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E. Thomas Burnard, Transportation Research Board staff

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Foreword

The papers in this Record were prepared by graduate students who were awarded stipends under the 1986–1987 Graduate Research Award Program on Public-Sector Aviation Issues sponsored by the Federal Aviation Administration and administered by the Transportation Research Board. The papers were presented at the Annual Meeting of the Transportation Research Board in Washington, D.C., January 13, 1988.

The Graduate Research Award Program is a pilot program intended to stimulate thought, discussion, and research by those who may be the future managers and policymakers in aviation.

The research reported in this Record deals with airline route structures, the orderly flow of air traffic, labor implications of a deregulated airline industry, and an analysis of risk factors bearing on the safety of aviation.

Airline Routes and Metropolitan Areas: Changing Access to Nonstop Service Under Deregulation

JOSEPH P. SCHWIETERMAN

As air transportation becomes more accessible to millions of Americans, the evolving network of airline routes continues to evoke both criticism and controversy. Some metropolitan areas are developing extensive nonstop air transportation networks, whereas others, often of similar size and economic status, continue to be served primarily by less desirable and more time-consuming connecting air flights. As shown by this study, these patterns are predictable and efficient market outcomes as carriers simultaneously attempt to minimize costs and cater to the diverging demands of consumers for high-quality and low-priced air service. Three aspects of airline route development are explored in detail: (a) why disparities in air route coverage have emerged among similarly sized metropolitan areas since deregulation, (b) which economic factors are acting to eliminate these disparities, and (c) in what cities consumers appear to be benefiting most from these arrangements. A computer-assisted survey of airline schedules and traffic volumes is conducted for each of the 60 largest population centers in the United States. The disparities in nonstop service among these cities are shown to be partly a result of economies of aircraft size, a factor that renders nonstop air service uneconomical compared with hub service in most city pairs. Market size, length of haul, and proximity to hubs are hypothesized as important determinants of the level of nonstop service provided. More recent trends suggest that other factors are encouraging carriers to move away from centralized hub operations—a reversal attributed to rising demand, falling costs, and varying pricing opportunities between cities.

The deregulation of airline prices and routes continues to have profound effects on U.S. metropolitan areas. In a turbulent marketplace marked by escalating competition and consumer demand, the prices of flights, schedules, and seat availability levels are shifting dramatically: since passage of the Airline Deregulation Act, prices have declined in real terms by 21 percent, new nonstop services have been added on 328 routes, and passenger miles have more than doubled (*1*).

As air transportation becomes more accessible to millions of Americans, however, the evolving network of airline routes linking the largest metropolitan areas in the United States continues to evoke both criticism and controversy. Some metropolitan areas are developing extensive nonstop air transportation networks, whereas others, often of similar size and economic status, continue to be served primarily by less desirable and more time-consuming connecting air flights. The effects of these disparities are borne primarily by time-conscious consumers such as those traveling for business or emergency purposes, for whom the absence of nonstop service means a costly loss of time, often exceeding 2 hr per trip. For even a relatively small metropolitan area, the collective value of this lost time can reach millions of dollars annually.

Prevailing public opinion often holds that the uneven development of nonstop air service under deregulation is a consequence of the oligopolistic structure of the industry—a factor alleged to encourage firms to tacitly collude to concentrate services at hubs to preserve regional market power or prevent costly product differentiation. Others misleadingly assert that the centralization of service is a function of hub "economies of scale." This study, which is supported by a unique computer-assisted survey of airline routes in the United States, is based on earlier academic research and illustrates that the uneven structure of nonstop service across metropolitan areas is an inevitable consequence of the market's response to varying passenger lengths of haul, market sizes, and pricing opportunities. The methodology allows the service disparities to be seen as predictable market outcomes as firms attempt to cater to the diverging demands of consumers for high-quality and low-priced air service. Technological and operational factors are shown to prevent nonstop air service from being provided in direct proportion to the quantity of service that consumers demand.

Three aspects of airline route development are explored in detail: (a) why disparities in the availability of nonstop service have evolved among similarly sized metropolitan areas since deregulation, (b) what economic factors are encouraging the elimination of these disparities, and (c) where time-conscious consumers are benefiting (or losing) most from these arrangements. By comparing the changing levels of nonstop service available from each of 60 major U.S. metropolitan areas, a useful perspective of how time-conscious travelers are being affected by the deregulation of air routes is provided. Evidence suggests that although the marketplace is eroding them, the disparities in nonstop air service among metropolitan areas remain a pervasive feature of the U.S. air transportation system.

The study is divided into four sections: important microeconomic factors affecting the development of nonstop air routes; their implications for metropolitan areas; the changing availability of nonstop air service from 60 metropolitan areas, based on changing commercial flight schedules; and general conclusions.

United Airlines, P.O. Box 66100, Chicago, Ill. 60666.

The term "nonstop route coverage" (or simply "route coverage") is used to describe the network of routes operated by regularly scheduled air passenger carriers; for any metropolitan area, this is the system of routes radiating directly to other metropolitan areas (the terms "city" and "metropolitan area" are used interchangeably). Frequency of service, schedule convenience, and seat availability along each route, of course, are also important determinants of service quality; however, for this study, attention is focused exclusively on the structure of air routes themselves. This narrow focus offers new insights into the distributional consequences of route deregulation.

CONTRASTING PATTERNS OF NONSTOP AIR SERVICE DEVELOPMENT

Before enactment of the Airline Deregulation Act of 1978, the Civil Aeronautics Board (CAB) regulated and strictly controlled airline routes and prices. Firms were expected to comply with regulatory processes and legal requirements before initiating service and were restricted from entering markets that the CAB considered adequately served by others—a philosophical position the agency held until the late 1970s.

A specific objective of this regulation appears to have been to encourage a more evenly distributed, highly decentralized allocation of nonstop air routes between urban areas by suppressing the cost differences that exist in the supply of these services (*2*). Three aspects of the CAB's regulatory policy encouraged this outcome. First, the CAB employed rigid controls on route additions, which limited the development of private hub-and-spoke systems on a national scale and encouraged carriers to pursue more point-to-point route strategies (*3*). Second, passengers on short-haul routes (where price elasticity of demand was high) were systematically cross-subsidized by those on longer routes (where price elasticity was low), allowing much otherwise infeasible nonstop service to be provided (*4*). Finally, and most significantly, the CAB required both long-haul "trunk" operators and regional operators to voluntarily interchange passengers at intermediate points to facilitate coordinated route development. For example, a passenger traveling from Washington, D.C., to Los Angeles could make transfers between any two airlines at dozens of locations en route, such as Chicago, St. Louis, or Kansas City, for the same price as if the same carrier had been used for the entire trip. All cities were regulated "public" hubs, and homogeneity in air service between cities was preserved (*5*).

Under deregulation, the fare agreements necessary to continue such interline sales are being phased out gradually as airlines compete for the passenger's entire flight itinerary. Integrated, "private" hub-and-spoke route systems are allowing carriers to link major metropolitan areas with multiple frequencies in all regions of the country. Between 1978 and 1986, the share of the flights serving airline hubs expanded from 74 to 86 percent of the total, and the number of airline hubs doubled (*1*). In contrast to the regulated era when 20 percent of passengers used two or more airlines en route to their destinations, only 6 percent switched airlines en route in 1986. Private hub systems have become more pervasive, and many cities that served as vital connecting points in the regulated framework lost nonstop service.

The relatively even allocation of routes has given way to a system in which carriers have the operating flexibility to choose the combination of fares, aircraft size, load factors, and frequency to maximize profits in each market. On each route, carriers weigh the diverging demands for service quality and low ticket prices. Frequency of additional flights, for example, improves passenger convenience but leads to higher average costs because carriers must substitute smaller, higher-cost aircraft for such service. Similarly, nonstop service is preferred by consumers to connecting service, but is often more costly because it provides carriers less opportunity to exploit the economies of aircraft size. (Hub service generally is able to consolidate passengers bound for numerous destinations onto a few planes, thus enjoying lower seat-mile costs through the operation of larger aircraft.) Thus, when passengers value the improved frequency and lower ticket prices provided by hub services more than the costs of making an additional stop, carriers have incentives to dispatch passengers through centralized hub facilities.

A Brookings Institution study by Winston and Morrison concludes that the deregulated industry is more efficiently meeting these contrasting consumer preferences for service quality (a function of flight frequency, travel time, and average load factor) and low ticket prices (a function of aircraft size and price structure), with an estimated gain in social welfare of at least $8 billion during 1983 (*6*). Carriers under deregulation are substituting larger aircraft for smaller aircraft when passengers place relatively little value on flight frequency relative to ticket prices, such as in predominantly pleasure markets. Conversely, in business markets where a premium is placed on time and convenience, smaller aircraft are being employed to provide higher frequency and an emphasis is placed on offering nonstop service—with accompanying higher fares.

As this discussion attempts to show, however, the market's responsiveness to a time-sensitive consumer's demand for nonstop service is greatly affected by exogenous market factors. This is illustrated by considering the simple analogy between the development of air service and the economist's idea of a "lumpy good." "Lumpiness" occurs in a good—or service—that can be efficiently supplied only when output exceeds some minimum threshold; technology prohibits the efficient division of output into smaller units. The development of nonstop airline routes is similarly constrained. Nonstop service can be provided between cities that are not hubs only when demand is sufficiently large to allow nonstop service operators to exploit the economies of aircraft size necessary to compete effectively with hub service. To the extent that traffic levels do not permit the operation of an aircraft sufficiently large to achieve the least-cost scale of operation, the cost differential between nonstop and connecting service grows, increasing the necessary price differential between these competing services. Thus, where lumpiness is severe, less nonstop service tends to be available for time-conscious consumers, and the gains from deregulation primarily accrue to those less sensitive to the added travel time required by hub service.

Previous research has not explored this aspect of deregulation in sufficient detail to fully illustrate its potential significance for consumer welfare. Consider, for example, consumers in Omaha, Nebraska, who had nonstop service to numerous

West Coast markets until 1984. With the increased competition brought about by the added frequency of flights to hubs in Denver, Salt Lake City, and Phoenix, this service evidently became unprofitable and was abandoned. Nonstop service could no longer compete with the lower effective price of hub service. Collectively, consumers in the Omaha market might have benefited from the increased efficiency of the expanded hub operations, but the benefits are distributed unevenly. The improvement in network efficiency is shared by all passengers using the improved hub service, such as those traveling between Omaha and Denver or Salt Lake City, or connecting to other points. However, the costs are borne exclusively by time-conscious consumers desiring to travel between Omaha and the West Coast. If the value of the added hub frequency or lower fares does not offset the costs of the lost nonstop service (i.e., the lost consumer surplus), consumers are worse off under the new arrangement.

A welfare loss emerges whenever the total benefits to consumers of a nonstop service exceed its total costs, but carriers are no longer able to implement a fare structure that extracts sufficient revenue to pay for the service. Indeed, when carriers cannot operate profitably at any price, they can attempt to charge higher prices to those willing to pay for the added convenience of the nonstop service and allow more discretionary passengers to travel at lower fares. However, these efforts are problematic and often unsuccessful; they contributed to the elimination of nonstop service on more than 400 routes between 1977 and 1983 (*1*). This yields a paradoxical outcome: if the addition of new hub service undermines the profitability of nonstop service, time-conscious consumers in affected city pairs might well be worse off because of the hub's increased availability. Depending on the nature of consumer demand, the losses to consumers who are time conscious might well exceed the gains to those who are not.

The scope of this phenomenon can be appreciated by consideration of a few examples. There is sufficient passenger demand on less than 25 percent of the routes linking the 100 largest U.S. metropolitan areas to support profitable nonstop service. The lumpiness phenomenon is exemplified by the absence of nonstop service in city pairs such as Washington, D.C.–San Diego, California; Portland, Oregon–New York, New York; and Boston, Massachusetts–Seattle, Washington. All are markets in which forecast travel volume exceeds 200 passengers a day (*7*). Indeed, the costly absence of nonstop service to many business centers from cities such as Cleveland, Ohio; Oklahoma City, Oklahoma; and Louisville, Kentucky, has prompted municipal governments to initiate bold marketing programs to expand the scope of services, ranging from free gate space to tax incentives.

