	938	2044	0.3145	2379	5361	2185	15301

TAR: Total Airport Revenue
TFP: Firms' Total Contrib'n to Profit
TPRM: Total Passenger Revenue Miles
CS: Consumer Surplus
TS: Total Surplus
TPR: Total Pax Revenue

the measures are also illustrated. Only the integer values of the abscissa are valid, but the points have been joined by smooth curves for clarity. Thus Figure 1 shows the impact of expansion on the peak slot price. Carriers operating small (50-seat) aircraft have no impact on peak traffic because it is only profitable for them to use the airport during the off-peak period. Slot prices are higher for the intermediate-sized aircraft because peak fares do not fall as rapidly as with the largest entrants. Total contribution to profit is shown in Figure 2. Contribution falls as competition increases with the effect most pronounced for the entry of the carriers with the largest aircraft. Figure 3 shows the growth in total consumer surplus as the number of carriers increases. This, too, is influenced noticeably by the size of the entrant carriers. The increase in consumer surplus is outweighed by the decline in the airlines' net revenue and thus total surplus decreases as more carriers compete for the same airport capacity. This results even in the absence of explicit congestion costs. Further experimentation with expansion using successive carriers with aircraft of different sizes produced similar results.

Barriers to Entry—Excluding a Potential Entrant

It was argued earlier that it may be possible and profitable for the existing four carriers to exclude a potential entrant by bidding up the price of slots to the point where a new carrier could make no contribution to profit. This involved solving the model for five carriers and computing the appropriate slot prices for the peak and off-peak periods. These prices were then used to calculate the reduced net contribution for the four carriers. This contribution was compared with the net contribution that would be earned by each of the same carriers if entry occurred and the slots were auctioned among the five carriers.

An airline with 100-seat aircraft has a potential for entry in both periods. The results of the simulations are given in Table 2. The first entry (Number of Slots) shows the number of slots that would be used by a new entrant and its contribution. From this can be calculated the exclusion price per slot. The impact of the new entrant is to increase the price of a peak slot by about $1,000 and the off-peak price by almost

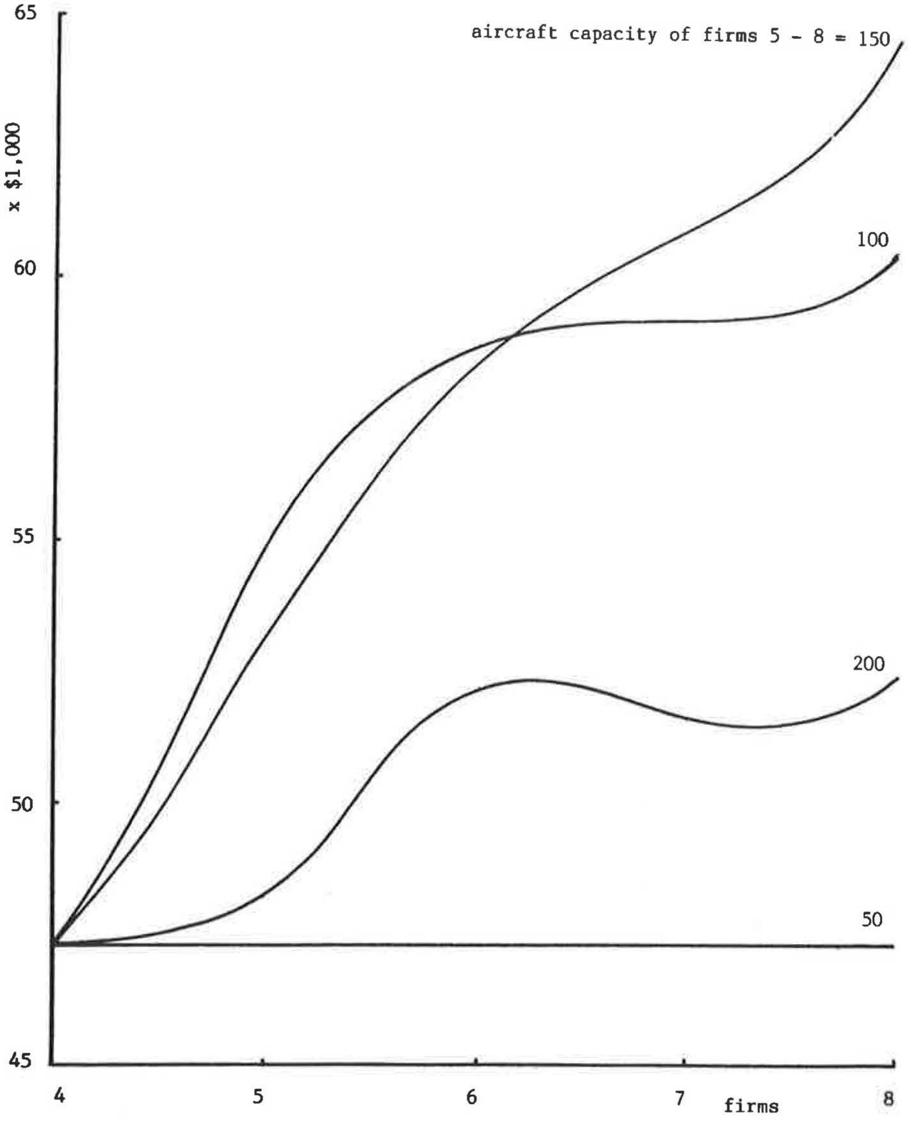

FIGURE 1 Peak slot price.

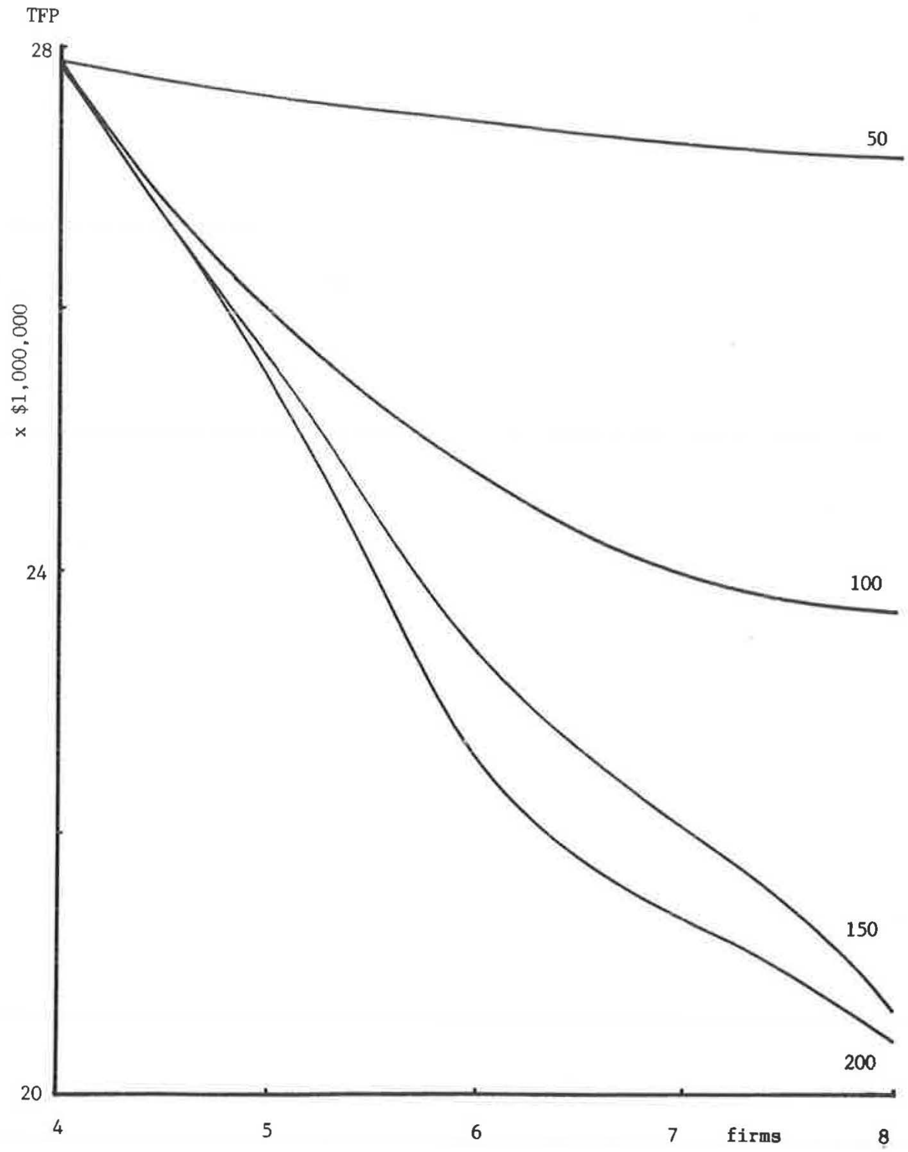

FIGURE 2 Total contribution to profit (TFP).

$3,000. To exclude a potential entrant, the existing carriers would have to purchase all slots at these prices, reducing their contributions both peak and off-peak. The second entry (A/C capacity: peak) compares the total contribution earned by the industry at peak where there is entry and where entry is precluded by outbidding potential entrants for the available capacity. The final entry (A/C capacity: off peak) provides the same comparision for the off-peak period.

A comparision of the total net contributions—with and without entry—demonstrates that exclusion is not profitable in either period for any of the carriers in the short run. However, in the long run, preventing entry of another carrier with aircraft with a capacity of 100 causes the existing carriers with aircraft with a capacity of 50 and 100 to exit. Thus the market would be reduced to a duopoly of the 150- and 200-seat carriers. At this stage, the slot price must be sufficient to deter the entry of a 100-seat carrier into the duopoly (Table 3). This table presents the same information as did Table 2, but for the long-run case.

As before, a comparision of the total net contributions shows that exclusion is not profitable in either period for either carrier. Thus exclusion of a 100-seat entrant is unprofitable both in the short and the long runs. Similar results hold for potential entry by a carrier operating 150-seat aircraft.

The case for a 200-seat entrant is less clear. Exclusion is not profitable for any of the carriers in the short run. In the long run, preventing entry of another carrier with aircraft with a capacity of 200 causes the existing carrier with aircraft with a capacity of 50 and 100 to exit and the 150-seat carrier remains in the off-peak period only. Thus the market would be reduced to a monopoly in the peak period and a duopoly of the 150- and 200-seat carriers, off-peak. At this stage the slot price must be sufficient to deter the entry of a 200-seat carrier from these markets. The results of this analysis are given as in Table 4.

It is profitable for the 200-seat carrier to maintain its monopoly in the peak period, although the maintenance of the duopoly in the off-peak period is unattractive to either

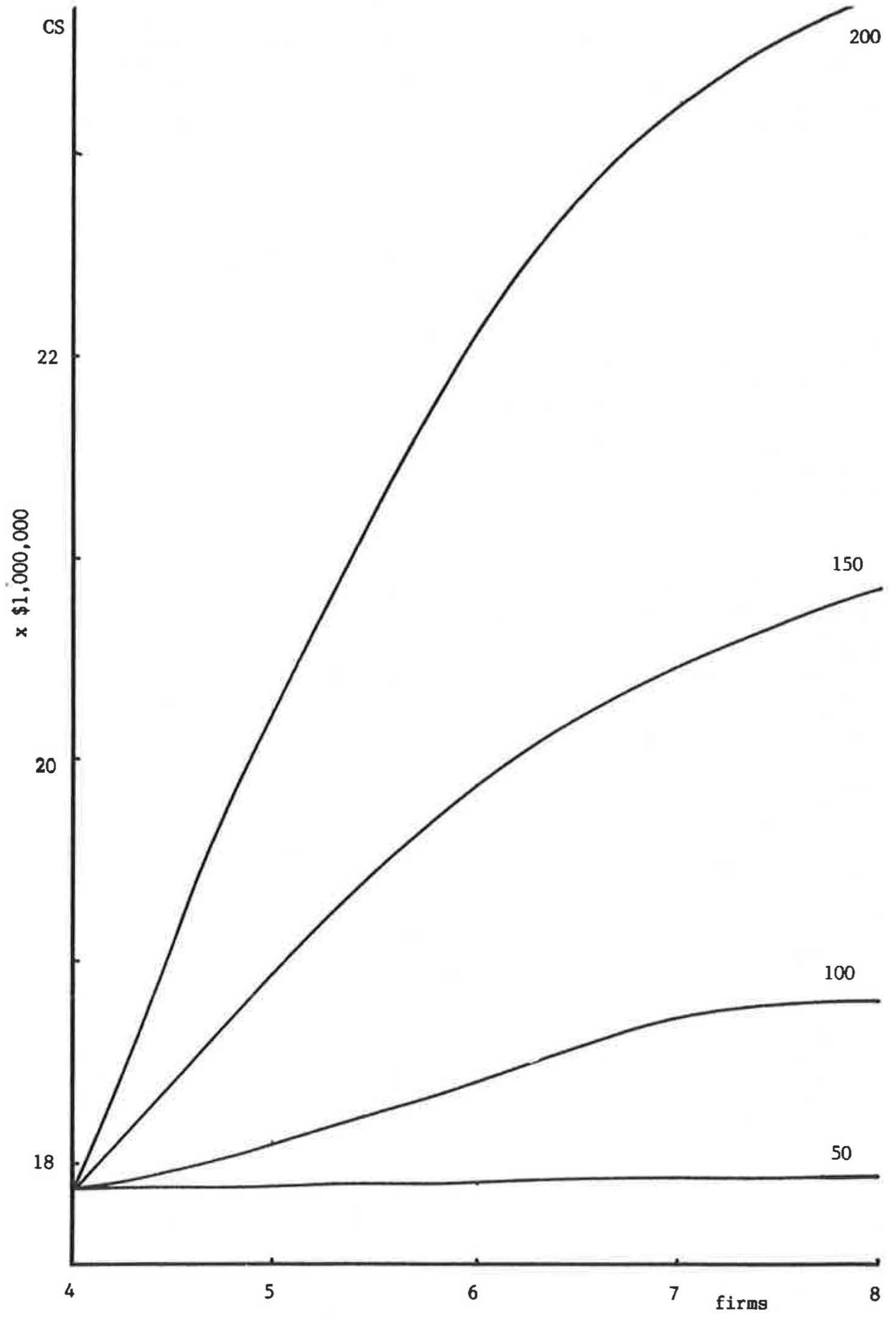

FIGURE 3 Consumer surplus.

firm. Attempting to exclude a second 200-seat carrier from the off-peak period causes the 150-seat carrier to exit leaving a monopoly in both periods. The situation in the off-peak period with a potential 200-seat entrant is given in Table 5.

Exclusion is profitable in the peak period. It is not profitable for the 200-seat carrier to attempt to exclude other carriers from the off-peak market in the long run unless it is necessary to do so in order to maintain the monopoly in the peak period.

Barriers to Entry—Expulsion of an Existing Carrier

For simplicity it is assumed that expulsion can take place in the absence of the threat of simultaneous entry by other carriers. Thus the expulsion decision can be considered in isolation. Although a variety of potential exclusion scenarios were considered in the analysis, only the "workhorse" case is considered here. This is the case involving a carrier using

TABLE 2 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING
POTENTIAL ENTRY BY A 100-SEAT CARRIER

Entrant:		Peak	Off-peak
Number of Slots	(1)	24	72
Total Contribution	(2)	1716144	559058
Exclusion price per slot	(3)=(2)/(1)	71506	7765

PEAK:

A/c Capacity	50	100	150	200
Without Entry	0	(56534)	1440426	3183399
With Entry:	0	413582	2147699	4097148

OFF-PEAK:

A/c Capacity	50	100	150	200
Without Entry:	(117470)	(12632)	210472	674204
With Entry	52205	343844	899745	1467699

TABLE 3 IMPACT ON CONTRIBUTIONS OF EXLUSIONARY BIDDING
POTENTIAL ENTRY OF THE 100-SEAT CARRIER—LONG RUN

Entrant:		Peak	Off-peak
Number of Slots	(1)	37	127
Total Contribution	(2)	2589187	958191
Exclusion price per slot	(3)=(2)/(1)	69978	7545

Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	2085159	3512960
With Entry:	–	838092	2818636	4779220

Off-Peak:

A/c Capacity	50	100	150	200
Without Entry:			216873	916776
With Entry:	–	696962	1316202	1831083

TABLE 4 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING
POTENTIAL ENTRY OF THE 200-SEAT CARRIER—LONG RUN

Entrant:		Peak	Off-peak
Number of Slots	(1)	79	169
Total Contribution	(2)	8439549	1443487
Exclusion price per slot	(3)=(2)/(1)	106830	8541

Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	–	11394531
With Entry:	–	–	–	6193701

Off-Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	(64159)	679601
With Entry:	–	–	1372484	1358632

TABLE 5 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING OFF-PEAK POTENTIAL ENTRY OF THE 200-SEAT CARRIER

Entrant:	Off-peak
Number of Slots (1)	222
Total Contribution (2)	2343576
Exclusion price per slot (3)=(2)/(1)	10557

Off-Peak:

A/c Capacity	50	100	150	200
Without Entry:	–	–	–	1657367
With Entry:	–	–	–	2359994

Combining Peak and Off-Peak:

Without Entry:	–	–	–	13051898
With Entry:	–	–	–	8537278

TABLE 6 IMPACT ON CONTRIBUTIONS OF EXCLUSIONARY BIDDING ATTEMPTS TO EXPEL THE 100-SEAT CARRIER

Excluded Firm:	Peak	Off-peak
Number of Slots (1)	37	127
Total Contribution (2)	2589187	958191
Exclusion price per slot (3)=(2)/(1)	69978	7545

Peak:

A/c Capacity	50	100	150	200
With Exclusion:	–	–	2085159	3512960
Without Exclusion:	–	838092	2818636	4779220

Off-Peak:

A/c Capacity	50	100	150	200
With Exclusion:	–	–	216873	916766
Without Exclusion:	–	696962	1316202	1831083

100 seat aircraft. It is referred to as the "workhorse" case because of the fact that it was the ready availability of this size aircraft that made possible the expansion of the airline industry in the period following deregulation of the U.S. airline industry.

Excluding the carrier with 100-seat aircraft implies excluding the carrier with 50-seat aircraft as well. The results of this simulation are given in Table 6. Using the auction mechanism to expel the 100-seat carrier in either period is not profitable for either of the remaining carriers. The total net contribution would be smaller after expulsion.

It should be noted that the largest carrier could attempt to expel its rivals. The results here are mixed. It would be profitable for the 200-seat carrier to expel its rivals only in the off-peak market. In such a case, the largest carrier would buy all of the off-peak slots, but use only 334 of them. It would then reap monopoly profits sufficient to make expulsion worthwhile.

CONCLUSION

The model discussed in this paper has a number of severe limitations. In particular, it treats a single hub airport as an isolated system, unconstrained by any other part of the transportation network. Moreover, each type of demand is characterised by a simple linear form with price directly related to distance. Each carrier operates a single size of aircraft, and there are no explicit congestion costs at the hub other than the rigid limitation on the number of available slots. However, within this framework, the results permit a few tentative conclusions.

During the peak period, when slots are at a premium, most of them will be used by larger aircraft. This would appear to be indicated by efficiency considerations as well as the profit motivation of the model. However smaller aircraft remain viable in the off-peak period. Increasing the number of carriers using a hub appears to benefit the consumers of air travel and to increase the airport's share of net revenue via the slot auction. Moreover there appears to be little incentive for existing carriers to use the slot auction to restrict entry into the market, except in an extreme case. If barriers to entry are used they may be expected to take other, less costly forms.

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Congestion, Concentration, and Contestability: The Case of the Airline Industry

John R. G. Brander, B. A. Cook, and John E. Rowcroft

When the contestability theory was first developed, it was believed that the airline industry represented the ideal case of ultra free entry. As empirical evidence mounted, it became clear that only the weak form of the theory applied. A major reason for this change was the recognition that, while entry was free in the regulatory sense, at the level of practice, problems still remained. A major contributor to restricted entry was airport capacity limitations. These shortages of capacity bestow a variety of competitive advantages on incumbent carriers. The auctioning of airport capacity is suggested as a means of increasing the contestability of the airline markets, given that it levels the playing field. The paper demonstrates that it is not feasible for financially strong carriers to attempt to use the auctions to exclude potential rivals, nor to expel competitors from the market.

Following deregulation in 1978, the number of carriers in the airline industry increased sharply. Easy market access and the ready availability of surplus jet-powered aircraft attracted new competitors. Although the pattern was not uniform across the nation, the overall supply of services increased and fare yields fell. The increased competition, coupled with the inherent tendency toward head-to-head (or service) scheduling, resulted in increased congestion at a variety of airports in the system. In turn, this fueled demands for airport expansion and other changes in the air transport system such as changing the separations between landings thereby increasing the number of slots available per hour (*1*, p. 70). It is fair to say that these congestion problems have not yet been resolved (*2,3*).

It is argued elsewhere (*4*) that the need to maximize the efficiency of airport infrastructural facilities exists and that an auction mechanism easily accommodates this need. Also, decreasing returns to flights exist, which, in turn, results in increased costs on a per passenger basis. The rising cost partly explains the increased concentration in the industry. Because the problems of congestion remain, the conclusion is that no parallel decrease in flights occurred as the concentration increased. (It should be noted that the consolidation of the industry and the hubbing activities of the participants reduced the number of flights at the 22 slot-constrained airports in 1987 (*5*, p. 81).

The renewed vigor of the oligopoly market structure in the airline industry reestablishes a sellers market, permitting increased fare yields and economic profits. These developments make the contestability of the industry important. At the same time, there are institutional barriers that greatly reduce the contestability, at least at the busiest hubs. A solution to this problem must be found.

The nature and extent of the contestability of the industry under present airport capacity allocation rules are reviewed. Other problems with the notion of perfect contestability are also discussed. The rationale for the adoption of the auction approach as a means of increasing the contestability of the industry is discussed next. The auction process, together with its benefits to the airport authorities and potential entrants, is then discussed. Finally, the conclusions from the analysis are presented.

CONTESTABILITY OF AIRLINE MARKETS

In the early stages of the evolution of the contestability hypothesis, deregulated airline markets were initially seen as representing the ideal case. Carrier-owned capital was highly mobile and the costly fixed capital facilities were provided by others. As empirical evidence has mounted, these attitudes have changed. At the present time, airline markets are viewed as only "partly" contestable. A variety of factors lie at the root of this revised position. From the perspective of the present research, the problem of airport access is considered the most important. But other problems associated with such competitive tools as frequent flyer programs and computer reservations systems also exist.

Problems of Airport Access

In order to *operate* flights on any given link in an air transportation system, an airline must have access to landing slots, gates and holding rooms, and airport counter space at both ends of the link. Thus it must have, or at least have ready access to, such facilities at both ends of the specific link that it wishes to *contest*. If that is not the case, the potential entrant will have to incur sunk costs of entry, reducing the contestability of the market, at least where only accounting costs—and not full economic costs—are incorporated into the analysis. The value of the landing slots to an incumbent must be imputed into its cost structure. Otherwise, there is the illusion that the incumbents can earn an element of monopoly rent.

Department of Economics, University of New Brunswick, P.O. Box 4400, Fredericton, N.B., Canada E3B 5A3.

Contestability theory is most applicable to a situation in which a carrier, possessing all of the requisite facilities, wants to initiate service on that link. There are few difficulties here. Aside from an advertising campaign designed to attract passengers to the new service, the sunk costs of entry are zero. This position abstracts from the opportunity costs of an airline's using its airport capacity in one fashion rather than another. For example, to contest a new link, it may have to forego profit opportunities on some other link. Brander et al. discuss the impact of this situation (*4*).