The technological relationship between aircraft size and flight distance heightens the lumpiness phenomenon on longer routes, further limiting the market's ability to provide cost-effective nonstop service. Fuel economy, labor, and maintenance render smaller aircraft less cost-effective (per seat-mile supplied) relative to larger aircraft as flight distance increases. On short routes, conversely, smaller aircraft are at a relative advantage over larger equipment because they provide greater ease in ground handling and more operational versatility.

The performance statistics of three common aircraft—the Fokker 28, McDonnell Douglas DC-9, and Boeing 747-200 (Figure 1)—illustrate this principle. Optimal aircraft capacity (i.e., that minimizing seat-mile costs) is shown to increase as a positive nonlinear function of length of haul (*8*). In the flight range of 200 mi or less, for example, the 80-seat aircraft (Fokker 28) is most cost-effective. On routes of 1,000 mi, the 325-seat aircraft (Boeing 747-200) is the most efficient, with direct operating costs as low as 2 cents/seat-mile (these estimates exclude nonvariable factors such as depreciation, managerial overhead, and administrative expenses). At intermediate distances, the 145-seat (DC-9) aircraft is the lowest-cost technological unit (*8*).

How does this affect route development? Consider a city pair between which 80 passengers travel daily. On a route of roughly 1,000 mi, nonstop service could be provided with an 80-seat plane at a cost of roughly 4 cents/seat-mile (Figure 1, Point *A*). However, if passengers were consolidated onto a larger 325-seat aircraft at an intermediate hub located 500 mi from each city, average costs would fall to nearly 3 cents/seat-mile (Point *B*), or approximately $10 less per passenger handled. In this example, the airline would have to operate an aircraft at least as large as a DC-9 with 145 seats to achieve cost parity per seat-mile supplied on the 1,000-mi nonstop route, as designated by Point *C*. Economies of aircraft size render nonstop service prohibitively costly relative to the hub service if market size is less than 145 passengers per trip; too much capacity would have to be made available to achieve cost competitiveness. However, if the length of haul in this example is reduced to 150 mi, nonstop service using 80-seat aircraft would be highly cost-effective relative to hub service. In this case, the economics are reversed: an airline seeking to establish hub service finds itself unable to compete effectively with the nonstop operator.

This simple principle suggests that the feasibility of nonstop service under deregulation is positively related to the size of the market and negatively related to the length of haul. A sample of 400 city pairs selected at random from among the 60 largest population centers in the United States supports this view. The city pairs were sorted into three categories on the basis of their relative sizes; large markets have 1987 traffic projections [published by the Boeing Commercial Airplane Company (*9*)] exceeding 200 passengers a day compared with 100 to 199 a day for middle-sized markets and 99 or fewer a day for small markets. Statistical estimates were made to assess the propensity for city pairs to have nonstop service, given forecast traffic and flight distance (Figure 2). City pairs in all three categories were found to exhibit a high likelihood (0.70 or higher) of having available nonstop service when separated by 400 mi or less. However, as length of haul increases, city pairs with higher passenger volumes fare disproportionately well relative to medium-sized and smaller city pairs. For large markets on long-haul routes (over 1,500 mi), for example, the probability of nonstop service is 0.37 compared with only 0.04 for smaller city pairs and 0.14 for medium-sized city pairs. Although traffic volume in small markets on long-haul flights averages about one-fifth that of large city pairs, only one-tenth as much nonstop service is provided. (In fact, when length of haul approaches 2,000 mi, the data suggest that the likelihood of

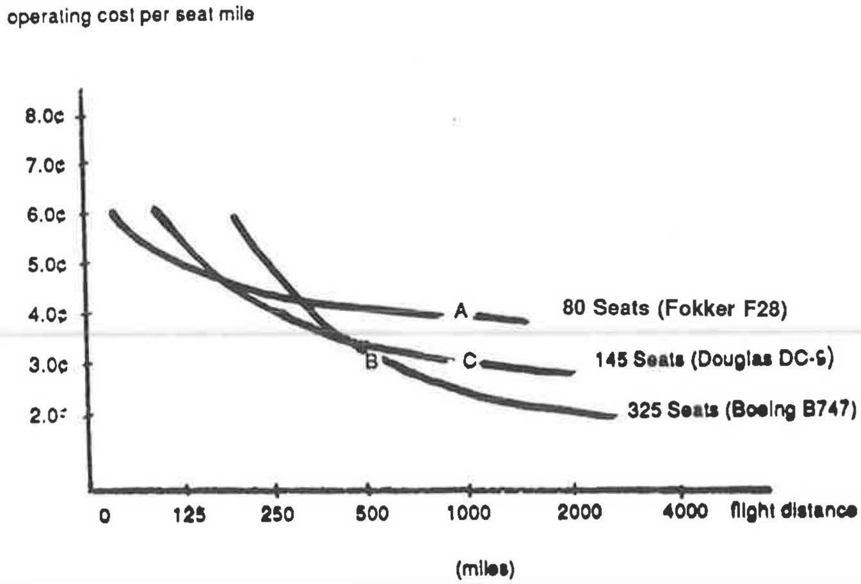

FIGURE 1 Length of haul and optimal aircraft size for three common aircraft.

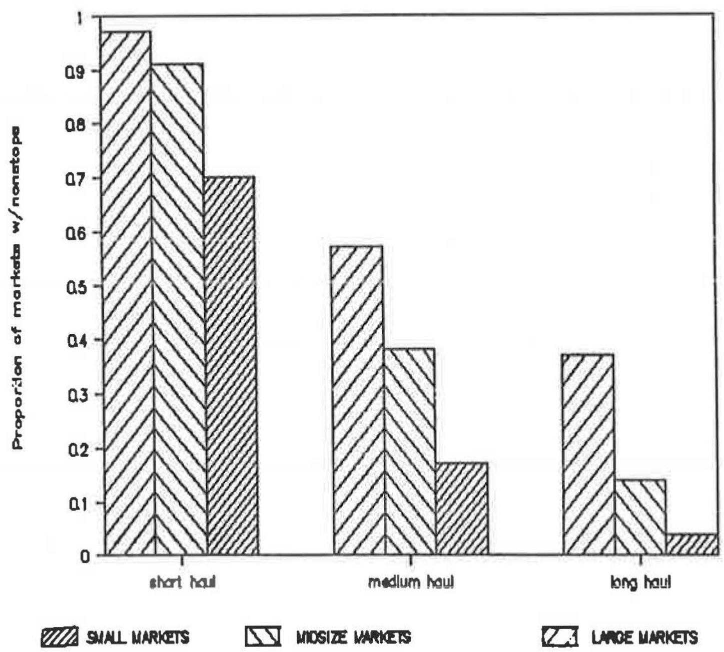

FIGURE 2 Likelihood of scheduled nonstop service: city pairs linking 60 largest U.S. metropolitan areas.

nonstop service in smaller city pairs approaches zero but levels off for larger city pairs at approximately 0.30 percent). Thus, the distribution of nonstop service is far from random—it is systematically related to the market's adaptation of least-cost transportation methods and will affect cities in profoundly different ways.

IMPLICATIONS FOR METROPOLITAN AREAS

These constraints on the development of nonstop air routes indicate that only a fraction of all city pairs will be linked by nonstop flights. Where quantity demanded is low or distance between cities is great, nonstop service will develop sporadically and service often will be provided more profitably by dispatching passengers to central hub locations. Because the true profit-maximizing market allocation of routes might differ substantially from the regulatory allocation, certain metropolitan areas will experience dramatic service changes under this arrangement. Four aspects of this phenomenon might foster apparent inequities in nonstop service availability.

First, the smaller the city or the more distant the consumers' destinations, the more likely that cost-competitive nonstop service will be infeasible, worsening the market's responsiveness to consumer demand for nonstop service. Seemingly minor differences in market demand and length of haul were shown in Figure 2 to foster potentially dramatic disparities in nonstop service availability. Consequently, cities located close to others will enjoy a wide range of nonstop service even though larger, more air-dependent cities in more isolated regions might be forced to rely primarily on connecting air service.

It is not surprising that relatively isolated cities such as Portland, Oregon, for example, now have less developed route structures than many smaller cities that are close to major business centers in the Midwest. Portland has nonstop service to only 16 of America's 60 largest business centers, comparing unfavorably with similarly sized eastern cities such as Indianapolis, Indiana (28); Baltimore, Maryland (38); and Columbus, Ohio (19).

This also suggests that consumers in metropolitan areas in which demand for air service is just high enough to mitigate the lumpiness problem will enjoy disproportionate advantages over metropolitan areas just below this threshold under deregulation. In the extreme case, consumers in certain cities will be provided with nonstop service to distant hub facilities even though far more passengers would prefer nonstop service elsewhere. For evidence of this tendency, consider the case of Fort Wayne, Indiana, where routes radiate to distant hubs such as Dallas, Texas; Denver, Colorado; and Atlanta, Georgia; whereas more heavily traveled destinations such as New York, New York; Philadelphia, Pennsylvania; and Washington, D.C., now are served only with connecting flights (*7*). Here many of the primary consumer destinations fall below the threshold at which nonstop service can effectively be profitably provided.

Second, cities with relatively poor hub service will enjoy substantially more nonstop routes than those with attractive hub alternatives. Heightened competition from hubs requires nonstop carriers to operate at increasingly favorable seat-mile costs—an objective often achievable only through the operation of larger aircraft. As a result, many relatively large city pairs with attractive hub alternatives (such as Indianapolis–Boston) remain without nonstop service, and smaller markets with fewer hub alternatives of similar length of haul (such as Billings, Montana–Seattle, Washington) are provided such service.

Third, a principal beneficiary of the lumpiness problem that exists under deregulation is the consumer in cities selected by carriers to function as airline hubs. If selected as a hub, a metropolitan area can acquire nonstop linkage to an entire network of cities that would otherwise not be available. Consumers in metropolitan areas selected as hubs accrue benefits from the lumpiness in supply that constrain the development of nonstop routes in other cities.

Hub selection, of course, is not an arbitrary process. A less-than-optimal hub location will lead to excessively long travel times for connecting passengers and unnecessarily high operating expenses—factors rendering geographical location of prime importance. However, carriers can compromise the geographical location of their hubs to the extent that gains (from the larger population located at the hub or other factors) equal or exceed the added costs. This will produce situations in which hub location is only loosely correlated with local population, encouraging what seems to be inequitable patterns of air-route development.

The fourth aspect is that metropolitan areas in which carriers can command premium fares for nonstop service will enjoy disproportionately high levels of nonstop service. The extent to which carriers will deviate from cost-minimizing hub systems described earlier depends on consumer willingness to pay fare premiums for nonstop service. Where consumers are willing to pay such premiums, it would be expected that route growth under deregulation would be higher than average. Nonstop service that would otherwise be economically less feasible than hub service will become feasible where such offsetting pricing opportunities exist.

Following deregulation, each of the foregoing aspects gave carriers incentives to restructure their route systems away from the relatively homogeneous regulatory allocation. This suggests that increased service "inequities" between cities have emerged. Two other factors, however, are simultaneously acting to lessen these disparities. First, lower operating costs are encouraging new nonstop service. Largely because of declining input costs and technological advancement, airline prices have dropped in real terms by 21 percent since deregulation (*1*). As prices fall, the quantity of air service demanded increases in a city pair, reducing lumpiness in supplying nonstop service. Second, rising demand is encouraging new nonstop service. The actual demand curve is shifting outward as population moves to more rural locations, income increases, demographics change, and levels of interstate commerce expand. This factor also stimulates the market's responsiveness in providing cost-effective nonstop service and might mitigate the incentives for a more uneven development of service cited earlier.

This hypothesis suggests that disparities in route coverage between cities will grow during the early years of deregulation as carriers reallocate their route systems away from the evenly distributed, decentralized distribution that existed under regulation. However, as the returns from investments in new hub-and-spoke systems diminish, it would be expected that countervailing forces such as rising demand and declining costs would eventually offset this trend toward centralization, reducing the scope of the disparities between cities. An empirical approach for testing this hypothesis is presented next.

MEASURING THE CHANGING AVAILABILITY OF NONSTOP SERVICE

Because nonstop airline routes will not develop in even proportion to the number of destinations to which consumers wish to travel, the traditional measures of the effects of deregulation on a city's air services—flight departures from a city, airlines participating in the market, or daily seats provided—are incomplete. It is also necessary to consider how well a city's system of air routes fits the distribution of consumer destinations. When the quality of service in a city pair is viewed as a dichotomous variable, classified as either nonstop or less desirable connecting service, the probability that randomly selected travelers from a metropolitan area will find daily nonstop service to their intended destinations can be calculated. This measure, entitled "nonstop route coverage," can be thought of as the proportion of travelers from a metropolitan area for whom nonstop service is available.

The analysis begins with flight schedules published in late 1981 for travel in January 1982, the end of the national air traffic control crisis, which greatly constrained the development of airline routes. Before this date, the route system from the era of regulation remained largely intact, and airline hub development remained in a relatively embryonic stage (*10*). Moreover, the wave of consolidations, standardized pricing structures, and aggressive entry of low-cost operators had not yet taken place. By observing shifts in route coverage in 1-year increments from January 1982 to January 1987, a clear pattern in the effects of deregulation can be discerned.

Each of the 60 largest U.S. metropolitan areas is examined using a cross-sectional time-series econometric model. The first objective is to determine, as suggested by theory earlier, whether increased disparities in nonstop air service among cities have actually emerged under deregulation. Second, a more exploratory focus helps to develop a clearer understanding of how carriers use hubs to exploit the advantages of hub-and-spoke systems. In this second subsection the growing concentration of nonstop route coverage in hub cities at the outset of deregulation is explored and the changing significance of hubs across time is traced. Finally, a measure of the varying pricing opportunities facing operators of nonstop service is added to the model, helping to further explain the apparent inequities in nonstop service facing time-conscious travelers across metropolitan areas (see Appendix).

The 60 metropolitan areas were selected on the basis of 1984 Standard Metropolitan Statistical Area (SMSA) census data for the 48 contiguous states. Numerous technical adjustments were necessary to eliminate geographic factors that affect air service in ways not germane to the analysis (such as the construction of an airport location equidistant from two SMSAs). This process is described in greater detail in the Appendix.

Flight data on the itineraries of all nonstop flights from each of the SMSAs were taken from *Official Airline Guide* records and coupled with ridership forecasts made by the Boeing Commercial Airplane Company for all city pairs (*9*). For example, in 1987 the traffic forecasts are considered in 11,500 city pairs, whereas nonstop air service is found to be available in 1,043 pairs. These results were sorted by SMSA, and the probability that consumers will have access to nonstop service to their intended destinations was calculated and found to vary for 1987 from 0.122 (Scranton–Wilkes-Barre, Pennsylvania) to 0.981 (Dallas–Ft. Worth, Texas). The changing levels of route structure coverage for all 60 cities for each year studied are summarized in Table 1. Notice a high degree of variability between SMSAs functioning as major hubs, such as Minneapolis, St. Louis, and Pittsburgh, and less important air centers such as Indianapolis, Columbus, and Seattle.

Growing Disparities in Route Coverage

If deregulation has actually fostered a more uneven distribution of nonstop service across metropolitan areas, one would anticipate less association between a city's size and its route coverage under deregulation than under regulation. Thus, if population were used as an independent variable in predicting the route coverage of a particular city (or probability that nonstop service to the desired destination of a randomly selected passenger would be available), its predictive power should deteriorate over time. To assess the changing relationship between population and nonstop route coverage, the multiple-least-squares model shown in Equation 1 was used:

$$\log [Pr_{xy}/(1 - Pr_{xy})] = a + bPop_{xy} + cPop_{xy}^2 + dSEC_x + u \qquad (1)$$

The log-linear structure linearizes the slope of the dependent variable, which by definition was bounded between zero and 1. Pr_{xy} denotes the route coverage in city x in year y (or the probability that a consumer would have access to nonstop service to his intended destination in SMSA x in year y). Pop_{xy} and Pop_{xy}^2 are functions of the population of SMSA x in year y. SEC_x is a dummy variable used to account for extreme values in the data caused by situations in which route development was affected adversely by the proximity of a larger SMSA. The use of the polynomial term reflects the nonlinear relationship between population and route coverage.

Separate regressions were run for each year from 1982 to 1987. The results confirm that the relationship between a city's population and its level of route coverage initially worsened over the period (Figure 3). The model exhibits significantly declining predictive power during 3 of the 4 years between 1982 and 1986; the proportion of variance in route coverage explained by the model (R^2) declined by nearly 30 percent, from .381 to .274. (Only between 1983 and 1984 was there no significant change in predictive power.) In 1987 a significant reversal of this trend took place, with the proportion of variation explained rising to .340. These findings are consistent with the theory that, following deregulation, carriers restructured their route systems away from regulatory allocation to a system that more properly considered the economic advantages of more centralized operations described earlier. Traffic in many city pairs simply was too light to sustain nonstop service that was as cost-effective as hub service. Not until 1987 did evidence indicate that this trend had reversed. The low coefficients of variation are not surprising; differences in market size, pricing opportunities, length of haul, and proximity to hubs—factors shown to be critical in route development—have been ignored to illustrate these general disparities in route coverage between cities.

Although the association between population and route coverage declined between 1982 and 1986, this, of course, does not necessarily indicate that cities have less nonstop service under deregulation. The growing disparities in route coverage (i.e., statistical heteroscedasticity) among cities might have offset a general, aggregate rise in nonstop route coverage. To assess this possibility, the model was run to consider data from all 6 years simultaneously, with dummy variables to denote incremental, year-to-year changes. If deregulation stimulated route growth beyond that explicable through population growth, the dummy variable's coefficients should rise with the passage of time. However, the data indicate that this was not the case. Although the coefficients for the population and *SEC* variables remained significant at a 5 percent level, the dummy variables were not significant, suggesting that deregulation itself has not significantly changed overall route coverage. (Statistical interaction terms also proved not significant:

TABLE 1 AIRLINE ROUTE COVERAGE BY SMSA

SMSA	1982	1983	1984	1985	1986	1987
Albany	48.83	47.58	46.44	48.31	47.44	50.27
Allentown/Bethlham	37.10	36.21	37.60	34.67	34.05	33.49
Atlanta	95.08	94.79	92.25	94.83	95.17	95.20
Austin	57.28	56.67	56.97	65.30	70.57	69.31
Birmingham	37.65	29.10	28.78	35.57	35.10	31.12
Baltimore	66.93	73.14	74.59	71.04	69.69	72.41
Boston	84.59	85.31	84.31	82.77	83.54	85.27
Buffalo	72.66	77.75	76.26	69.73	66.19	68.75
Chicago	94.76	93.58	93.64	93.53	95.71	95.33
Cleveland	84.63	84.57	81.11	83.34	81.12	80.55
Charlotte	72.69	76.78	79.87	81.12	84.41	86.49
Columbus	67.43	75.69	65.55	60.25	64.99	58.05
Cincinnati	63.59	75.51	81.31	79.13	78.62	65.90
Dayton	52.53	50.50	56.12	55.93	64.67	65.90
Denver	80.58	86.70	87.73	88.26	88.78	87.28
Dallas/Ft. Worth	98.08	98.09	98.10	98.11	98.11	98.12
Detroit	85.83	85.64	86.41	85.02	83.64	87.54
Ft. Lauderdale	87.01	89.12	88.27	86.09	82.20	84.14
Grand Rapids	25.78	34.97	27.27	26.66	26.10	25.62
Greensboro	67.81	69.97	65.77	63.94	64.81	64.51
Hartford/Springfield	57.19	58.58	57.40	60.78	60.61	58.93
Houston	78.85	81.47	85.29	74.91	70.45	79.52
Indianapolis	61.94	61.91	58.64	54.69	61.60	72.22
Jacksonville	60.68	53.98	35.64	32.28	37.42	60.35
Kansas City	71.16	76.87	71.88	81.15	80.12	81.48
Los Angeles	88.72	86.00	84.73	81.91	90.67	90.76
Louisville	65.22	67.41	67.10	61.69	63.90	64.35
Memphis	70.39	75.39	76.02	74.71	75.89	80.03
Miami	88.75	88.51	88.71	88.65	87.74	89.55
Milwaukee	76.07	67.13	68.83	65.22	71.08	57.78
Minneapolis/St. Paul	80.85	81.88	81.55	83.74	84.62	85.41
Nashville	61.11	57.36	54.52	55.32	55.57	62.16
New Orleans	73.39	76.02	76.42	74.48	74.43	72.88
New York City	83.36	84.70	83.26	83.17	83.00	84.92
Norfolk	68.48	65.05	68.25	71.24	67.34	67.37
Oakland	28.51	28.27	29.79	24.29	30.56	27.73
Oklahoma City	51.38	50.37	51.68	31.14	29.68	31.69
Orlando	83.97	83.33	84.22	85.99	84.53	85.69
Philadelphia	73.21	74.22	72.14	76.12	76.13	78.44
Phoenix	71.86	67.64	63.06	71.98	73.00	72.95
Pittsburgh	92.58	91.16	93.77	91.92	91.87	91.88
Portland	61.60	61.15	63.50	67.37	67.08	71.49
Providence	58.97	46.70	57.27	53.68	53.38	53.47
Raleigh/Durham	69.47	66.75	67.00	66.98	68.82	66.90
Richmond	62.87	83.82	63.97	64.11	64.26	64.42
Rochester.	71.79	71.40	72.98	68.72	68.52	66.19
San Diego	63.55	63.26	63.58	65.27	65.25	66.84
San Antonio	44.60	33.78	42.86	44.64	44.65	46.30
Scranton/Wilkes-Barre	21.21	20.21	19.64	19.16	18.77	12.26
Sacramento	65.83	65.11	64.46	68.95	68.45	67.99
Salt Lake City	66.44	66.09	70.75	74.50	72.25	75.65
San Francisco	65.97	65.64	62.59	59.90	59.14	61.12
San Jose	70.31	69.87	69.51	69.20	70.00	69.04
Seattle	64.42	63.71	58.92	59.79	62.35	63.76
St. Louis	97.29	99.03	94.06	94.78	99.87	95.73
Syracuse	69.02	74.95	76.50	73.62	74.20	70.95
Tampa/St. Petersburg	89.77	90.08	87.37	84.77	84.66	84.13
Toledo	49.15	49.99	40.60	40.36	30.76	30.55
Tulsa	32.20	53.06	55.68	53.80	28.83	28.87
Washington	79.01	80.96	80.75	80.59	80.44	80.31

NOTE: Figures multiplied by 100 to simplify interpretation.

changes in route coverage across time apparently were not highly dependent on SMSA population.) Indeed, although route coverage rose from an average of 0.65 to 0.69 over the period, this improvement only kept pace with the rise in SMSA population. The implication is that because so much of the route development apparently has centered around hub systems, consumers in zero-growth cities are no more likely to have available nonstop service to their intended destinations than they did 7 years ago, but increased variances among metropolitan areas evolved. To the extent that demand is proportional to city population, it is concluded that time-conscious consumers in certain cities are enjoying disproportionate gains—and losses—in route coverage.