Of more interest is the capability of a new airline carrier to penetrate a new market. Here, the effectiveness of contestability can be likened to the effectiveness of competition in the neoclassical model. It is the entry of a new carrier into the industry—not the expansion of an existing carrier—that has the most profound impact in the marketplace. (Consider the impact of Freddie Laker.) However, given existing airport capacity allocation practices, a new entrant faces a variety of sunk costs. Most important are the costs of obtaining landing slots and the requisite internal airport space, if, in fact, these were available at all. Contestability of the market may be lowered as a result. Much of this is, of course, already known. For example, Baumol and Willig (*6*, p. 24) have noted that recent experience in the industry has "revealed several elements of the structure of supply that conflict significantly with the conditions necessary for the pure theory of contestability to apply." According to Morrison and Winston (*7*, p. 61, *8*) one of these elements is airport access. They argue that newcomers must incur sunk costs to obtain airport capacity and to recruit passengers.

Further discussion of these supply elements is given by Cohen (*9*) who reports on a Civil Aeronautics Board (CAB) study related to antitrust policy for a deregulated airline industry. That study suggests four potential barriers to the entry of new carriers:

- Systemwide scale economies,
- Control of feeder traffic,
- Equipment and financial constraints, and
- Airport access.

Cohen suggests that the power of incumbent carriers might be such as to contribute to a reduction in the contestability of specific city-pair markets. One important aspect here is the long-term leases of internal airport space which is controlled by the lessee regardless of whether it is actually in use. A second, relevant aspect is the potential incumbent influence over airport management decisions. According to Cohen (*9*, p. 144) taken together, these could permit carriers to "both block new entry to existing facilities and prevent the airport operator from expanding to accommodate additional entry or growth by small incumbents."

Schedule committees are a third aspect of the problem. The potential for actions to limit new entry by the incumbent carriers does exist and is likely to increase as the level of congestion increases. This potential, together with other possible exclusionary anticompetitive actions have raised congressional concern to the extent that one trade publication (*10*, pp. 34–37) has suggested that Congress "may well legislate the industry back into regulation." Part of this concern for reregulation is due to an increasing number of consumer complaints and part of it comes from the increasing concentration of the industry (*11*).

There are serious access problems in the industry. These occur because although there is freedom of entry into the industry, there is not necessarily freedom of entry into the individual city-pair markets. The cause is the set of accumulated institutional arrangements for the allocation of capacity. In effect, these arrangements constitute a new form of industry regulation. The new regulation is different from the old in that it is less visible, stemming from lease arrangements and slot allocation procedures. It also affords less protection for the consumer given that there is no forum in which they can air their views. A return to the past is a second best solution, one that trades one set of deadweight welfare losses for another. Public policy would be better directed toward improving the contestability of the airline markets by ensuring that the playing field is level.

The exact effect of these limitations on contestability is a function of the amount of excess capacity at the airports involved. Where the airports are highly congested, there will be sunk costs of entry because it will be necessary to purchase the requisite facilities from incumbents. Thus the direct (cash) costs of the entrant will be higher than those of the incumbent. It should be noted that economic costs (i.e., the sum of the cash costs and imputed costs) will be the same for incumbents and new entrants. Where there is substantial excess capacity at both airports, the sunk costs of entry would be much less.

The Question of Sunk Costs

The question of sunk costs is usually raised with respect to potential entrants. However, there is some evidence that, during the transition to a deregulated environment, incumbent carriers may encounter sunk costs that new entrants into the industry—not entrants into a particular market in the industry—do not face. Meyer and Tye (*12*, p. 277) note that "individual prices seemed to have little to do with the costs of individual services." They enumerate choice of aircraft, labor contracts, and excess capacity among legacies of the regulatory period, which impose sunk costs on incumbents, at least in the short run.

Another relevant sunk cost of incumbents is the liabilities built up over time as a result of the use of frequent flyer programs as competitive tools. This is an interesting subject, although not a well-researched one. Some believe that this competitive bonding technique significantly reduces the contestability of a market (*13*). Others express growing dismay over the programs. Ott reports concern in both the industry (*14*) and accounting groups because estimates of liabilities run up to $1 billion (*15*, p. 131). Closely related is the question as to whether "the industry as a whole has gained any additional passengers as a result of the frequent flyer programs" (*16*). Estimates here vary widely, but analysts agree that the contingent liabilities are substantial. One can only conclude that incumbents have substantial sunk costs in this area as well as others.

In discussing the issue of sunk costs, two opposing forces must be considered. That a new entrant may incur sunk costs is obvious. As the previous discussion shows, landing slots or internal airport space, or both, must be purchased by new entrants from incumbents. There are, however, sunk costs that incumbent carriers must bear as well. Most, if not all of these, are legacies from the regulatory period. The impact of sunk costs on contestability is presumably the net result when these are offset against one another.

Coursey et al. (*17*, p. 71) consider contestability in the presence of sunk costs. As is customary in the contestability literature, they distinguish between fixed and sunk costs, defining the latter as costs that "can be avoided by a decision not to enter a particular market." In that analysis, entry permits (valid for five periods) were required. The cost of these was the sunk entry cost in the model. Coursey et al. concluded that (*17*, p. 82–83)

> the effect of an entry cost is to weaken support for the strong form of the contestable markets hypothesis. . . . [However] the disciplining power of market contestability remains impressive even where entry cost weakens that power.

Although generalization from a single analysis is risky, the results imply that where the entry barriers are financial in nature, a weaker form of the contestability hypothesis remains valid.

Access, Entry, and Rents in Specific Markets

Artificial entry barriers permit incumbents to earn monopoly rents even in deregulated industries. Bailey and Williams (*18*) argue that "local monopoly rents reflect the benefits of sunk costs at a strategically located facility." Although they argue that these rents arise because of the ability to develop a hub-and-spoke network, the rents appear to be more generalized. A central question is the dominance of certain carriers at single airport facilities.

This dominance arises through control of the critical groundside and airside facilities at such airports. In other words, the rents are not intramarginal, arising from the greater efficiency of individual carriers at specific airports. They are monopoly rents stemming from the fact that, in the presence of airport congestion, control of airport capacity is important. It is the possession of landing slots or the requisite airport terminal facilities, or both, that generate the economic rent for the carrier. It is also this dominance over the airport facility that permits the development of the hub-and-spoke system. These outcomes will occur regardless of the network configuration involved.

Also of relevance in the present discussion is Bailey and William's assertion that (*18*, p. 184)

> deregulation was premised on the ability of local governments, which operate the airports, to maintain competitive entry at their facilities and on the ability of U.S. antitrust laws to prevent full control of an airport by an air carrier.

Given that the supply curve of airport capacity is not perfectly elastic, competitive entry into an airport can be accomplished only through a freely functioning market. That such a market does *not* exist was clear for at least a decade before deregulation. Arbitrary administrative allocative mechanisms have been used for at least that long.

The Bailey and Williams argument leans strongly toward the position that entry into the industry was to be accomplished—or at least facilitated—by shifting the problems of new entry to local government. Local government would have the responsibility for ensuring that adequate infrastructural facilities were available. Other problems were given to the U.S. Department of Justice which would ensure that no violations of the antitrust laws occurred. The efficacy of deregulation is a function of the ease of entry. Although it is true that entry is free in an administrative sense, it is less than free in a practical sense because of the inability of local government to provide the necessary airport facilities. By extension, it also means that it is necessary to focus attention on the ability of a new entrant to obtain the requisite airport facilities needed to make contestability meaningful. If those facilities cannot be obtained directly from the airport, then they must be obtained from rival carriers. Because this situation strengthens the competitive position of incumbents, it becomes necessary to consider the entire question of ease of airport entry, and, in particular, the associated mechanisms for the allocation of the scarce airport capacity.

A Look Back

In the period since Baumol's pathbreaking work on contestability, a large number of empirical tests have been completed. Current opinion leans toward the airline markets being only partially contestable. One issue that has arisen in examining the literature relates to the nature of the cost data used. The appropriate costs for inclusion in such an analysis are economic costs—including a variety of imputed costs, for example, the value to the incumbent of currently held airport capacity. In many of the studies the focus appears to have been on accounting costs.

Runway capacity allocation procedures, as well as use of long-term leases of internal airport space, force new entrants to incur expenditures not borne by incumbents. To find the economic cost to incumbents, the imputed value of such factors must be incorporated into the cost structure (i.e., be added to the received accounting costs). If one is interested in the optimal allocation of resources, as in the case of the contestability analysis, economic costs rather than accounting costs must be employed. If one is interested in increasing the efficiency—productive and allocative—of air transportation, it is apparent that the contestability of the airline markets must be improved.

IMPROVING MARKET CONTESTABILITY

Access to the infrastructural facilities required by new entrants contesting specific city-pair airline markets is limited. This situation offers competitive advantage to carriers already in the market, permitting them to earn monopoly rents. Although reregulation of the industry is one possible way out of the difficulty, it is a nonmarket solution. Before it is adopted, it is necessary to decide if there is another solution that would permit market forces to allocate available capacity so that the contestability of specific markets is improved and deadweight losses reduced or eliminated. Auctioning of available capacity is one technique that would produce this effect. In the absence of existing auctions, it is necessary to simulate the auction prices that would emerge. Although, in principle, the process is equally applicable to landing rights and internal airport space, only the slot prices are considered in the following discussion.

Auction Mechanism

The public provision of airports allows airlines to earn economic rents by capturing the available passenger stock. If the industry is unregulated, congestion may emerge. The presence of congestion necessitates the establishment of some mechanism to allocate the scarce airport capacity. Different allocative techniques will, of course, have different impacts on incumbents, new entrants, airport revenues, and society as a whole.

Under administrative types of allocation procedures, an incumbent carrier typically possesses a number of landing slots, and given the usual attitudes toward the disruption of the system, is likely to retain most of them in the long-run. The airline pays a price for the landing slots determined by the airport authorities on the basis of the financial requirements of the airport and aircraft size and weight. Such a price bears no relationship to the value of the slot to the carrier. It is this spread between the value of the slot—or any other measure of a unit of airport capacity that might be employed in an analysis—to the carrier and the price paid for it that generates the economic rent for the firm. A new entrant or, for that matter, a firm wishing to expand, must purchase a slot at a price at least equal to its value to the seller. In the extreme, incumbents could forestall entry by refusing any offer to purchase though they would not do so under the usual assumptions of profit maximization. Existing carriers therefore have both a competitive and a cost advantage over new entrants. The contestability of the market is therefore reduced. The introduction of an auction mechanism would place both groups on the same competitive footing, enhancing the contestability of the market in question.

Preferences for particular slots are related to potential profit, which in turn is related to market demand conditions. Congestion and the value of specific landing slots are therefore both time and location specific. Elsewhere, it is argued that an auction mechanism using discriminatory bidding—a system in which the highest bidder wins and makes a payment equal to the maximum bid of the second highest bidder—is the preferred means of dealing with congestion. From an economic perspective, it is important to deal with the congestion issue. Congestion, as is well-known, generates social costs. In the absence of peak-load pricing, carriers are able to externalize these social costs and so generate deadweight losses. Congestion pricing corrects this distortion, and, from this study's perspective at least, an auction mechanism is the easiest means by which to implement it.

However, the auction mechanism is more powerful, and more useful, than this. Because of the relationship between the desirability of particular slots and their shadow (auction) price, it is also the best means of allocating scarce capacity so as to increase the contestability of the individual city-pair market. It does so by removing one of the impediments to the contestability of a market. With the system fully implemented, all competitors, actual or potential, would have identical access to airport capacity, and what is more, would have that access on the same basis. Thus one of the preconditions for ultra-free entry into a given airline market would be better satisfied.

Toward an Auction Mechanism

The auction mechanism would function as follows. As an initial step, the airline would formulate a draft schedule. This would determine the specific landing slots and related airport capacity it required. Because the airline is able to estimate the contribution that each flight (or perhaps segment) would earn, it is possible for it to develop a set of bids for the capacity in question. These bids would be submitted in sealed tender form. At the appointed time, the bids would be opened by the airport authorities, and the bids for each unit of capacity would be ranked. The successful bidder would be the carrier submitting the highest bid in each instance, and that bidder would pay the amount indicated by the second highest bidder. In any auction, no one bids against himself, thus, the auction price paid is fractionally above that at which the second last bidder withdraws. If the carrier was successful in obtaining the slots required, it would proceed to complete its schedule.