Conclusions cannot be readily drawn about the reversal of this trend in 1987. The hypothesis suggests that, at this point, the incentives to concentrate operations at hubs must have been

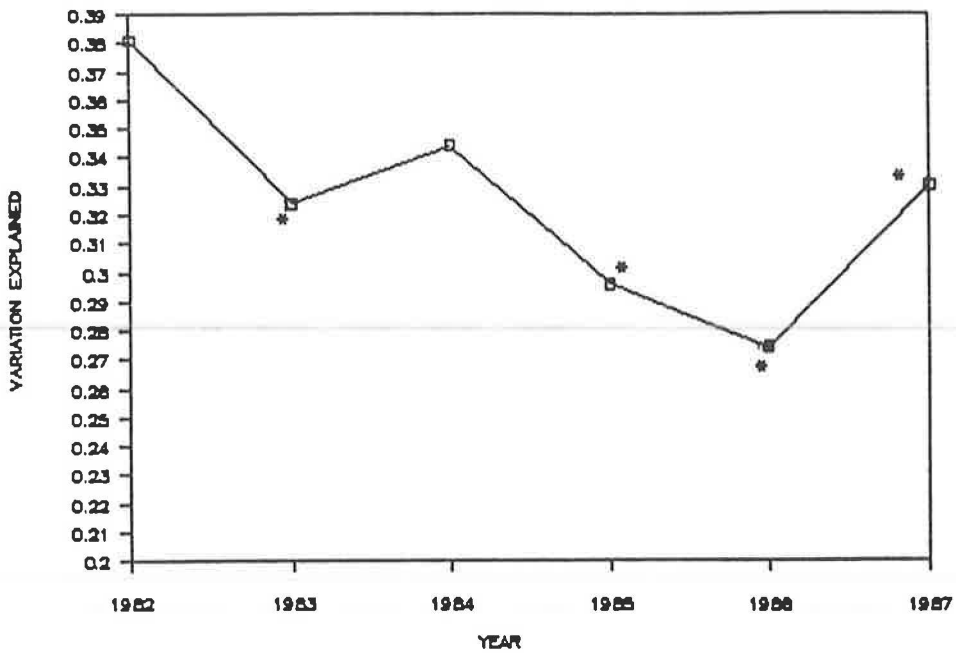

FIGURE 3 Proportion of variation explained by SMSA population. [Asterisk denotes statistically significant change from prior year (all variables significant at 5 percent level).]

offset by the incentives to decentralize made possible by rising demand, declining costs, or other factors. Although the model is unable to control for these exogenous factors, it suggests that after a half-decade of growing service disparities, all 60 metropolitan areas now appear to be participating in the establishment of new nonstop service.

Evolution of Hub Systems

Incorporating the status of metropolitan areas as privately operated airline hubs for air carriers improves the predictive capabilities of the model. The extent to which routes are increasingly allocated to hub systems—after the population of the metropolitan area has been fully considered—illustrates the scope of the disparities among metropolitan areas and provides a barometer of how incentives to centralize operations affect the development of routes. As hubs grow in importance, they bestow disproportionately high benefits to time-conscious consumers in those cities; as their importance declines, their ability to bestow more benefits than nonhub cities lessens.

Dummy variables designating a city's status as a hub were added to the model. Hub status, which frequently changed from year to year as airlines invested in or divested themselves of hub facilities, is presented in Table 2. Variable HB_{xy} denotes an SMSA designation as a minor ("regional") hub in year *y*. Variable SH_{xy} reflects SMSA *x*'s status as a major ("super") hub in year *y*. [The definition of a hub here is considerably different from the CAB definition, and was based on the number of routes to the hub operated by an individual firm (see Appendix).] Of the 60 SMSAs in the study, 23 functioned as hubs during at least 1 year of the period; three grew from "minor" to "major" hub status over the period. Only one SMSA—Cleveland, Ohio—lost its status as a hub during this time period, whereas eight others gained such status. For example, Nashville, Tennessee, did not serve as a hub until 1986 when American Airlines selected the city as a minor hub.

Incorporating hub status into the model helps explain the growing disparities in nonstop route coverage between metropolitan areas. The model indicates that, although there might have been a declining association between route coverage and population, SMSA hub status grew markedly more important. Major-hub status was highly significant throughout the model (Table 3), bolstering route coverage to a city in each of the 6 years studied. The proportion of variance explained between cities increased by 50 percent (from 0.4177 to 0.6206) with the addition of the hub variables.

Equally significant is the growing magnitude of the coefficients of the major-hub variables (*SH*) (from 1.396 in 1982 to 1.502 in 1985, and subsequently to 2.027 in 1986—changes significant at the 5 percent level). This is consistent with the popular prevailing belief that deregulation exacerbated the differences between the "winners" and "losers" in the competition for airline routes. However, the coefficients illustrate the same reversal for the year 1987 observed in the previous section, declining significantly between 1986 and 1987 (from 2.027 to 1.619, respectively). Why did this occur? With the growing market for air services, smaller hubs or nonstop operators appear to be achieving the scale of operation necessary to compete with major hubs on many routes, reducing the relative advantages of serving as a major hub.

The steadily increasing importance of the minor-hub variable (HB_{xy}) reinforces this hypothesis. During the early years of deregulation, the economic advantages bestowed on time-conscious consumers in cities serving as minor hubs were found to be largely inconsequential. This appears to be attributable to the higher degree of multicollinearity between minor-hub status and population, and the regional focus of most minor hubs during the early years of deregulation. However, at a 10 percent level of significance, minor-hub status (*HB*) became

TABLE 2 AIRLINE HUB STATUS

	Minor Hub Status						*Major Hub Status*						*Private Operator*[a]
	82	83	84	85	86	87	82	83	84	85	86	87	
Atlanta	0	0	0	0	0	0	1	1	1	1	1	1	Delta/Eastern
Baltimore	0	0	0	0	1	1	0	0	0	0	0	0	Piedmont
Boston	0	0	0	0	1	1	0	0	0	0	0	0	Delta
Chicago	0	0	0	0	0	0	1	1	1	1	1	1	United/American
Cincinnati	0	0	0	0	1	1	0	0	0	0	0	0	Delta
Cleveland	1	1	1	0	0	0	0	0	0	0	0	0	United
Charlotte	1	1	1	1	1	0	0	0	0	0	0	1	Piedmont
Dayton	0	0	0	1	1	1	0	0	0	0	0	0	Piedmont
Denver	0	0	0	0	0	0	1	1	1	1	1	1	United/Continental (Frontier)
Dallas	0	0	0	0	0	0	1	1	1	1	1	1	American/Delta
Detroit	1	1	1	1	1	1	0	0	0	0	0	1	Northwest
Houston	1	1	1	1	0	0	0	0	0	0	1	1	Continental
Kansas City	1	1	1	1	1	1	0	0	0	0	0	0	TWA/Eastern
Memphis	1	1	1	1	1	1	0	0	0	0	0	1	Republic
Minneapolis	0	0	0	0	0	0	1	1	1	1	1	1	Northwest (Republic)
Nashville	0	0	0	0	0	1	0	0	0	0	0	0	American
New York	0	0	0	1	1	1	0	0	0	0	0	0	Continental (People Express)
Phoenix	0	0	0	1	1	1	0	0	0	0	0	0	America West
Philadelphia	0	0	0	0	1	1	0	0	0	0	0	0	USAir
Pittsburgh	1	1	0	0	0	0	0	0	1	1	1	1	USAir
San Fran.	1	1	1	1	1	1	0	0	0	0	0	0	United/Pacific Southwest
Salt Lake C.	1	1	1	1	1	1	0	0	0	0	0	0	Delta (Western)
St. Louis	0	0	0	0	0	0	1	1	1	1	1	1	Northwest/Republic
Washington	0	0	0	1	1	1	0	0	0	0	0	0	Continental (NY Air)/United

[a]Names of hub operator before airline merger or acquisition shown in parentheses.

increasingly important in each of the final 4 years of the study, reaching its extreme level of significance in 1987.

In light of the general hypotheses outlined in the previous section, it has been shown that as the market expands, minor hubs have a higher propensity to develop new routes—previously constrained by lumpiness in supply—than larger hubs. One would expect minor hubs to become competitive initially on shorter routes where economies of aircraft size are less severe; only as the market further expands can they be expected to compete on longer routes where the operation of larger aircraft is the least-cost scale of operation. A similar pattern should ultimately emerge in the development of nonstop flights between cities that are not hubs.

Hubs most sheltered from this trend toward decentralization are those serving city pairs with the greatest lumpiness in supplying nonstop service relative to the volume of traffic handled. (One might expect predominantly high-density and short-haul hub operations, such as Pittsburgh, to be more vulnerable to new nonstop service than principally longer-haul hub operations such as St. Louis or Dallas–Ft. Worth.) The model discussed earlier is unable to confirm or deny these propositions. However, it serves as a useful foundation upon which additional research will be conducted. Differences in average length of haul, passenger volume, and proximity to hubs undoubtedly explain much of the remaining variation in nonstop route coverage between cities.

Role of Price in Route Development

Carriers deviate from cost-minimizing transportation methods such as the hub-and-spoke system for a variety of reasons, ranging from competitive pressures to fleet considerations and capital constraints; the significance of these factors varies widely among carriers and regions. However, at least one factor can be expected to remain constant in its effect on route development and add considerable explanatory power to the model—the opportunity to demand higher prices for nonstop services. On many lightly traveled routes, nonstop service is less cost-effective than hub service but offers strong advantages with respect to passenger demand. Fare premiums of up to $100 are not uncommon for the convenience of nonstop service, often enabling carriers to profitably provide such service in city pairs that could otherwise be served only with connecting flights. It is expected that (a) certain cities will

TABLE 3 GROWTH OF HUB-AND-SPOKE SYSTEMS

$\log(Pr_{xy}/1-Pr_{xy}) = a+bPOP+bPOPSQ+cSEC+dHB_{82}...+eHB_{87}+f\,SH_{82}...+g\,SH_{87}+u$

$R^2 = 62.06$

descriptive variables:	*intercept*	*POP*	*POPSQ*	*SEC*
coefficient:	0.1890	0.00035	-1.639×10^{-08}	-0.8512
std error:	0.0729	0.0000424	2.671×10^{-09}	0.1158
prob > t:	0.0099	0.001	0.001	0.0001

major hub variables:	SH_{82}	SH_{83}	SH_{84}	SH_{85}	SH_{86}	SH_{87}
coefficient:	1.3955	1.5597	1.5183	1.5024	2.0268	1.6194
std error:	0.2509	0.2376	0.2522	0.2524	0.2695	0.2695
prob > t:	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

minor hub variables:	HB_{82}	HB_{83}	HB_{84}	HB_{85}	HB_{86}	HB_{87}
coefficient:	0.3099	0.1941	0.3939	0.3582	0.3556	0.4117
std error:	0.2651	0.2353	0.2356	0.2051	0.1846	0.1847
prob > t:	0.2431	0.4100	0.0955	0.0817	0.0550	0.0304

develop superior nonstop routes relative to other, similar-sized cities because market conditions permit substantial premiums to be charged, and (b) the degree of the price difference will partially reflect the extent to which nonstop service faces higher costs than hub service.

Factors affecting an airline's ability to offset the higher costs of nonstop service with higher fares include the proximity of competing airports, business climate, geographic location, and ground transportation alternatives. For example, most carriers have found it uneconomical to charge more for flights from Toledo, Ohio, than for service offered from nearby Detroit, a highly competitive market, because of the convenience of driving between the cities. In many nonindustrialized markets, soft levels of business traffic similarly prohibit premium charges for nonstop service. These types of considerations can profoundly affect a carrier's decision to establish new nonstop routes. Previous research underscores this observation (*11*).

Only the most time conscious of passengers will willingly pay such fare premiums. One study estimates that premiums can be extracted from only about 30 percent of the market (*12*). Business, emergency, and government travelers generally are considerably more time sensitive than their pleasure-oriented counterparts, and are among those willing to pay for the convenience of nonstop service. Because these passengers make advance reservations an average of less than 4 days in advance compared with 11 days ahead for pleasure-oriented passengers, the unrestricted fares typical of this portion of the market are used exclusively in the analysis (*12*). Excursion fares, fares with cancellation penalties, and those with special restrictions are excluded (fares with only capacity control restrictions are included).

Matching scheduling information from *Official Airline Guide* records with fare information from Airline Tariff Publishers Company allows measurement of the differences in nonstop and one-stop fares on routes from each of the 60 metropolitan areas as of July 1, 1987. For each of the 1,043 nonstop segments, the lowest nonstop unrestricted fare offered by a carrier with nonstop service was compared with the lowest one-stop unrestricted fare. The ratio of nonstop to one-stop fares was calculated for each of the city pairs in which nonstop service is available, and the results were sorted by city. For example, during July 1987, the lowest nonstop unrestricted fare between Chicago, Illinois, and Seattle, Washington, was $325 compared with the lowest one-stop fare (via Denver) of $179—an average fare premium of 82 percent. Nonstop premiums are found to vary substantially between cities (Table 4, Column 1), ranging from virtually no premium in Toledo to 99.6 percent in Chicago.

A significantly positive correlation between city size and price difference suggests that a strong business market is essential for maintenance of fare premiums. Furthermore, a random sample of 100 of these city pairs confirms that nonstop fare premiums become increasingly pervasive as the expected cost differences between nonstop and hub service increase. For city pairs separated by more than 1,000 mi, the average premium was 58 percent compared with 42 percent for city pairs separated by less than 1,000 mi.

The regression equation described earlier was used to assess the explanatory power of the price variable ($PRICE_x$) on route coverage (Table 5) (the SEC_x variable was deleted due to multicollinearity problems). As shown in Table 5, price differences between nonstop service and one-stop service are

TABLE 4 STATUS OF SMSA NONSTOP SERVICE DURING 1987

SMSA	Average Fare Premium	# Cities Served Nonstop	Infrastructure Status
Albany	41.4%	12	below
Allentown/Bethlham	25.6	8	below
Atlanta	86.6	57	signif. above
Austin	33.1	3	below
Baltimore	68.2	38	above
Birmingham	22.5	11	signif. below
Boston	57.0	39	signif. above
Buffalo	21.7	15	below
Chicago	99.6	59	signif. above
Cleveland	76.2	34	above
Charlotte	50.4	38	signif. above
Columbus	59.8	19	signif. below
Cincinnati	51.3	34	above
Dayton	38.1	29	above
Denver	72.4	42	signif. above
Dallas/Ft. Worth	71.8	54	signif. above
Detroit	70.1	44	above
Ft. Lauderdale	68.0	26	above
Grand Rapids	44.4	11	signif. below
Greensboro	28.9	13	below
Hartford/Springfield	94.7	20	below
Houston	85.9	45	above
Indianapolis	93.3	28	above
Jacksonville	28.9	13	below
Kansas City	21.1	32	signif. above
Los Angeles	29.6	39	above
Louisville	53.2	20	below
Memphis	29.6	32	below
Miami	97.1	32	signif. above
Milwaukee	57.0	22	below
Minneapolis/St. Paul	86.5	44	signif. above
Nashville	81.2	29	below
New Orleans	99.0	25	signif. below
New York City	52.1	52	below
Norfolk	38.6	16	signif. below
Oakland	17.6	9	signif. below
Oklahoma City	34.1	14	signif. below
Orlando	97.5	34	above
Philadelphia	32.0	38	below
Phoenix	87.8	29	above
Pittsburgh	81.8	46	signif. above
Portland	41.7	16	signif. below
Providence	48.0	9	below
Raleigh/Durham	58.5	17	below
Richmond	52.6	12	below
Rochester˙	26.5	13	below
San Antonio	38.6	14	below
San Diego	90.7	20	signif. below
San Francisco	98.8	32	below
San Jose	52.6	14	above
Salt Lake City	42.9	24	above
Sacramento	12.4	14	below
Scranton/Wilkes-Barre	0.0	4	signif. below
Seattle	69.8	15	below
St. Louis	64.5	43	signif. below
Syracuse	39.1	17	above
Tampa/St. Petersburg	60.5	30	above
Toledo	0.0	9	signif. below
Tulsa	69.7	12	signif. below
Washington	50.0	37	above

statistically significant in explaining disparities in route coverage during 1987. The proportion of variation explained rose marginally from .53 to .57 with the addition of the price variable to the population and hub variables. All other variables remained highly significant except minor-hub status (*HB*), the significance of which was only marginal. Although high standard errors limit interpretation, markets offering carriers the greatest opportunities for premium-price nonstop service appear to be better able to combat the tendencies that encourage carriers to provide hub-only service.

Critics of airline pricing under deregulation often dismiss fare premiums for nonstop service as an undesirable side effect of monopoly power. The methodology presented here does not allow this perspective to be fully discounted, but it provides convincing support for an alternative view that the ability to maintain fare premiums is often a necessary condition for the

TABLE 5 ROLE OF FARE PREMIUMS IN ROUTE DEVELOPMENT

model: $\log(Pr/1\text{-}Pr) = a + b\,POP_{87} + c\,POPSQ_{87} + d\,HB_{87} + e\,SH_{87} + f\,PRICE_{87} + u$

	Intercept	*POP*	*POPSQ*	HB_{87}	SH_{87}	*PRICE*
coefficient:	-0.9370	0.00041	-2.10065×10^{-08}	0.3742	1.6951	0.5751
std error:	0.3917	0.00012	7.1239×10^{-09}	0.2862	0.2895	0.2416
prob > t:	0.0203	0.0011	0.0047	0.1966	0.0005	0.0208

$R^2 = 0.5718$

development of nonstop routes. These conclusions, of course, must be tempered by the many aspects of airline pricing not considered in this exploratory model.

SUMMARY AND CONCLUSIONS

Considering the review of airline schedules from America's 60 largest population centers, it is clear that deregulation has unleashed powerful incentives for carriers to concentrate operations at centralized hub facilities, which in turn initially encourages widening disparities in the establishment and development of routes. These disparities were postulated to be partly a result of economies of aircraft size, a factor rendering nonstop air service analogous to the microeconomic "lumpy good," and uneconomical compared with hub service in most city determinants of the lumpiness problem. More recent trends suggest that other factors are lessening this phenomenon, encouraging carriers to move away from these centralized hub operations—a reversal attributed to rising demand, falling costs, and varying pricing opportunities.

Throughout the study, it has been speculated that the ramifications of the disparities depend on the time sensitivity of the consumer. A simple comparison of each city's level of route coverage with that of other similarly sized cities provides an interesting perspective of how such consumers have fared. Column 3 of Table 4 indicates the number of cities served by nonstop flights from each of the 60 largest areas studied. Column 4 illustrates how successfully this route network is providing nonstop service to these cities relative to other similarly sized cities. Entries in this column indicate whether a city's route coverage is significantly higher or lower than that expected from its population. (Cities designated as having significantly higher or significantly lower levels of route coverage differ by at least one standard deviation from their expected levels.) It will come as no great surprise to many that time-conscious consumers in cities such as Pittsburgh, St. Louis, and Charlotte fare disproportionately well, whereas those in Columbus, San Antonio, and Birmingham have much poorer access to nonstop service.

Differences in air transportation routes have important and largely unrecognized implications for the welfare of urban economies—factors beyond the scope of the paper. For consumers, poorly developed route systems are costly in terms of lost time, inconvenience, and fewer flight alternatives. Additional research is needed to quantify the economic impacts of these disparities. However, although certain cities and consumers might be found to suffer, it is important to reassert that these disparities do not necessarily reflect suboptimal allocations of resources. Hub-and-spoke systems reflect, among other factors, carriers' efforts to operate efficiently sized aircraft relative to the market's length of haul; carriers will deviate from this least-cost arrangement only to the extent that consumers are willing to pay premium prices for the convenience of nonstop service.

Accordingly, the "inequities" fostered by deregulation must also be put into the proper context. A compelling argument can be made that the geographic location of a city is itself a scarce resource, entitling that city to any rents from its utilization, such as its function as an airline hub. Chicago and St. Louis, for instance, have historically exploited their preferential location by functioning as domestic transportation hubs. Moreover, to the extent that hub locations are selected arbitrarily among numerous equally attractive substitute sites, competitive bidding systems emerge as cities seek to acquire the external benefits of hub status. Dayton, Ohio; Nashville, Tennessee; and Raleigh, North Carolina—cities in regions where many attractive alternative hub locations are available—are among the more recent winners of this competition for new air routes because they have offered attractive financial packages to incoming carriers. Although one might question the efficacy of this tactic, it is certainly worthy of increased analytic attention.

The quality of air service available to time-conscious consumers must ultimately involve such factors as flight frequency, reliability, and seat availability, which are beyond the scope of the exploratory model used in the study. Moreover, factors such as local economic conditions, landing and takeoff "slot" controls, technological advancement, and user fees were not considered. These factors were deliberately reserved for future analysis to help build a more solid conceptual framework upon which such research can proceed. The findings suggest that, even without considering these added complexities, disparities in routes among cities are a paradoxical and inevitable result of open market competition.

APPENDIX

The daily number of flights to all destinations in the contiguous 48 states was programmatically summarized for each city by using *Official Airline Guide* data. Four frequencies per week were necessary for a city pair to qualify as having nonstop service. Multiple airports were considered for Houston; Chicago; New York; Washington, D.C.; Los Angeles; and Dallas. The following SMSAs were combined because carriers consider them "co-terminals" (common terminals) for ticketing and scheduling purposes: (a) Chicago, Illinois, and Gary-Hammond-Whiting, Indiana; (b) New York and Suffolk in New York State; and (c) Los Angeles, Ontario, and Orange County in California. Baltimore and Newark were maintained as separate SMSAs; even their airport facilities are commonly used by residents of neighboring SMSAs. The San Francisco Bay Area SMSA—San Francisco, Oakland, and San Jose—was also maintained separately.

Ridership forecasts published by the Boeing Commercial Airplane Company were used. Actual ridership statistics compiled by the CAB were also available. However, they do not provide unbiased estimates of the actual size of the market. As more supply is added to a market, ridership systematically grows because of factors such as added consumer convenience and increased price competition. The Boeing forecasts, conducted in 1981, are not subject to this problem and are a better barometer of the actual market size.

The *SEC* dummy variable ("secondary city diversion") was set equal to one in nine of the SMSAs: Toledo (60 mi to Detroit), Baltimore (45 mi to Washington, D.C.), Milwaukee (70 mi to Chicago), San Jose and Oakland (both less than 1 hr by car to San Francisco), Providence (55 mi to Boston), and Scranton (75 mi to Newark).

To qualify as a minor hub, a city must have a single, private firm offer nonstop service to a minimum of 17 destinations. A major hub requires service to a minimum of 35 nonstop destinations from a city. Services offered by "partner" carriers (generally commuter operators) were excluded for this purpose.

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The Late, Late Show: How a Priority Flight System Can Reduce the Cost of Air Traffic Delays

CHRISTOPHER J. MAYER

Air traffic delays, although not new, have become increasingly worse in the 1980s and are now estimated to cost over $2 billion a year. A system of using flight priorities to make more predictable flight schedules is suggested, a system that could save consumers tens of millions of hours in travel time and produce millions more on-time arrivals. Such a system would allow consumers to choose among different priorities of service, such as express flights versus regular flights, with fare differences reflecting the differences in flight time. Airlines would be better able to use their planes, gates, and crews because flight schedules would be more predictable. All of this would occur without arbitrary restrictions on capacity and in a system that would encourage airlines to compete with on-time performance. A repeated auction could be used to distribute the priorities competitively and efficiently. Reducing the ticket tax by the revenue raised in this auction would leave average ticket prices unchanged. This research simulates how such a system would operate at Chicago's O'Hare Airport, using several different priority plans. With this system delays at O'Hare alone can be cut by 3.5 million hr a year. This figure is a lower bound for savings, because it does not include the savings to airlines or other related businesses and does not account for benefits such as a more predictable system. Although additional research is certainly required, a priority system seems to hold significant potential for alleviating much of the cost of air traffic congestion.

"The Late, Late Show—Airline delays are bad—and they are going to get worse," according to the *U.S. News and World Report* (*1*). A *Wall Street Journal* headline read, "Hurry Up and Wait: Airline Delays Bring Gripes—And Lots of Excuses" (2). The newspaper further reported, "Cosmetic Change: Airlines' Pledge To Reduce Delays May Be Illusory" (*3*). Although travel delays are not new, the dramatic increase in their number has attracted much media attention. In this paper a priority system is proposed that would make delays more predictable and allow consumers to choose among several probabilities of delay as they now choose between levels of service (i.e., first class, business class, or coach class). This method will also have the potential to save consumers tens of millions of travel hours, allow airlines to have better control of their schedules at a lower cost per seat, and remove significant public pressure from the FAA.