It is anticipated that not all carriers will be fully satisfied with the outcome of the auction. Inevitably, some carriers will have only one of the two slots necessary to provide the service on the link. Thus some airlines will have slots that they wish to sell whereas others will want to acquire missing slots. In all likelihood, a slot aftermarket, similar in nature to the over-the-counter stock market, would develop. Once transactions in this market have been completed, all carriers would be in a position to complete their schedules.

In principle, the same approach can be followed with respect to internal airport facilities such as counter space, lounges, and loading gates. In practice, however, it would appear preferable to establish bundles of facilities at each airport and to auction these packages. The process would be the same as described for both the initial auction and for the aftermarket.

In theory, the auction approach is workable. It deals with the congestion problem, and at the same time, increases the contestability of the airline markets. The transitional difficulties in implementing such a scheme are discussed below. Also, the question of the length of time that an airline could hold property rights to a slot purchased at auction remains unanswered. The answer here is a function of the frequency of the auctioning, and the fraction of slots to be auctioned each time. If auctions were to be held twice per year, with, perhaps 20 percent of the slots being auctioned each time (peak and off-peak being considered separately), then the property right would extend for a 30-month period.

Simulating the Auction

Given the absence of the sort of auction envisaged here, it was necessary to develop a simulation model in order to give some credence to this discussion. That model consisted of four carriers operating different sized aircraft into a single congested hub airport from a number of smaller airports. The demand was specified in such a way that all of the available landing slots at the hub were used, both peak and off-peak. A small sample of the results of the simulations is given in Table 1. The first line of the table provides the output for the

TABLE 1 IMPACT OF ADDITIONAL ENTRY ON SLOT VALUES

	Slot Prices ($)		Revenues (×10) ($)	
Carriers	Peak	Off-peak	Airport	TFP[a]
4	47,327	2,587	892	2,789
5	54,822	3,067	1,037	2,599
6	58,654	3,250	1,107	2,480
7	59,159	3,477	1,127	2,402
8	60,490	3,548	1,152	2,374

[a] TFP is the total contribution to profit by all firms taken together.

four-carrier case, with the fourth carrier employing an aircraft of 200 seats. The other three carriers employ aircraft of 50, 100, and 150 seats, respectively. The carriers were related to their aircraft size for analytical tractability. In reality, mixed fleets are employed, and the carriers would then differ in average aircraft size. All new entrants were deemed to use a 100-seat aircraft. This size was chosen for the example because it was the aircraft that carried the burden of the expansion of the industry following deregulation. The slot prices in the table are for the period under review, presumably a schedule period. Airport and airline revenues net of operating expenses are also shown.

The slot prices for both peak and off-peak approach upper bounds asymptotically in this example. That is, the simulated auction prices rise by decreasing absolute amounts as the number of firms operating at the hub are increased. In other words, as the number of participants in the auction increases, the fraction of the total rents appropriated by the airport authorities through the auction mechanism increases. In the four-carrier case, airport revenues constitute 24 percent of the sum of airport revenues plus total carrier contributions. In the eight-carrier case, the airports earn almost 33 percent of that total. Finally, the total contribution to carrier profit declines as the number of participants rises. Intuitively, these are the outcomes one would expect.

The simulated auction approach can provide further information for those concerned about the contestability of the airline markets. With the simulated auction prices in hand, the simple subtraction of the current landing fee charged from that estimate would yield an approximation of the extent of the economic rents that are being earned by incumbents because of the difficulties of airport access. We would argue that much of the rents estimated by Bailey and Williams derive from this source (*18*). The estimated slot auction prices also indicate the minimum cash cost disadvantage that would be faced by a new entrant wishing to contest the markets at that particular airport.

Implementation

Because the adoption of the auction mechanism as a means of allocating scarce airport capacity would fundamentally alter the face of the airline industry, some attention must be devoted to the question of implementation. The intent here is to point the way, not to provide definitive answers, to all potential questions. The objective of developing an implementation scheme is to reduce the amount of disruption in the system.

In the first place, it appears that auctions would have to be introduced into the airport system on a gradual basis in order to minimize the extent of disruption to activities by incumbents. This might be accomplished by phasing in the process over a two- or 3-year period. If a 2-year period were chosen, a quarter of the slots could be auctioned every 6 months, and successful bidders would retain the property rights to their slots for a 2-year period. Increasing the length of the phase-in period would reduce the fraction of slots to be auctioned each time, and lengthen the duration of the property right as well. It should be noted that care must be taken not to reduce the fraction too far, for this would defeat the objectives sought in the adoption of the auction process. Although a policy of gradualism is necessary, it should not be so slow as to defeat the policy initiative.

Second, a phase-in of the process would also allow time for adjustments by the incumbent carriers. Over time, they have made investments in airport facilities, and these capital assets should not simply be appropriated by the airport authorities. An alternative would be for the airports to purchase the assets at fair market value.

Third, it may be necessary to permit airlines to bid on packages of airport capacity. Landing slots, gates, and related facilities are necessary at both airports if a flight is to be completed. This is a simple administrative problem in the Canadian context because the major airports are all under the control of Transport Canada. It may be more of a problem in the United States, although aside from fee splitting, no real difficulties appear to exist. In fact, the simulation model has been extended to a "three-hub" case (*19*) and works there as well. The use of such bundles of airport capacity does complicate matters, but does not defeat the auction approach *as long as aftermarkets are permitted to function freely*.

A fourth problem that is sometimes suggested is the possibility that a large carrier would be able to preclude entry (or in the extreme, expel) weaker rivals. The authors in another paper in this Record, show that this is an unlikely scenario. A final objection is that small communities would suffer under such a capacity allocation process. This is admitted as a possibility for the peak period. However, unless the airport in question is congested all of the time, off-peak access by such communities remains possible.

CONCLUSIONS

The contestability of airline markets is severely circumscribed by the lack of open and evenhanded access to critical airport facilities. In effect, the allocative techniques used implement a new and hidden form of regulation. In place of the requirement for the showing of public convenience and necessity administered by the CAB, one now finds entry control in the form of the administrative allocation of airport capacity. This approach bestows cost advantages on incumbent carriers, and in the extreme, gives them exclusionary power via their control of airport capacity.

Allocating airport capacity via an auction mechanism is a feasible alternative to the formal reregulation of the industry, and is preferable to it. Under such an allocative mechanism, carriers would be granted short-term, rather than perpetual, property rights to airport facilities with a certain fraction becoming available for competitive bidding two or three times per year. Because it results in fairness, the auction approach enhances the contestability of the airline markets.

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Analysis of Airline and Aircraft Safety Posture Using Service Difficulty Reports

ADIB KANAFANI, THEODORE E. KEELER, AND SHASHI K. SATHISAN

The objective of this paper is to analyze an important aspect of the safety posture of airlines during the years following deregulation using service difficulty reports (SDRs). Safety posture is measured by the incidence of serious aircraft service difficulties that can be taken as an indication of the potential for safety failures. SDRs report aircraft problems encountered while in operation. They vary in severity from the mundane to the serious. Despite the weaknesses stemming from potentially poor reporting, SDRs can be taken as one indicator of the effectiveness of an airline's maintenance program and can therefore shed some light on safety posture. In explaining safety posture, variables used are an airline's maintenance expenditures, aircraft fleet composition and age, and scale of operation. We also differentiate between carriers established before airline deregulation and new entrants. With the help of statistical analysis on data for the period 1980–1984, we look at some of the evidence on airline safety posture as defined. The consistent evidence we have suggests that safety posture, as indicated by SDRs, is associated with the scale of operations—the rate of serious SDRs per block hour is likely to increase with exposure (stage length) and decrease with the number of departures. The rate of serious SDRs per departure is likely to decrease with number of block hours of operations. The aging of aircraft, with respect to SDRs, is significantly different for different aircraft size groups—large wide-bodied aircraft appear to have a sharper increase in the incidence of SDRs with age than do the smaller narrow-bodied aircraft. Further, there is also consistent evidence that the incidence of SDRs is not any higher for the new entrants than it is for the established carriers.

Airline safety has always received a substantial amount of attention from the aviation industry, policy makers, and the general public. Concern has increased in the years following deregulation of the airlines, and safety has become an important topic in public debate and mass media coverage. One of the key issues being discussed is whether there has been a deterioration of safety since airline deregulation.

The Airline Deregulation Act of 1978 has resulted in a highly competitive environment and has also permitted the entry of many new airline firms into the industry. One of the primary concerns has been that these new firms might not be able to operate as safely as the more experienced ones. One of the main reasons for this concern is that perhaps the new entrants would be more strapped financially and would therefore adopt cost-cutting strategies at the expense of safety. The main objective of this paper is to analyze one important indicator of the safety posture of airlines with specific attention to new entrants.

Safety Posture

It is fortunate that aircraft accidents and incidents are rare. Nonetheless, accidents, fatalities, and their rates have traditionally been used to analyze safety performance in civil aviation. As Figure 1 shows, the rate of incidents of these rare events have declined precipitously since the mid-1950s. This rarity of events complicates statistical analysis and leaves one searching for elusive causal relationships. If the proposition is accepted that an aircraft or an airline that experiences a high incidence of mechanical difficulties in service may be *positioned* with a higher risk of accidents or incidents, then the concept of safety posture can be used as a possible indicator of an airline's risk and consequently of safety. But it is rather hard to test this proposition because there are not enough accidents to yield significant evidence. The analysis of safety posture can have important implications for the development of preventive safety programs such as maintenance or inspection.

Safety posture is measured by the incidence of service difficulties. These are difficulties encountered while an aircraft is in service and usually refer to mechanical problems. They are recorded in service difficulty reports (SDR) that are assembled by the FAA. SDRs are classified into five severity groups ranging from minor, nonthreatening service difficulties such as the failure of galley equipment to serious service difficulties that are often life threatening such as in-flight engine failure. As indicators of safety posture, all SDRs could be examined or only the serious ones. In this study, SDRs with the highest two severity levels are classified as "serious" for two reasons:

- Serious and total SDRs are correlated.
- Serious SDRs are likely to be reported vigilantly.

There are difficulties involved in using SDRs as numeric indicators. One major difficulty is the reporting issue. FAA

Institute for Transportation Studies, University of California, Berkeley, Calif. 94720.

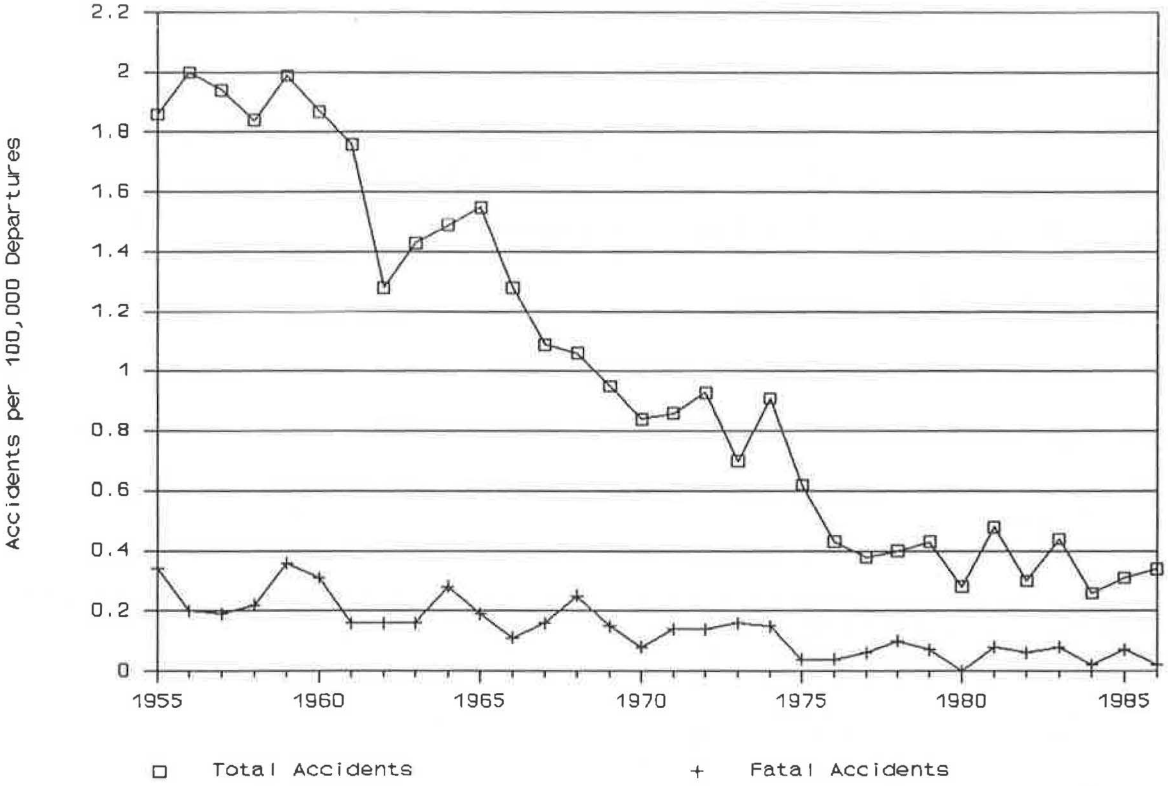

FIGURE 1 Accident rates of U.S. certificated air carriers.

regulations require that service difficulties be reported, however, little is done to ensure compliance. Little is known about the incidence of noncompliance but the general suspicion is that reporting is inadequate (*1*). In using serious SDRs only, and in staying with comparative analysis, the impact of poor data reporting should be minimized. Another difficulty with SDRs is the apparent ambiguity in the causal relationship between maintenance and the detection of service difficulties. When aircraft maintenance and inspection is vigilant, detection and reporting of service difficulties is more likely. If this is true, then the higher incidence of SDRs may be representing a higher level of vigilance and consequently a better safety posture. To prove this assumption would require an in-depth analysis of the relationship between SDRs and maintenance expenditures and procedures. Such an analysis is outside the scope of this study but has been reported elsewhere (*2*). Research suggests that the relationship between maintenance expenditures and SDR rates is elusive, and that other indicators of maintenance practice need to be analyzed. In this study, the focus on serious SDRs is also an attempt to get at an indication of safety posture that transcends this possible ambiguity. It is hard to believe that a higher incidence of serious, life-threatening SDRs does not reflect a deteriorating safety posture, regardless of the maintenance practices.

Previous work is reviewed, factors believed to affect air carrier safety posture are discussed, and results of the statistical analysis of the SDRs are presented. To analyze safety posture, propositions are made about the following factors in the causal chain:

- Aircraft fleet composition and age,
- Scale of operation and route network characteristics, and
- Airline operating structure and size.

PREVIOUS WORK

A debate has been sparked regarding the expected safety of the airline system after deregulation. The economic competition introduced by deregulation has forced the industry to increase productivity and efficiency. Increased productivity and efficiency have resulted in pressures to reduce operating costs. Maintenance, which is a substantial proportion of an airline's operating costs, may be jeopardized in some airline's cost cutting efforts. In an era of intense competition, new carriers could have a weaker financial posture than established carriers. It has been argued that this represents added pressure to take cost-saving shortcuts on maintenance.

On the other hand, as Kanafani and Keeler (*3*) point out, the new entrants should have a strong incentive to maintain good records to build a safety reputation. A serious accident is likely to be more detrimental to the reputation of a new carrier than to an established carrier. Consequently, new entrants can be expected to devote more of their resources to safety.

Although there are two sides to the argument regarding the expected safety posture of new entrants, very little empirical evidence has been produced. Work that sheds indirect light on the argument deals with the relationship between safety performance and financial health of an airline. Graham and Bowes (*4*) investigate the link between a firm's financial condition and its accident rates, maintenance expenditures, and service complaints. The relationship between profitability and accidents is analyzed by Golbe (*5*) who shows that the financial strength of a carrier does not have an effect on its propensity for accidents. Rose (*6*) investigates the relationship between accident rates and financial performance of air carriers, and finds that on an aggregate level, lower operating profit margins do not imply higher accident rates. Oster and Zorn (*7*) find that the new commuter air carriers have slightly higher accident rates in that category.

However, these studies address only the accident rates rather than safety posture. Advanced Technology (*8*) analyzes the bivariate correlations between financial measures and a carrier's inspection ratings in the FAA's National Air Transportation Inspection (NATI) program of 1984 and finds a clear correlation between financial posture and safety posture. Kanafani and Keeler (*3*) find essentially no difference between the safety records of new entrants and established carriers using accident rates, near mid-air collisions (NMACs), NATI performance, and maintenance expenditures. Recent research on SDRs, reveals economies of scale of operations associated with safety posture, making the larger carriers *appear* better positioned in terms of safety, but the *actual* posture of new carriers may be better than that of the established carriers.

INFLUENCES ON AIRCRAFT SAFETY POSTURE

Aircraft safety ultimately depends on aircraft maintainance. An airline's maintenance activities and expenditures are dependent on many important factors such as age and composition of the aircraft fleet, scale of operations, and operating structure and size. All of these factors influence an airline's maintenance policy, its level of maintenance expenditures, and potentially its safety posture. This study postulates some relationship between these factors and the incidence and severity of SDRs. Using a data base for 1980–1984, these postulates are tested statistically.

It is expected that older aircraft would require a greater level of maintenance activity as various components age. To corroborate this empirically requires care in evaluating maintenance expenditures. As aircraft age and amortize, an airline is less likely to pay for nonessential maintenance such as seats, walls, and so forth. Therefore, the statistics might show a reduction of maintenance expenditures with age for some aircraft types. It is also expected that older aircraft would experience a higher rate of SDRs than newer aircraft of the same type. A question to be resolved empirically is whether this is always the case or whether maintenance expenditures do neutralize the effect of age. The composition of a carrier's aircraft fleet is another factor that could influence its maintenance activity and SDR performance. This study explores how different aircraft types, and maintainenance expenditures for each type, affect the results.

In order to account for any possible economies of scale involved with the maintenance activity, the scale of operations is considered. Scale effect can stem from the exposure of aircraft that fly longer hours or engage in more frequent operations. Also, scale effect can stem from the size of an airline's flight operations or maintenance program. The number of departures and the number of flight hours are appropriate indicators of the scale of operations of the specific aircraft type. The average stage length tells something about the route network of the carrier, and it is inversely proportional to departures for a given number of flight hours. For any given aircraft type, these output indicators reflect the effect of exposure, but another measure is needed to account for the size of the airline itself. An airline structure indicator, in the form of an overall airline size stratifier, is postulated. Finally, to permit comparison among airlines and aircraft types, SDR rates based on departures and flight hours are studied.

The incidence of SDRs varies widely among aircraft types and airlines. Some of these variations are shown in Figure 2 for the DC-9 and in Figure 3 for the B-747 aircraft. The wide-bodied B-747 aircraft report a significantly higher rate of SDRs than the narrow-bodied DC-9 aircraft. These figures also suggest that the relationship between aircraft age the incidence of SDRs is not clear, implying that age alone does not have a specific influence on the incidence of SDRs. The effect of age is probably compounded with the effect of other factors. As is discussed later, the results of the statistical analysis suggest age as a significant factor, but show that other factors and interactions are also important.

DATA, ANALYSIS AND RESULTS

The SDR data are compiled by the FAA. The analysis period, namely 1980–1984, was chosen to examine a period sufficiently close to the start of deregulation in 1978, yet far enough away to provide some time for the carriers to make adjustments to their new operating environment and for some new carriers to establish themselves in the market. The latest year for which complete data were available at the start of this research was 1984.

The data on flight hours and average stage length are as reported in the *Aircraft Operating Cost and Performance Report* published by the U.S. Department of Transportation (DOT). The number of departures is derived by using average airborne speed, average stage length, and number of airborne hours of operations. The financial data on maintenance expenditures are also obtained from the same source. The aircraft fleet age data were obtained from the *Inventory and Age of Aircraft: Majors and Short-Haul Nationals* published by the Civil Aeronautics Board. Additional information on aircraft fleet composition and age was obtained from the Avmark Database. The pooled cross section and time series data set, with one observation per aircraft type per carrier per year, contains 274 observations.

The data include the "majors" and the "nationals" of the U.S. air carriers operating during 1980–1984. The Hawaiian and Alaskan carriers were not included in the data panel because of the significant difference in their operating environment. The classification of the carriers as new entrants follows Kanafani and Keeler (*3*). As justified there, Continental and Braniff are classified as new entrants following their reorganizations; Pacific Southwest Airlines is classified as an established carrier and Southwest Airlines is classified as a new entrant.

The airlines are also stratified into five groups (Table 1) based on their size and organizational structure. Group 1 is made up of the largest airlines, and the inclusion of Eastern Airlines in Group 2 was intended to keep the Texas Air group together, although they were not consolidated during the study

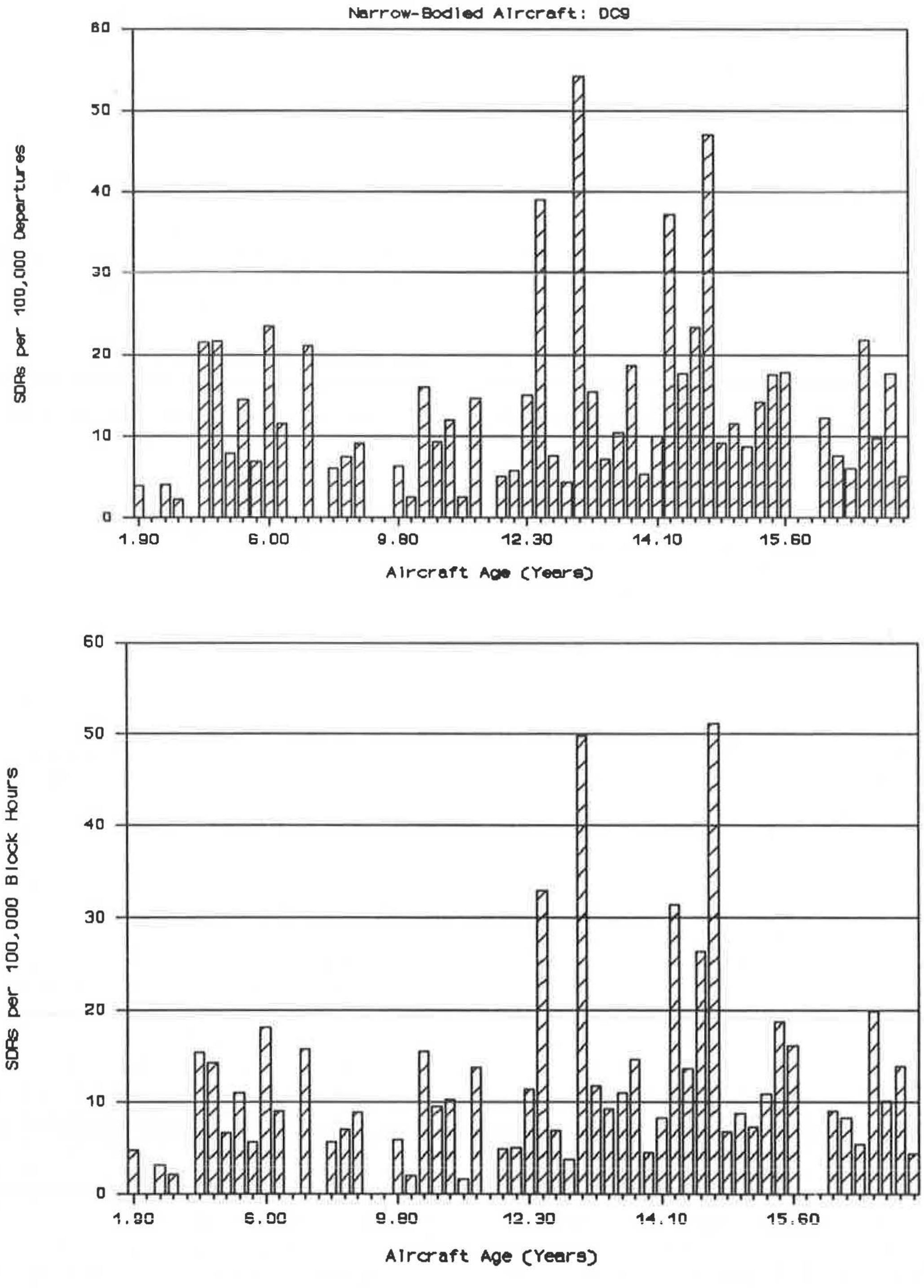

FIGURE 2 Rate of serious SDRs versus aircraft age for narrow-bodied aircraft (DC-9).

period. Similarly, the airlines comprising the current USAir group have been lumped together in Group 3. As a result, Northwest Airlines falls in Group 4 even though it would have been in a group with larger carriers had the classification been based solely on size. Group 5 is made up of airlines that are more regional in nature. There is a certain degree of arbitrariness involved in the study's classification scheme.