The history of the delay problem is often traced to two events: airline deregulation in the late 1970s and the strike by air traffic controllers in 1981. Deregulation removed flight routes from the government's control, allowing airlines almost complete freedom to schedule flights. The air traffic controllers strike cut back on the number of adequately trained controllers and, some claim, still affects the capacity of the air traffic control system. Responsibility for the delays that followed these two events has been hotly debated. Some blame the FAA for not rehiring the fired controllers. The FAA claims that the airlines are to blame because they bunch flights, creating unrealistic schedules that exceed capacity at many airports. The airlines often blame the public for all wanting to fly at the same time and claim that any airline that unilaterally rescheduled flights would commit competitive suicide.

Meanwhile the delay problem continues to worsen, at an increasing cost to all involved. Businessmen and frequent flyers spend more and more time traveling and less time working. The airlines' increased use of the hub-and-spoke system has caused many more missed connections and unplanned overnight stays. Delays raise the labor costs of airlines and cause them to use their capital inefficiently (e.g., for gate space and aircraft). The Air Transport Association (ATA), a trade association for the major airlines, estimated that these annual costs exceed $2 billion.

The U.S. Department of Transportation (DOT) has recently forced airlines at four major airports to amend their timetables to reduce flight delays. [By April 1, 1988, flights at the four airports must operate within 30 min of published schedules at least 75 percent of the time (*4*).] This change, as Congressman Pete DeFazio noted, makes schedules more predictable for the consumer, but has little substance (*3*). Flights do not arrive more quickly than before this ruling; airlines simply add more time to the schedules of existing flights. Without structural or procedural changes in the way the air traffic control system operates, congestion will continue and air travel will still be erratic and time-consuming.

Many people have proposed other solutions to the current problem. Some have recommended applying "classical" economics to the problem (i.e., treating the delays as excess demand for scarce resources). This reasoning led to the system of slot control that the FAA is testing at four airports—National Airport in Washington, D.C.; O'Hare in Chicago; and Kennedy and LaGuardia in New York. Slot control, however, has not managed to reduce delays greatly at these airports; they are still among the most congested in the system. (Furthermore, no one knows what the right number of slots is for any airport.) Other

Department of Economics, Massachusetts Institute of Technology, 50 Memorial Drive, Cambridge, Mass. 02139.

"market" solutions range from recommendations to raise the landing fees during congested times to the ATA recommendation to make the FAA a private organization. (The ATA proposal presumes that a private FAA would be free of bureaucratic restraints and would use market mechanisms and greater investment to create a more efficient air traffic control system.)

Others have concluded that deregulation has failed and that regulations are necessary. Currently proposed bills in Congress would require all airlines to publicize various types of service information and would fine airlines that have "unrealistic" schedules. Still others support the current DOT policy that gives airlines exemption from antitrust laws to coordinate their schedules and eliminate the bunching that accounts for many delays.

The third class of solutions would increase the capacity of the system. Congress is now releasing the funds in the Airport Trust Fund to build newer and larger airports, hire more air traffic controllers, and modernize the whole system. Some have suggested that Congress spend even more. A few believe that some current FAA safety margins are too restrictive and that changing the safety margins would increase the capacity of the air traffic control system.

When the problem of delays is considered, however, the optimal solution should address many concerns. Clearly safety should be protected with any proposal. The ideal solution should also produce socially optimal results and, if possible, benefit all parties involved. Competition must also be preserved. Of course, the solution should be politically feasible. Finally, some short-term benefit (i.e., some immediate relief from delays) is very important.

Many of the earlier solutions fell short of this ideal. The market solutions, as a group, certainly have potential for social gains, but are often politically infeasible, potentially noncompetitive, and too complicated to be realistic. (For example, an optimal landing fee to relieve congestion was proposed that would change depending on the weather.) Reregulation also has its problems. It could likely restrict competition, raise fares, and negate some of the social gains made from deregulation. Increasing capacity would certainly help to solve the delay problem, but is a long-term venture that is being held up because of budget constraints. Even without budget constraints, there is no good way to determine what the optimal investment in the air traffic control system should be. Finally, there is often local opposition to expansion and much political opposition to rehiring the fired air traffic controllers.

A NEW IDEA: ATTACH PRIORITIES TO FLIGHTS

In this paper a very different strategy to attack the delay problem is analyzed: attaching priorities to flights. Although this concept carries its own potential implementation problems, which will be addressed later, these problems appear to be solvable. For now, the more fundamental questions will be discussed: how might such a plan work and what are its potential gains?

A system of priorities is a market-based alternative to reregulation of the airline industry. It creates more carefully defined property rights, whereas the current system creates only ambiguous ones. A landing slot carries the right to land at an airport—a priority gives the additional right of landing before other users of lower priority. Indeed, inefficient congestion could not occur if a fully defined system of property rights existed, because market transactions would readily eliminate undesirable congestion.

How the Priority System Would Function

Currently all flights are treated equally. A fully loaded 747 is given the same probability of delay as a partly filled 737 with one-tenth the number of passengers, even though the costs of delaying the former greatly exceed the costs of delaying the latter. A system of priorities could allow airlines to separate travelers according to the value of their time, putting those with a high value of time (e.g., businessmen or other frequent fliers) on express flights and those with a lower value of time (e.g., vacationers) on regular flights. As odd as this might seem, it is similar to the structure of train service in Japan, Italy, and France, where travelers pay a premium for express service. American Airlines Chairman Robert Crandall has publicly advocated such a system.

A system of priorities allows the air traffic control system to differentiate among aircraft. This would not necessarily mean that larger aircraft would always have priority over smaller aircraft. Highest priorities should go to the most valuable users. As will be discussed later, an auction would provide an economically efficient way to distribute priorities to the most valuable users of an airport.

In addition, a system of priorities would potentially allow airlines to reduce their per-seat costs. For example, larger aircraft could be used on the express routes, so these aircraft would receive fewer delays and be used for more flights. Because express flights with larger, more expensive crews would receive fewer delays, labor costs would also fall. These gains would result in lower overall ticket prices.

How the FAA Handles Congestion: Central Flow Control

An brief explanation of how the FAA deals with air traffic congestion will also show that the priority system proposed is very compatible with current operating procedure and would not require a large-scale retraining of controllers. The FAA Central Flow Control Office in Washington, D.C., regulates congestion throughout the country. Initially, flow control was created to decrease the fuel costs of airplanes flying in lengthy holding patterns while waiting to land. Since then, safety and increased congestion have further supported the need for flow control, by which airport congestion is anticipated and demand is regulated by delaying planes from taking off until there is space for them to land.

Flow control accomplishes this by using both computers and staff. There is always a weather forecaster on site to help predict where and when the weather will constrain capacity. The controllers in flow control then discuss these forecasts with both local and regional air traffic controllers as well as with airline officials to get a good estimate of the future capacity at the target airport. This is usually done 4 hr before the expected congestion. Then the controller enters this estimate into a computer and runs a program to determine gate holds. This program looks at the intended arrival time of all scheduled service at the target airport and in an unbiased, random fashion delays the departure time of some aircraft to give an even flow of traffic into the airport. This controlled flow also ensures that plans will have minimal airborne holds before landing.

It is important to note that these programs are frequently run when airports have perfectly clear weather, because flight bunching causes everyday congestion. The flow control mechanisms are unpredictable and uncontrollable, so neither the airlines nor the public has advance warning about which flights will be delayed. Adding a system of priorities would increase the information to all involved parties. It would require only a minimal change in the software to add priority as another parameter in the flow-control program.

A priority system would only apply to aircraft before they take off. Some have suggested that the system continue while flights are in the air. This is infeasible because it would require retraining air traffic controllers at a time when there are not enough of them. Treating aircraft differently in the air could also pose a severe safety hazard.

SIMULATION OF AIRPORT WITH PRIORITY SYSTEM: 47 DAYS AT O'HARE

An important question is, How might such a system function and how would it compare with the current operating system? A computer simulation has been devised to help understand how such a system might work and to help predict any social gains that might be realized. The simulation was designed to test a priority system at a single airport using actual flight data and weather conditions. Chicago's O'Hare Airport was chosen for several important reasons. First, it is an example of a fully saturated airport that, even with slot control, has serious congestion problems and thus has potential for significant improvement. Next, very accurate weather and landing data are available that show the actual constraints on capacity by hour for 47 days during the first 6 months of 1987. Finally, O'Hare has been closely studied by FAA to determine the causes of delays there.

How the Simulation Works

The simulation does not provide minute-to-minute accuracy, because such a system would be too precise to be realistic. Instead it looks at the capacity and scheduling at O'Hare in 15-min intervals, dealing with a 14-hr "window" of flights from 7:00 a.m. to 9:00 p.m. The simulation also assumes that there are no cancellations or mechanical delays and that all flights are able to leave at their appointed times.

For example, assume that between 9:00 and 9:14 a.m. 30 flights are scheduled to arrive at O'Hare, but there is capacity for only 25 flights. Assume that these flights have the following priorities attached to them: 5 priority-one flights, 7 priority-two flights, 14 priority-three flights, and 4 priority-four flights. The simulation would clear all priority-one and -two flights to land. Priority-four flights would all be delayed 15 min and placed in the 9:15–9:29 a.m. time slot. One of the priority-three flights would be randomly chosen to be delayed with the priority-four flights; the rest would be cleared to land. The delayed flights in the new time slot would be treated as other flights of the same priority in that slot. (Later different plans will be discussed to determine whether flights should be given a higher priority after a certain amount of delay.)

This simulation, although simple, is not as unrealistic as it might seem. Adding flight cancellations, for example, should not change the results much. [Even Continental Airlines, considered by some to be the most unpredictable airline, cancels about 1 percent of its flights (5).] Small departure or mechanical delays should also have little effect on accuracy because the simulation uses 15-min slots. Finally, it is recognized that scheduled arrival times refer to arrival at the gate, not the runway. However, one could simply subtract 5 or 10 min from the arrival time to account for taxiing time and not disturb the results. Certainly the simulation does not assess how the priority system would affect the operation of the whole air traffic control network instead of a single airport. It will, however, give some idea of the potential gains that could be realized systemwide.

The Current System

First, a simulation was made of the delay system that is currently in use in flow control. All flights were given the same priority and when congestion occurred, flights were randomly delayed. This resulted in a mean delay time of 9.92 min a flight. (The mean delay time is the average delay per flight. The simulation, however, only gives delays in 15-min increments. Some flights receive no delays, whereas others are delayed in 15-min increments.) Figure 1 gives the distribution of those delays; 25.7 percent of all flights received a delay of at least 15 min. Only 13 percent of the flights received a delay of more than 30 min and about 0.5 percent of the flights received a delay of more than 3 hr.

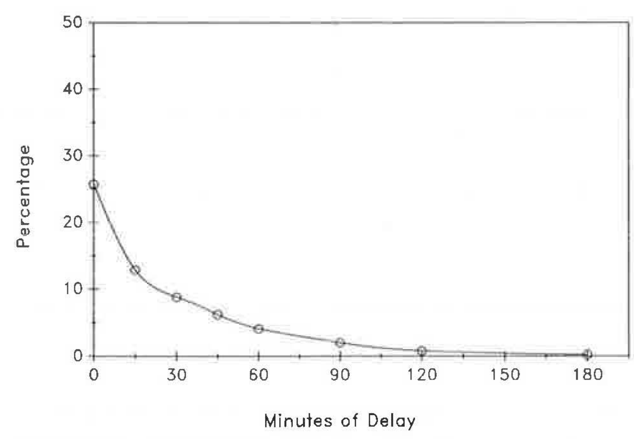

FIGURE 1 Percentage of flights with delays exceeding *X* min, current system.

FAA figures show that in 1986, flights at O'Hare were actually delayed an average of 11.34 min each. Thus the simulation seems to somewhat underestimate delays at O'Hare. This is expected because the simulation does not account for delays while the plane is taxiing, having mechanical work, and so on. Some, including ATA, argue that even FAA figures are too low because they only measure delays of 15 min or more and do not include delays caused by aircraft arriving late from their previous stop. Even with these considerations, the simulation does seem to account for most of the average delay.

The time of the simulated delays was calculated by using industrywide seating capacities for specific aircraft and individual airline load factors. This amounted to 16,264 passenger-hr a day, or almost 6 million hr a year. Assuming that travelers' time is worth $10 an hour, the total amounts to about $60 million a year. This is only a conservative estimate of lost passenger time and does not include any costs of delays to the airlines, to those waiting for late passengers, or to any other parties involved. Some might argue that $10 an hour is too low. The costs can be easily rescaled to another value of time. Using $15 an hour, the cost is almost $90 million a year.