Variations of the same aircraft model are combined to form one aircraft group. For example, DC-10-10, DC-10-30, DC-10-40—which are all variations of the DC-10 aircraft model—are put together in the aircraft group DC-10. This resulted in seven different aircraft groups in the data set: B-727-100, B-727-200, B-737-200, B-747, DC-9, DC-10, and MD-80. The B-757 and B-767 aircraft have not been included in the analysis because they had just been introduced to the air transportation industry.

The variation of age, maintenance expenditure per block hour, stage length, and rate of serious SDRs for the seven

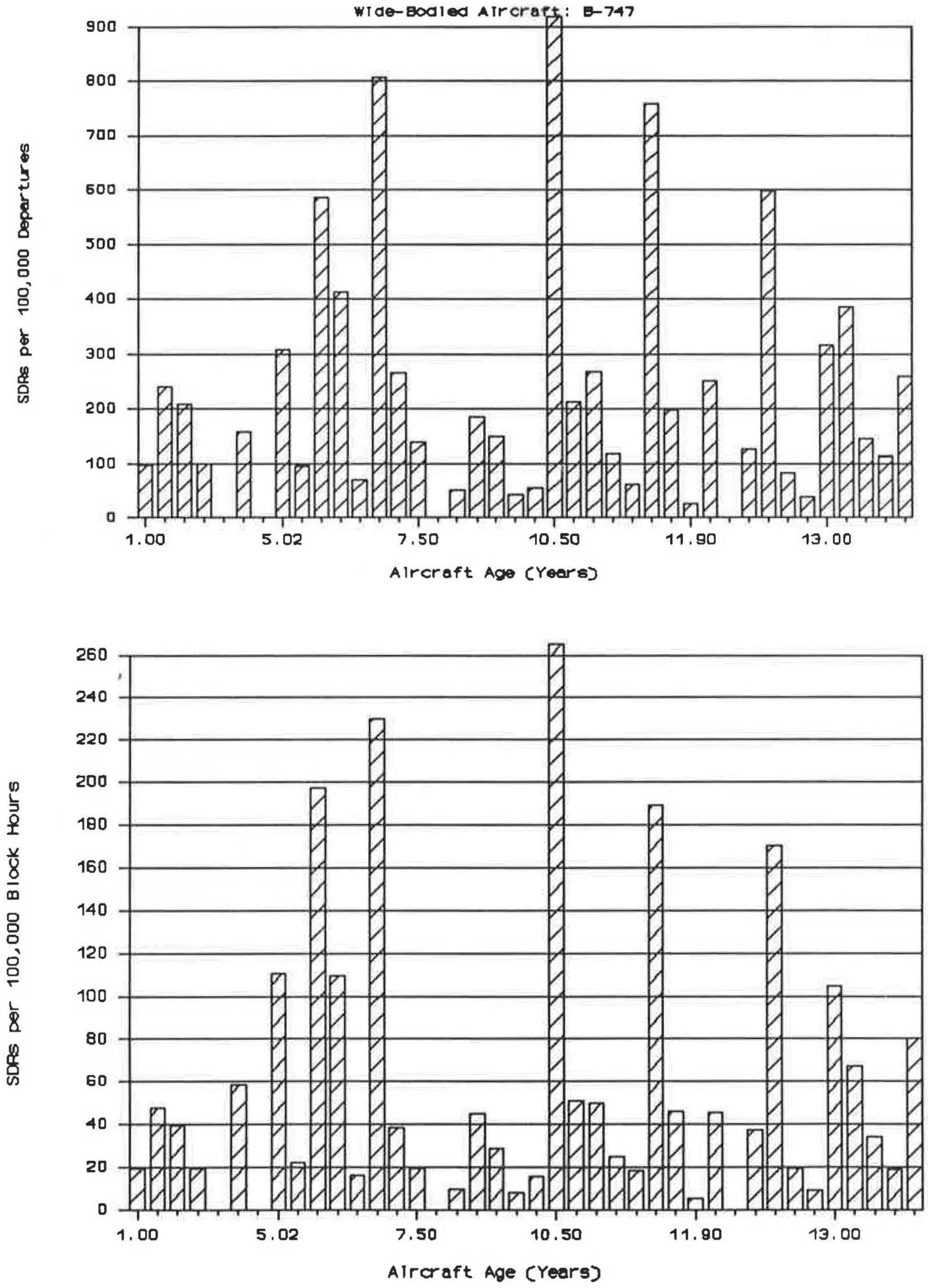

FIGURE 3 Rate of serious SDRs versus aircraft age for wide-bodied aircraft (B-747).

groups of aircraft are given in Table 2. These are the average values for the entire data set from 1980 to 1984. It can be observed from the table that large wide-bodied aircraft such as the B-747 and the DC-10 appear to have significantly different operating characteristics compared with the other types of aircraft. These wide-bodied aircraft have longer lengths of haul, higher rates of serious SDRs, and greater maintenance expenditures per block hour. Further, the SDR rate per departure for these wide-bodied aircraft are much higher than the SDR rate per block hour when compared with the other aircraft groups. This could be the result of the higher number of block hours per departure (the longer stage lengths for these aircraft), suggesting the presence of some nonlinear "exposure" factor related to flight hours. This analysis uses the rate of serious SDRs per 100,000 block hours as well the serious SDR rate per 100,000 departures. The variables are

TABLE 1 AIRLINE GROUPS BY SIZE AND ORGANIZATION

Group 1	Group 2	Group 3	Group 4	Group 5
American	Continental	Piedmont	Northwest	Aircal
Delta	Eastern	PSA	Ozark	Air Florida
TWA	Texas Int'l	USA	Republic	Frontier
United	Panam	Western	Southwest	
	Braniff			

two different rates of serious SDRs. The variables discussed in the previous section are to be used as explanatory variables.

The SDR models are then specified in multiplicative form to allow for interaction among factors as follows:

$$
\begin{aligned}
(SDR/Blkhr) = {} & e^{a0} * NEWENT^{a1} * \mathrm{DEPS}^{a2} * STGL^{a3} * \\
& AG7271^{a4} * AG7272^{a5} * AG7371^{a6} \\
& * AG747^{a7} * AGDC10^{a8} * AGDC9^{a9} * \\
& GROUP1^{a10} * GROUP2^{a11} \\
& * GROUP3^{a12} * GROUP4^{a13}
\end{aligned}
$$

A logarithmic transformation is then applied to permit simple statistical estimations:

$$
\begin{aligned}
\mathrm{Ln}(SDR/Blkhr) = {} & a_0 + a_1 \, \mathrm{Ln}(NEWENT) \\
& + a_2 \, \mathrm{Ln}(DEPS) + a_3 \, \mathrm{Ln}(STGL) + a_4 \mathrm{Ln}(AG7271) \\
& + a_5 \, \mathrm{Ln}(AG7272) + a_6 \, \mathrm{Ln}(AG7371) + a_7 \, \mathrm{Ln}(AG747) \\
& + a_8 \, \mathrm{Ln}(AGDC10) + a_9 \, \mathrm{Ln}(AGDC9) \\
& + a_{10} \, \mathrm{Ln}(GROUP1) + a_{11} \, \mathrm{Ln}(GROUP2) \\
& + a_{12} \, \mathrm{Ln}(GROUP3) + a_{13} \, \mathrm{Ln}(GROUP4)
\end{aligned}
$$

where

$SDR/Blkhr$ = serious SDRs per 100,000 block hours,
SDR/Dep = serious SDRs per 100,000 departures,
$NEWENT$ = (e^0,e^1) dummy variable for new entrants,
$DEPS$ = number of departures (in 1,000s),
$BLKHRS$ = number of block hours (in 1,000s),
$STGL$ = average stage length (in miles),
$AGxxxx$ = average age of aircraft group "xxxx" (in years), and
$GROUPy$ = airline Group "y"—(e^0,e^1) dummy variable.

This specification is to estimate the serious SDR rate per 100,000 block hours. Similarly, in the mode for the serious SDR rate per 100,000 departures the independent variable for the block hours is to be used in place of the variable for the number of departures.

The *AGxxxx* variables are defined as

$$
\begin{aligned}
AGxxxx &= AGE \text{ if Aircraft Group} = \text{xxxx} \\
&= e^0 = 1 \text{ otherwise.}
\end{aligned}
$$

This enables the capture of the interaction of the age of the aircraft groups with the rate of SDRs. An identical approach is adopted for defining the *GROUPy* variables also. In addi-

TABLE 2 AIRCRAFT OPERATING CHARACTERISTICS: SDR ANALYSIS: 1980–1984

Aircraft Group	Age Years	Maint. Exp. $/BkHr	Stage Length Miles	Deps 1000's	Block Hours 1000's	SDRs/100,000 BlkHrs	
						BlkHrs	Deps
B-727-100	16.00	117.02	580	29.9	51.9	14.41	20.15
B-727-200	7.02	87.70	620	81.9	137.7	13.37	20.46
B-737-200	7.77	99.68	354	85.0	93.5	16.09	17.92
B-747	9.09	305.20	2056	4.2	18.9	63.89	267.51
DC-9	11.47	95.53	374	86.6	99.0	11.11	12.64
DC-10	7.69	233.04	1449	19.2	60.8	14.72	49.60
MD-80	0.88	48.88	605	20.4	30.1	14.37	21.34

tion, the logarithmic transformation of the rates of SDRs are modified and computed as follows:

$$SDR/Blkhr = SDR/[(BLKHRS * 1{,}000)/100{,}000]$$

$$SDR/Dep = SDR/[(DEPS * 1{,}000)/100{,}000]$$

and

$$\text{Ln}\ (SDR/Blkhr) = \text{Ln}\ [\{(SDR/Blkhr) + 2\}]$$

$$\text{Ln}\ (SDR/Dep) = \text{Ln}\ [\{(SDR/Dep) + 2\}]$$

This is equivalent to increasing the SDR rate by two uniformly across the data set. This has been adopted to ensure that there would be no negative values for the SDR rates after the logarithmic transformation and is necessary because the actual SDR rate is less than unity for some observations.

To analyze safety posture, a total of eight alternative specifications—four for the SDR rate per block hour and four for the SDR rate per departure—are presented. In the first model, the rate of SDRs are explained by using *NEWENT*, *DEPS*, and *AGxxxx* as explanatory variables. The *NEWENT* variable allows us to measure whether new entrants have a safety posture that is significantly different from the established airlines as evidenced by the SDRs. Accordingly, the variable *NEWENT* takes on a value equal to e^1 for the new entrant airlines and e^0 otherwise.

In the second model, *GROUPy* variables are included to observe the variation of the SDRs with the size and organization of the airlines. The *STGL* variable is introduced in the third specification wherever the *GROUPy* variables are dropped from the second model, in order to determine the influence of stage length on the rate of SDRs. Finally, the fourth model includes all the explanatory variables used in the first three models.