A "Maximum Efficiency" System

Considered next was how the foregoing situation might change if some priority system were implemented. Initially the flights were divided into four classes depending on the size of the aircraft involved. (Large jets were in the first class, "stretch" 727s and MD80s were in the second class, all smaller jets were in the third class, and the rest of the planes were placed in the fourth class.) This classification scheme by no means implies that this is how it should be established administratively. Rather, it approximates what it is believed a market-based auction of priorities would produce. In the simplest terms, the bigger airplanes with more passengers should be able to demand the most prompt scheduling, and hence would likely end up with the highest priorities.

When congestion occurred in the simulation, flights were delayed by their class, rather than by random factors. That is, Class 1 flights were released before Class 2 flights, which were still in front of flights in Class 3, and so on. Within a given class, flights were treated equally. Flights were never able to change classes, no matter how long they were delayed. This is Plan A.

The results of the simulation of Plan A were quite interesting. The mean delay time of 9.92 min stayed the same because there were no changes in capacity. The distribution of delays, however, showed significant changes from the current system. Figure 2 shows that, overall, only 16 percent of the flights received delays of at least 15 min. However, these delays were longer and more concentrated. This is shown in the distribution by class in Figure 3. Class 1 flights ran virtually on time, receiving delays less than 0.1 percent of the time. Class 2 flights did almost as well, with 6 percent of the flights receiving any delay. Only 2 percent of Class 2 flights received delays of at least 30 min, and virtually no flights received delays of 45 min or longer. Classes 3 and 4 did significantly worse, with 21 and 46 percent of their flights, respectively, receiving delays of at least 15 min. Class 4 was hit the hardest, with 15 percent of its flights receiving delays of over an hour and 8 percent of its flights receiving delays of over 3 hr.

Figure 4 shows the average delay per flight by class. As might be expected, Class 1 flights were delayed, on average, for less than 0.01 min. Class 2 flights were delayed an average of 1.8 min, and Class 3 and 4 flights were delayed an average of 7.8 and 39.4 min, respectively. Rather than have small planes wait all day, airlines would have a great incentive to reschedule lower-class flights.

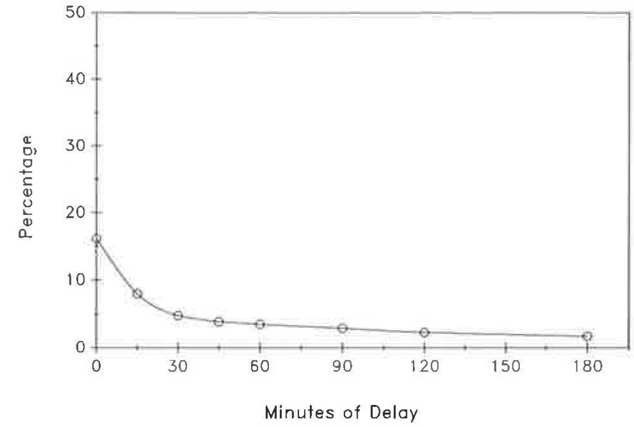

FIGURE 2 Percentage of flights with delays exceeding *X* min, Plan A.

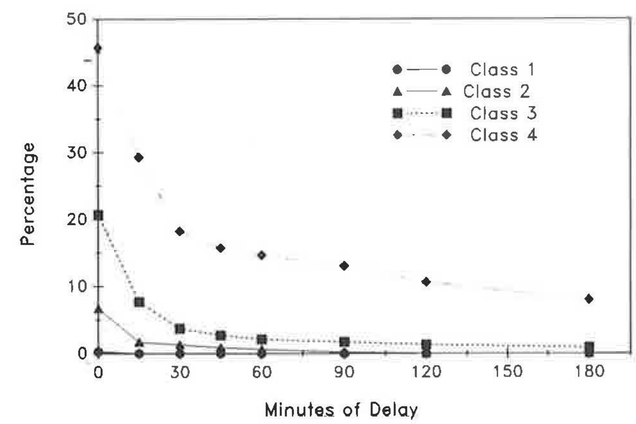

FIGURE 3 Percentage of flights with delays exceeding *X* min, Plan A, by class.

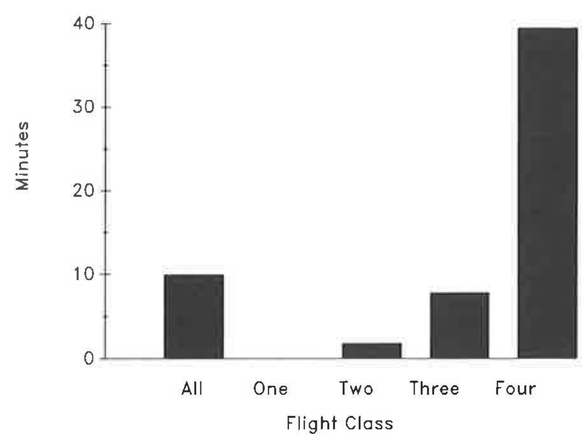

FIGURE 4 Average delay time by class, Plan A.

When the delay time of this system is calculated, however, it is 7,014 passenger-hr a day, or about $2.6 million hr annually, which is more than half of the delay under the current system. Again at $10 an hour that amounts to an annual passenger savings of $34 million. The large decline occurs because this plan concentrates delays on the smaller aircraft with fewer passengers.

Four Other Plans: Allowing Planes To Change Class

Those who live in smaller communities or travel by smaller aircraft could well argue that Plan A is not equitable and would crowd smaller planes out of the system. Although an auction might allocate some higher priorities to airlines that use smaller aircraft, in general it would be difficult for a smaller commuter airline to outbid its larger counterparts. It is possible to devise plans that afford aircraft in lower classes some protection. The trade-off is that as the lower classes get more protection, there are smaller reductions in delays.

Four such plans to provide this protection were tested. These schemes provide ways for aircraft in lower classes to automatically jump their priority, depending on the length of their delay. Plan B, the strictest of these plans, allows aircraft to increase their priority by one class every 60 min; Plan C allows this every 45 min; Plan D, every 30 min. The most lenient scheme, Plan E, allows a class upgrade every 15 min. Again, within a class, all flights are treated equally.

The results of these simulations are both straightforward and significant. The mean delay is a constant 9.92 in all the plans. The difference in delay distribution between classes, however, decreases as the plans get more lenient. In Plan B, which is described in Figures 5–7, Class 1 flights receive much the same treatment as in Plan A. In each case, Class 1 flights carry essentially a guarantee of on-time performance. However, the results change more significantly for Class 2 and 3 flights, which are much better off in Plan A than Plan B. Class 2 flights receive worse treatment, with their mean delay time almost tripling and the frequency of their delays almost doubling. Class 3 average delay and frequency of delay also increase, although not by the same magnitude as for Class 2. Flights in Class 4, however, do significantly better, with the mean delay time dropping almost one-third.

This trend continues in Plans C, D, and E. Figures 8 and 9 summarize this information, showing how the results change for each class of flights from the previous plan. A few generalizations become apparent. From Plan B to Plan E, both the mean delay time and frequency of delay for Class 1 increase almost 200 percent with each successive plan (i.e., Class 1 service becomes less guaranteed). Class 2 flights suffer smaller percentage losses between successive plans, so that by Plan E, they are similar to Class 1 flights. Class 3 flights show

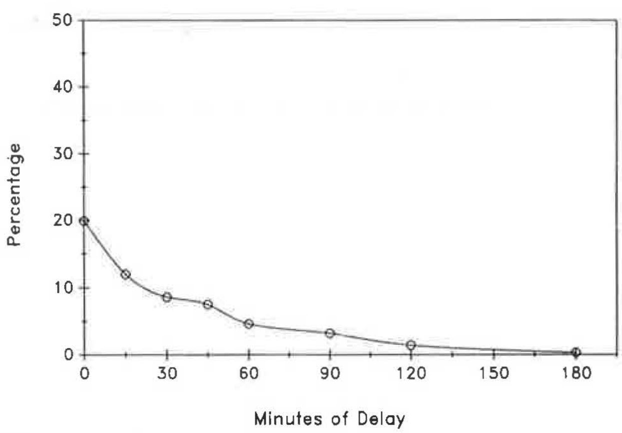

FIGURE 5 Percentage of flights with delays exceeding X min, Plan B.

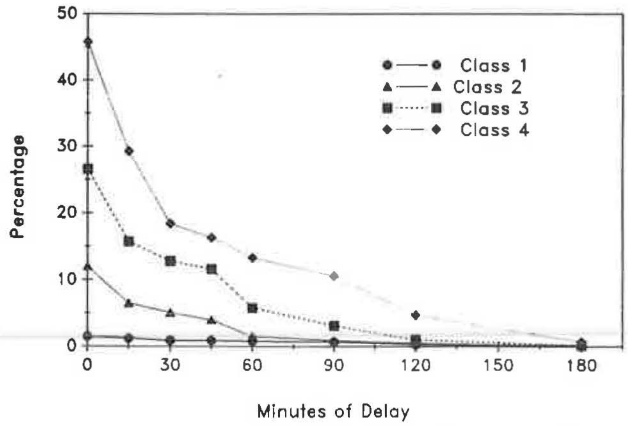

FIGURE 6 Percentage of flights with delays exceeding X min, Plan B, by class.

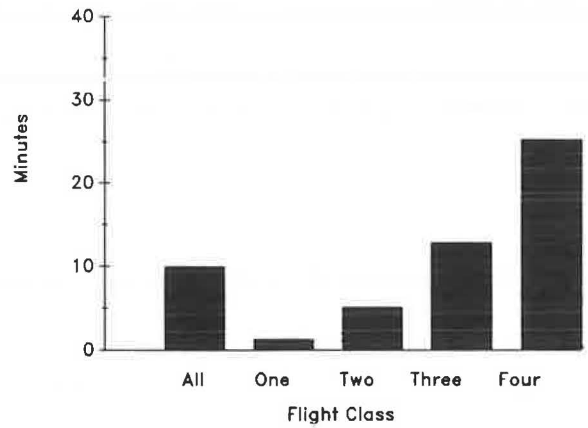

FIGURE 7 Average delay time by class, Plan B.

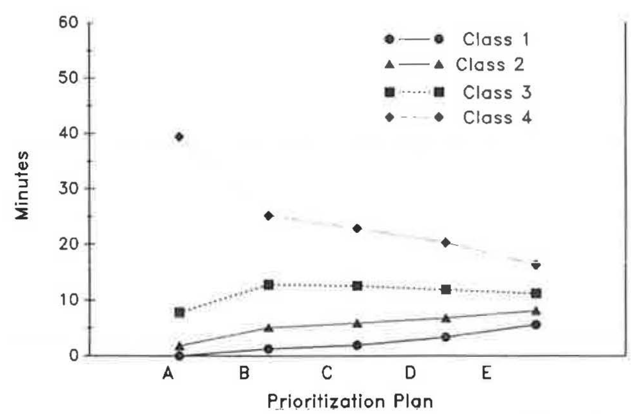

FIGURE 8 Average delay per flight.

very little change between plans. Their mean delay time shows a slight decrease, but they are delayed more frequently. Class 4 flights show significant gains in mean delay time with each successive plan, but are still delayed with the same frequency. Most of these gains are at the expense of Class 1 and 2 flights.

Delays Versus Costs: What Is the Optimal Protection for Lower Classes?

As might be expected, the more lenient the plan, the greater its annual cost of delays. (The annual delay costs for all plans and

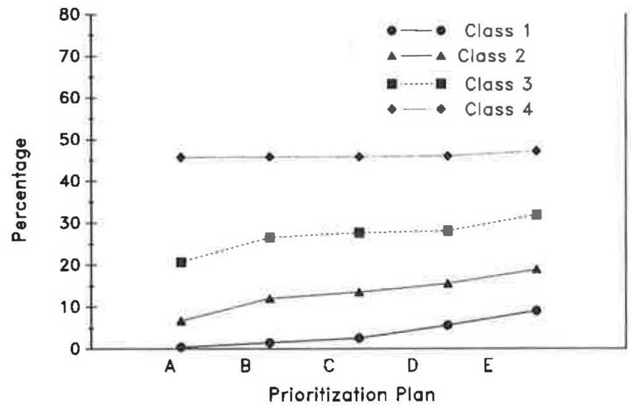

FIGURE 9 Percentage of flights delayed 15 min or more, by class.