The results of the analysis for the SDRs per block hour are given in Table 3 and those for the SDRs per departure are given in Table 4. They are notable on several counts. First, the coefficients of the dummy variable for new entrants are consistently negative and are always significant. This suggests that the safety posture of the new entrants is, if anything, better than that of the established carriers. Second, the coefficients of departures and block hours in the respective models are always negative and very significant. When specified in conjunction with the stage length variable, the variable for departures is probably capturing the scale effects in the models for SDRs per block hour while the stage length accounts for the exposure effect. Thus, air carriers with a greater number of departures of a particular aircraft are likely to have a lower than average "rate" of serious SDRs. Because stage length is an inverse measure of exposure in this case, the negative sign of its coefficient is to be expected. Stage length does not appear to be significant in the model for SDR per departure probably because departures have already been normalized. If any, the coefficient of stage length is expected to have a positive sign because for a given number of departures, the number of hours per flight and a direct relation to stage length, is a measure of the exposure. So the negative sign of the coefficient in the third model is contrary to the study's expectations, whereas in the fourth model the coefficient of stage length is not significant, which is what was expected.

TABLE 3 SUMMARY OF SDR/BLKHR ANALYSIS

Independent Variable	Dependent Variable: SDR/Blkhr Estimates of the Coefficients for			
	Model 1	Model 2	Model 3	Model 4
Constant	2.941	2.924	10.355	8.763
	12.56	*10.38*	*8.32*	*5.70*
NEWENT	-0.376	-0.350	-0.302	-0.357
	-2.35	*-1.95*	*-2.00*	*-2.04*
DEPS	-0.211	-0.146	-0.287	-0.238
	-3.53	*-2.42*	*-4.99*	*-3.75*
STGL	- -	- -	-1.134	-0.892
			-6.05	*-3.86*
AG7271	-0.040	0.038	-0.043	-0.011
	-0.50	*0.46*	*-0.57*	*-0.13*
AG7272	0.187	0.254	0.266	0.276
	1.67	*2.20*	*2.51*	*2.45*
AG7372	0.311	0.281	0.113	0.143
	2.66	*2.47*	*0.99*	*1.23*
AG747	0.418	0.615	0.943	0.925
	4.11	*5.74*	*7.31*	*7.02*
AGDC10	0.101	0.261	0.525	0.513
	0.96	*2.36*	*4.32*	*4.07*
AGDC9	0.125	0.170	-0.034	0.024
	1.33	*1.72*	*-0.37*	*0.23*
GROUP1	- -	-0.710	- -	-0.333
		-2.85		*-1.27*
GROUP2	- -	-0.449	- -	-0.152
		-1.74		*-0.58*
GROUP3	- -	0.244	- -	0.164
		0.92		*0.63*
GROUP4	- -	-0.356	- -	-0.234
		-1.43		*-0.96*
R-Square	0.265	0.333	0.354	0.369
Adj. R-Sq.	*0.243*	*0.302*	*0.332*	*0.338*
F-Statistic	12.0	10.9	16.2	11.8
Deg. of Freedom	266	262	265	261

NOTE: The *t*-statistics are presented below the coefficients.

Third, the variables used to account for the age of the different aircraft types present an interesting picture. From our attempts to arrive at a proper model specification, age and aircraft types were both observed to be very significant factors influencing the rate of SDRs. The interaction terms for the age of the aircraft groups were introduced in order to capture the aging process of the different aircraft groups. The coefficients of the variables representing B-747, DC-10, and B-727-200 are always positive and very significant. Among these three aircraft groups, the coefficients decrease in their order of magnitude and also in their level of significance in the order B-747, DC-10, and B-727-200. Note that this order suggests that the larger wide-bodied aircraft experience a greater-than-average increase of their SDR rates as they age.

TABLE 4 SUMMARY OF SDR/DEP ANALYSIS

Independent Variable	Dependent Variable: SDR/Dep Estimates of the Coefficients for			
	Model 1	Model 2	Model 3	Model 4
Constant	3.581 *12.87*	3.478 *10.20*	6.337 *4.66*	5.026 *3.05*
NEWENT	-0.392 *-2.27*	-0.417 *-2.06*	-0.345 *-1.99*	-0.414 *-2.05*
BLKHRS	-0.284 *-4.27*	-0.218 *-3.00*	-0.281 *-4.26*	-0.230 *-3.12*
STGL	- -	- -	-0.433 *-2.07*	-0.240 *-0.96*
AG7271	-0.046 *-0.52*	-0.009 *-0.10*	-0.056 *-0.64*	-0.027 *-0.28*
AG7272	0.296 *2.24*	0.308 *2.20*	0.297 *2.44*	0.302 *2.33*
AG7372	0.224 *1.82*	0.197 *1.59*	0.122 *0.93*	0.148 *1.11*
AG747	0.937 *8.90*	1.042 *9.03*	1.153 *7.79*	1.136 *7.50*
AGDC10	0.479 *4.06*	0.554 *4.41*	0.636 *4.55*	0.623 *4.30*
AGDC9	0.052 *0.52*	0.071 *0.66*	-0.031 *-0.30*	0.020 *0.17*
GROUP1	- -	-0.432 *-1.53*	- -	-0.330 *-1.10*
GROUP2	- -	-0.214 *-0.74*	- -	-0.126 *-0.42*
GROUP3	- -	0.179 *0.60*	- -	0.161 *0.54*
GROUP4	- -	-0.274 *-0.99*	- -	-0.237 *-0.84*
R-Square	0.485	0.500	0.493	0.502
Adj. R-Sq.	*0.470*	*0.478*	*0.476*	*0.477*
F-Statistic	31.3	21.9	28.7	20.3
Deg. of Freedom	266	262	265	261

NOTE: The *t*-statistics are presented below the coefficients.

This may be because these aircraft have three or four engines and that many of the serious SDRs related to the maintenance of engines. The larger aircraft appear to have a faster aging process than the smaller ones, at least as far as safety posture and serious SDRs are concerned.

Fourth, the variables for the size and organizational characteristics of the airlines only result in a marginal improvement of the explanatory power of the models. The airlines represented by *GROUP1*, the largest four, are consistently better than the rest of the airlines although the coefficients are not very significant. Also, the *GROUP3* airlines are consistently worse, and once again the coefficients are not very significant. This suggests that there are differences between the airlines. This relates to the structure of the organization of each airline and its management. It is difficult to quantify this aspect of airline operation and, consequently, it is difficult to capture all the differences between airlines in the models. Perhaps, difference in safety performance among airlines should be explained by researching the underlying differences in organizational and management structure. Quantitative empirical work of the type presented here is unlikely to shed much light on these differences, although it does certainly point to their existence and significance.

Fifth, the analysis explains the rate of SDRs per departure better than the rate of SDRs per block hour as can be seen from the R^2 values. Maintenance problems related to fatigue of the airframe and aircraft components depend more on the number of cycles of operations performed than on the number of hours of operation. On the other hand, corrosion problems relate more directly to the age of the aircraft and environmental conditions. Perhaps it is the number of cycles of operation that is more significant for aircraft maintenance. This analysis suggests that SDR per departure may be a better measure of the safety posture from a maintenance point of view.

The coefficients of determination, R^2, varies from 0.27 to 0.50 and the F-statistics indicate significant results. Thus, the underlying factors that appear to be influencing airline safety posture can be explained in part.

An unexpected result is that the inclusion of maintenance expenditures in the models does not improve the explanatory power. Maintenance expenditure was seen to be strongly correlated to the rate of SDRs, but there appears to be other exogenous forces involved in the causal link between maintenance expenditures and the rate of SDRs. The exact nature of the causal relationship is not clear—is the maintenance expenditure dependant on the SDRs or are the SDRs dependant on the maintenance expenditure? Using the maintenance expenditure that is lagged over a time period may help shed more light on the nature of the causality of the relationship between these variables. Another factor that might be important is the utilization rate of aircraft and equipment.

The airlines have been classified into groups with a certain degree of arbitrariness. Techniques such as factor analysis may be useful in arriving at a classification that is more rational and meaningful. These are areas of further research that are suggested from this analysis.

CONCLUSIONS

The consistent evidence from this study suggests that there are some scale economies in favor of safety posture, as indicated by the SDRs. The evidence suggests that the rate of serious SDRs per block hour is likely to increase with exposure (stage length) and decrease with the number of departures. The rate of serious SDRs per departure is likely to decrease with number of block hours of operations. Another important piece of evidence is that the increased incidence of SDRs with age is significantly different among the different aircraft types. In general, large wide-bodied aircraft appear to have less tolerance to age than smaller aircraft.

Further, there is no evidence that the safety posture of new entrants is any better or worse than that of the established carriers. This can be taken to mean that if deregulation has increased the entry of new air carriers into the air transportation market, then by doing so it has not adversely influenced aircraft safety. On the contrary, one might go as far as inferring from these results that the smaller aircraft typically operated by new entrants are, if anything, safer than the rest of the fleet. However, given the difficulties of the data base that were discussed earlier in this paper, a strong statement cannot be made one way or the other. Besides, the analysis does not consider other factors such as airspace congestion that may have been affected and that may have a relation to safety.

The factors included in this analysis are by no means exhaustive and there remain a number of factors and issues to be studied more closely. Some of these are network characteristics, aircraft and equipment utilization rates, and airline organizational structure and management practices. Quantification of the organizational structure and management of the airlines poses problems, but there is some indication that these may be particularly important factors influencing the safety posture.

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Estimating Practical Maximum Flight Hours for General Aviation Turboprop and Jet Aircraft

GERALD S. MCDOUGALL AND DONG W. CHO

A production relation linking total flight hours to size of the general aviation fleet is used to derive a nonlinear model explaining average flight hours per plane per year. The model includes parameters measuring the effect of relative operating costs and corporate profits, as well as a parameter measuring the maximum practical flight hours from an aircraft. An estimate of maximum practical flight hours is useful information for aircraft manufacturers in developing marketing strategies and for aircraft operators in making purchase decisions and in planning fleet expansion. Model parameters explaining average flight hours for general aviation turboprop and jet aircraft are estimated over annual data from 1969 through 1985. As expected, relative operating costs are negatively related to average flight hours and corporate profits are positively related to average flight hours. Practical maximum flight hours are estimated to be approximately 1,055 hr per year for general aviation turboprop aircraft and approximately 900 hr per year for general aviation jet aircraft. These values are approximately twice the mean average hours flown and several hundred flight hours above the maximum average hours observed for these type of aircraft over the sample period. However, the estimated values are consistent with use observed among operators of general aviation turbine aircraft with sufficiently large facilities and staff to support intensive aircraft operations.

Knowledge about the practical maximum flight hours available from a general aviation turboprop or jet aircraft is important to both aircraft owners and aircraft manufacturers. A potential aircraft owner requires information about the practical constraints on aircraft use to evaluate the possible benefits of ownership. Businesses with one aircraft and corporate operators of multiple aircraft, require information on maximum flight hours to plan fleet expansion and enhancement. Manufacturers also require accurate information on maximum flight hours to market their general aviation products properly and effectively.

This study presents statistically derived estimates of maximum flight hours for general aviation turboprop and jet aircraft based on calculated average flight hours per plane. Given the difficulties in deriving meaningful estimates for maximum flight hours, it is prudent to compare the study's methods and results with estimates derived using other methods. For example, this study's results might be compared with estimates based on analysis of the engineering and design characteristics of general aviation aircraft.

Estimates derived using statistical methods applied to actual flight hours have the advantage of implicitly accounting for not only the engineering and design characteristics of an aircraft but also many, if not all, of the other nonengineering factors that influence or constrain aircraft operation. For example, an engineering analysis of maximum flight hours available from an aircraft may be completed under the assumption of ideal flight conditions, and ignoring flight delays associated with tower workloads and congested airports. Presumably, in an aggregated way, an estimate based on actual flight hours will reflect these kinds of nonengineering impediments that help determine the limits on aircraft operation. The estimates presented are best interpreted as statements about the practical limits on aircraft operation.

The conceptual framework, data, and empirical results for the statistical approach to estimating maximum flight hours are summarized below.

CONCEPTUAL FRAMEWORK

The foundation for this study is the production relation linking reported total flight hours to the size of the general aviation fleet:

$$TFH = \alpha\ MFH\ FLT \tag{1}$$

Equation 1 simply states that total flight hours, TFH, is determined by the size of the aircraft fleet, FLT, the maximum flight hours available from a single aircraft, MFH, and the average aircraft utilization rate, α. For brevity, notation identifying different types of aircraft has not been included. If data were available it would be desirable to analyze this production relation using data disaggregated both by type of aircraft and use (e.g., general aviation turboprop aircraft in executive use). Unfortunately, sufficiently long data series are not available to undertake such analysis. Therefore, the results presented below distinguish between turboprop and jet aircraft type only.

To simplify the right-hand side of the relation it is convenient to rearrange this expression in terms of average flight hours per plane, AFH. Dividing through Equation 1 by size of the fleet, FLT, yields:

$$TFH/FLT = AFH = \alpha MFH \tag{2}$$

G. S. McDougall and D. W. Cho, Institute for Aviation Research, The Wichita State University, Wichita, Kans. 67208.

Equation 2 includes, on the left-hand side, average flight hours, which is measurable. On the right-hand side is the production parameter MFH, which is unobservable, as well as the average utilization rate, α, the value of which is determined by the aircraft utilization function. Ideally the utilization function would include factors related to substitute commecial air services (e.g., variables measuring the amount of commuter air traffic or the number of scheduled commuter air flights). Unfortunately, sufficient data over these variables are not available. Nonetheless, a previous study (*1*) has shown that aircraft utilization is related to relative operating costs (*ROP*) of general aviation aircraft and corporate profits, *PRFT*. Therefore, it is reasonable to assume that the following logistic utilization function explains the average aircraft utilization rate:

$$\alpha = 1/(1 + \exp(\delta + \beta ROP + \tau PRFT)) \tag{3}$$

where δ, β, and τ are unknown utilization parameters. Though values are unknown, β is expected to be positive and τ negative as an increase in *ROP* should reduce α while an increase in PRFT should increase α. A logistic specification is selected for the utilization function because it imposes an S-shape on the relationship between the utilization rate and the various explanatory or independent variables.

A stylized utilization function is shown in Figure 1 under the assumption that β is positive. The figure shows that the utilization rate is bounded between 0 and 1, and that it is inversely and nonlinearly related to relative operating costs. Over the intermediate range for this relationship (segment a, b) the utilization rate is sensitive to changes in operating costs. When operating costs are very low or very high, however, the utilization rate is relatively insensitive to changes in operating costs. The latter is represented by the relatively flat portions of the utilization curve on the the left of point "a" and to the right of point "b".

Substituting Equation 3 into Equation 2 gives the relationship explaining aircraft average flight hours.

$$\begin{aligned} AFH &= 1/(1 + \exp(\delta + \beta ROP + \tau PRFT))MFH \\ &= MFH/(1 + \exp(\delta + \beta ROP + \tau PRFT)) \end{aligned} \tag{4}$$

Assuming β is positive, the utilization rate increases as operating costs decline (see Figure 2). This in turn increases average flight hours. In the extreme, operating costs may decline to the point where the practical limits on aircraft operation are approached—*AFH* nearly equals *MFH*. Equation 4 is an interesting algebraic expression for average aircraft use because maximum flight hours, *MFH*, enters the numerator as an unknown parameter.

Using data on average flight hours, relative operating costs and corporate profits, unknown parameters, including maximum practical flight hours, *MFH*, in Equation 4 are estimated using nonlinear estimation techniques.

DATA

Average flight hours for turboprop, *AVTUHR* and jet, *AVJETH* aircraft can be calculated using annual data on total flight hours and fleet size reported by the FAA in the *Statistical Handbook of Aviation*. Though a comprehensive measure of relative operating costs is not available, a previous study (*1*) has shown that a reasonable proxy measure for these is the ratio of the price of general aviation jet fuel to the price of a commercial air flight *ROP*. The former is available from *Fuel Price/Supply Survey* published by the Aircraft Owners and Pilots Association. The price of a commercial air flight is measured by the average passenger per mile rate reported by the FAA and published in the *Statistical Abstracts of the United States*. Two measures for corporate profits are considered. After-tax corporate profits, *PRFT*, is from the U.S. Department of Commerce, *Business Conditions Digest*. This is a broad measure of business activity and the capacity to purchase and use general aviation aircraft for business purposes. A narrower measure is after-tax profits for the petroleum and coal products sector, *PRFTO*, taken from the U.S. Department of Commerce, *Survey of Current Business*. This measure reflects the importance of the oil and gas industry as a submarket for general aviation aircraft; especially turboprop aircraft. Summary statistics are given in Table 1, covering the period 1969–1985.

ESTIMATES

Equation 4 was estimated using these data for turboprop and jet aircraft. Complete single equation results are summarized

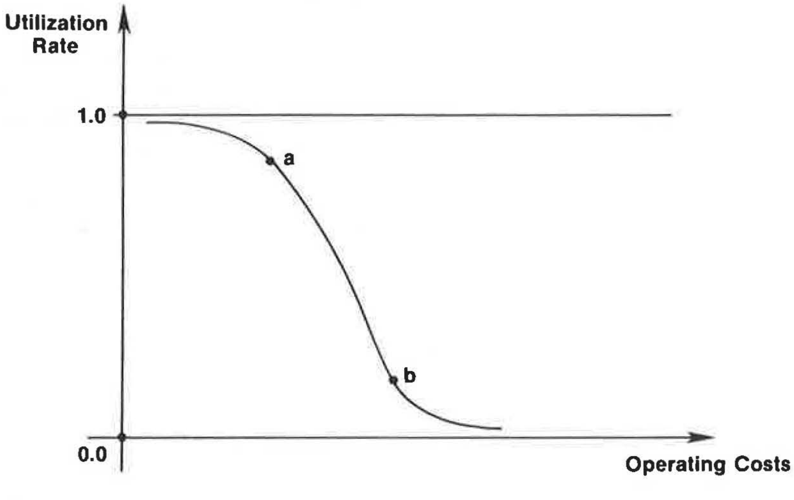

FIGURE 1 The utilization rate and operating costs.

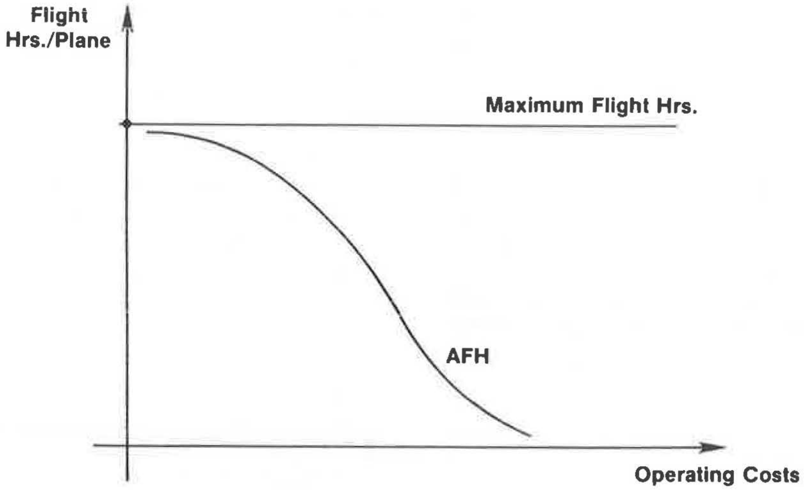

FIGURE 2 Aircraft operation and operating costs.

in Table 2 with estimates for practical maximum flight hours repeated in Table 3 for ease of reference. In each table, estimates under the broad measure of corporate profits are summarized in columns 1 and 2, respectively. Columns 3 and 4 present estimates when profits for the petroleum and coal products sector is used. Before discussing the specific estimates for maximum flight hours some general comments about these estimated models are in order (see Table 2). The explanatory power of the models is relatively high suggesting this modeling approach is a reasonable attempt to explain aircraft use. For the turboprop models the R^2 values are 0.75 and 0.79, respectively. For the jet models the R^2 values are 0.59 and 0.60, respectively. It can be concluded that changes in relative operating costs and corporate profits explain a relatively large portion of the variation in average aircraft use. For both types of aircraft the model with after-tax profits from the petroleum and coal products sector performs slightly better in terms of explanatory power or statistical fit.

The estimated coefficients for *ROP* and *PRFT*, though not statistically significant, have the expected algebraic sign: an increase in *ROP* is associated with a decrease in the utilization rate, α, and, therefore, average flight hours, *AFH*. As expected, an increase in corporate profits (measured either by *PRFT* or *PRFTO*) is associated with an increase in the utilization rate and average flight hours.

Referring to Table 3, the estimated practical maximum flight hours for turboprop aircraft is approximately 1,050 hr per year. Estimated practical maximum flight hours for general aviation jet aircraft is somewhat lower—approximately 900 hr per year. These estimates are robust to changes in the definition of corporate profits, and they appear reasonable given the summary statistics in Table 1. Each of the upper practical limits on aircraft operation is approximately twice the respective mean value for average hours flown and several hundred flight hours above the maximum value observed over the sample period. It appears that these estimates are consistent with the use observed among operators with large facilities and support staff.

The data used to derive these estimates is aggregate flight information drawn from a diverse set of flight operations, including executive use, general business use, commercial and aerial applications use, and even some personal use. As such, these estimated upper limits are best interpreted as practical limits over the entire set of uses for general aviation turboprop and jet aircraft. It would not be surprising to find an aircraft used in some very specific and narrow manner exceeding these limits, and it is expected that the estimates presented earlier are less than values derived from studying only the engineering and design characteristics of general aviation aircraft. Nonetheless, the estimates provide some guidance concerning the capacity of general aviation turboprop and jet aircraft in providing a variety of general aviation air transportation services.

SUMMARY

A production model linking total flight hours to fleet size and the average utilization rate is used to derive a statistical model explaining average flight hours per plane. The model includes, as a production parameter, the maximum flight hours available from an aircraft. The unknown parameters, including one representing maximum flight hours, are estimated using nonlinear estimation techniques applied to data on average

TABLE 1 SUMMARY STATISTICS

Variable	Mean	Standard Deviation	Maximum	Minimum
AVTUHR[a]	528	88	665	384
AVJETH[a]	452	55	516	362
ROP	1.04	0.3	1.64	0.65
PRFT[a]	150	35	217	100
PRFTO[a]	66	20	101	40

[a] Values rounded to nearest unit.

TABLE 2 ESTIMATED UTILIZATION FUNCTION

	1 Turboprops	Standard Error	2 Jets	Standard Error	3 Turboprops	Standard Error	4 Jets	Standard Error
Maximum flight hours (MFH)	1,055	3,375	904	2,869	1,055	1,803	904	2,321
Relative operative costs (ROP)	0.849	2.633	0.437	1.284	0.913	1.461	0.546	1.321
Corporate profits (PRFT)	−0.0001	0.002	−0.003	0.010	−0.003	0.004	−0.006	0.015
R^2	0.75		0.59		0.79		0.60	

NOTE: Columns 1 and 2 are based on the broad measure of profits. Columns 3 and 4 are based on the narrow measure of profits.

TABLE 3 ESTIMATED PRACTICAL MAXIMUM FLIGHT HOURS

	1 Turboprops	2 Jets	3 Turboprops	4 Jets
Maximum flight hours (MFH)	1,055	904	1,055	904

NOTE: Columns 1 and 2 are based on a broad measure of profits. Columns 3 and 4 are based on narrow measure of profits.

aircraft flight hours and a proxy measure for relative operating costs. It is estimated that the practical maximum flight hours available from general aviation turboprop and jet aircraft is approximately 1,050 hr per year and 900 hr per year, respectively.

Given the difficulty in deriving meaningful estimates for the limits on aircraft use, it is prudent to compare these estimates with ones derived from different methods and information. Nonetheless, statistical estimates based on flight operations such as those presented have the advantage of indirectly accounting for factors other than engineering and design features that may limit or constrain aircraft operation. The estimates are reasonable when compared to actual flight operations reflected in average flight hours per plane calculated from FAA data.

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