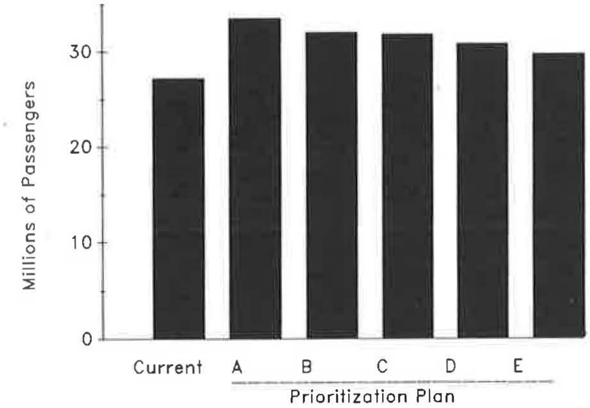

FIGURE 11 Annual number of on-time arrivals at O'Hare International Airport by plan.

for the current system are shown in Figure 10. To determine hours of delay, divide by 10.) Figure 10 raises the interesting question of how much society might be willing to give up (in delays) to have a more "equitable" system. That question will not be addressed here, although it may be noted that even the most lenient scheme (Plan E) provides for annual savings at a single airport of about $8 million or a decrease amounting to 15 percent of the cost of delays. The stricter plans do much better; Plan B cuts the annual cost of delays by 35 percent, or $20 million. The greatest savings is achieved by Plan A, which cuts costs over 55 percent, or over $34 million.

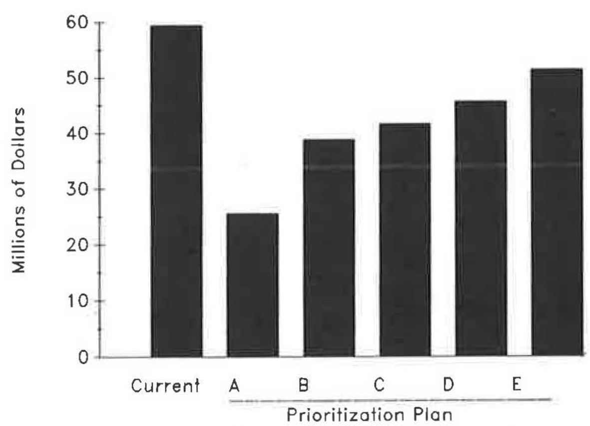

FIGURE 10 Annual passenger delay costs at O'Hare International Airport by plan.

Another way to measure the gains by a priority scheme is to look at how many passengers arrive on time (see Figure 11). With the current system, the simulation predicts about 27 million on-time arrivals. With Plan A, that number increases 23 percent to about 34 million. Even Plan E results in 3 million more on-time arrivals than the current system.

It may be pointed out that it is important to have at least one class of flights run virtually delay free. Presumably, there is a significant number of people whose time, especially while on business travel, is much more valuable than $10 an hour. Even if less stringent plans are considered, safeguards should be built in to ensure that Class 1 service is always extremely reliable. These safeguards might protect Class 1 by limiting its size or how fast flights can be moved up to Class 1. This brings up the possibility of combining some of these plans to achieve an optimal one. For example, Plans A and E could be merged so that flights might be allowed to move one class every 15 min, but never into Class 1. Other similar combinations are possible to determine a system that fits in with the overall policy goals of the FAA.

The Long-Run: What Is Missing?

On further thought, it may be suggested that this simulation significantly underestimates the gains from adopting one of these plans. The simulation does not address the potential savings to airlines. A priority scheme that makes delays more predictable would significantly improve planning, leading to more efficient uses of capital and labor. Better information would also allow airlines to get more use out of gates, ground personnel, and equipment, which are often scarce resources. They would be able to use their larger and more valuable aircraft with greater frequency, handling more passengers and cargo. They could potentially match their highest-rated cockpit crews with their best-instrumented planes, creating flights that would be even less susceptible to weather delays. Because planes with larger crews would receive fewer delays, crews could fly more flights a month. Costs per available seat should fall. Most important, it would give airlines much greater control over their timeliness.

This could permanently change the way airlines do business. They would realize that under Plan D, for example, Class 1 flights have a 98.5 percent chance of running on time and the average delay is only 1.3 min. If the airlines were able to do their part to reduce delays (e.g., by creating more realistic schedules and reducing mechanical problems), they would be able to compete on timeliness in addition to service and price.

Airlines could advertise these different classes of flights and their differing abilities to be on time, giving consumers a greater variety of flying options. (Eastern Airlines already advertises the on-time performance of its Boston–New York–Washington, D.C., shuttle. Imagine how many more shuttles, express flights, and so on, might develop if airlines had better control of scheduling.) Predictable timeliness and more accurate flight times would relieve much public dissatisfaction with the system, taking pressure away from the FAA and Congress.

The FAA would be able to concentrate more on safety and increasing capacity and less on policing the airlines.

A priority system would have varying effects on airports. There are essentially two types of airports—those with one hub airline and those with either two hub airlines or none. At an airport dominated by one airline, delays often result because that airline attempts to have all its flights arrive at one time and leave half an hour later. A priority system would force that airline to recognize that this is impossible. Instead, the airline would have the incentive to write a more realistic schedule and could enforce a priority system among its flights during bad weather. Other airlines at that airport would be able to compete with the dominant carrier by bidding for priorities in an anonymous auction.

At airports without one dominant airline, the priority system gets around the "overscheduling externality." Often airlines schedule flights at congested times for competitive reasons, knowing that these flights will be delayed. A system of priorities reduces this problem, giving airlines a better idea of how to schedule at these airports.

The simulation does not account for the secondary changes that would occur if a priority system were implemented because it does not differentiate between aircraft of the same size. To assume that all aircraft have the same load factors and a single type of passenger is to understate the potential for gain. It is likely that the optimal use of a priority system is to serve markets with a variety of different classes of service. Currently, passengers on the same aircraft are mixed as to the value of their time. If an airline were able to have express service for passengers with a high value of time and regular service for other passengers, it could price these services according to the various passengers' willingness to pay. The airlines would make more profits, and consumers would have greater choice of service at varying prices.

A look at the breakdown of flights at O'Hare shows that this segregation is possible, but very hard to predict. There is a great discrepancy in costs, even between Plan B and the optimal Plan A ($38.8 million versus $25.6 million), because of the large number of flights in Class 2. (See Figure 12 for a breakdown of the number of flights in each class.) The difference between the two plans is that the average delay for Class 2 roughly triples from Plan A to Plan B. A decrease in costs could be realized by dividing Class 2 into different groups depending on the value of individual flights in that group. These gains would be increased further by increasing the number of classes.

How Many Classes?

These simulations, however, do not determine the optimal number of priorities. The use of four priority classes was arbitrary based on a natural split of the types of aircraft used at O'Hare. The choice of how many priority classes to use and how large each should be will have a profound impact on the gains realized by each priority scheme. The problem here is a trade-off between economic gain and complexity. Presumably the largest gain would occur if each flight were given a priority based on its value of time, meaning that the number of classes would equal the number of flights. This, however, would be very hard to implement. To fully utilize an airport, a constant

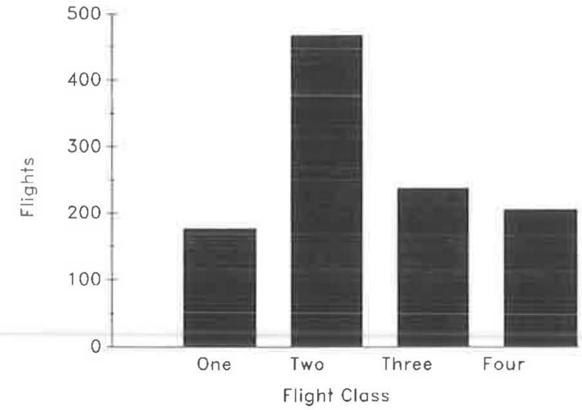

FIGURE 12 Number of flights per class.

flow of traffic is essential. Specifically, the more precise a priority system gets, the harder it is to ensure a steady flow of traffic. Because of this, a system with a relatively small number of classes (e.g., four) using moderate time blocks (e.g., 15 min) may be feasible. No attempt is made here to determine the optimal number of classes and increments of time. It is suggested, however, that it could be possible to find a feasible system that had even larger gains than those that have been shown.

IMPLEMENTATION ISSUES

The priority system is completely compatible with any enhancements to the current air traffic control system. If the system capacity were increased in some way (by hiring more controllers, building more runways or airports, using updated technology, etc.), a priority system would use the additional capacity in the most efficient way.

Use of Competition To Stop the Bunching of Flights

A priority system might also restructure the way airlines use resources such as runways and others. Currently there is a "Catch 22" in which airlines see that bunching flights causes delays, but are competitively unable to stop the bunching, especially while using a hub-and-spoke system. A priority system would solve this dilemma because it orders the importance of flights at any given time. An airline might be hesitant to schedule a Class 4 flight at a time when many Class 1 and 2 flights are scheduled, knowing that the Class 4 flight would always be released last. This is a competitive method for encouraging the smoothing out of the schedule of flights without relying on relaxed antitrust standards, the current approach. It does not arbitrarily set the number of slots at an airport either, but instead allows the market to decide.

Earlier in the paper the political problems associated with many of the proposed solutions for air traffic congestion were noted. The priority system has the potential to benefit all parties involved and thus would be politically feasible. However, some further elaboration might be needed, especially how the priorities might be distributed.

Efficient and Equitable Allocation of Priorities

No matter which plan is chosen, the priorities involved have great value. The same problem came up when the FAA introduced slot control at four airports. There was debate as to who should own the slots and the duration of any property rights that were given. The FAA decided to divide the slots into different groups: commercial service, commuter service, and "essential" service, including international flights, private users, and so forth. Slots were numbered and the owners were given lifetime property rights, provided that the slots were regularly used and were not transferred between groups (e.g., commuter slots were not to be used for larger commercial service). The slots could be revoked by the FAA either for nonuse or in a random, predetermined order if the FAA needed them for another purpose. In a highly controversial move, the FAA gave slots to their current users rather than auctioning them to the highest bidder. This allowed the airlines, not the public or the airports, to generate the "scarcity rents" at slot-controlled airports (*6*).

The distribution of priorities also involves many of the same issues. Any system of distribution must ensure that new carriers have the means to obtain priorities and that no user is able to monopolize them, either in a given market or on a single route. It is also important that the priorities end up in the hands of the carriers that would use them most efficiently. The priorities must have a long enough duration to allow their owners to establish a profitable and consistent business strategy. Finally, the public should receive the revenue from the sale of these priorities.

A Repeated Auction

It is recommended that the FAA distribute the priorities using a revised "Clarke tax," also referred to as a "repeated auction" (*7*). The repeated auction is a multistage process that is not finished until each bidder is satisfied with the results. The first stage of the auction involves soliciting a list of bids from the various players for each of the priorities (or classes) available. This could be done simultaneously for each of the airports in question. Then the commissioner of the auction gathers all bids and awards the priorities to the highest bidders at the price of the highest losing bid. That is, if there were 25 Priority 1 slots available at O'Hare at 9:00 a.m., they would be awarded to the 25 highest bidders at the price of the 26th-highest bid. If there are fewer bidders than priorities for a given time, all bidders receive those priorities at no cost. Limits could be set up to ensure that no one is able monopolize any subset of the priorities.

The commissioner then publishes an anonymous list of bids and gives each player a list of his winning bids. The players would have a specified period of time to evaluate their positions and change any of their bids. If there are no changes, the commissioner declares the bidding closed and the awards are final. Otherwise, the commissioner would take the revised bids and, using the same method as he did in Stage 1, hand out the results of Stage 2. This process would continue until there were no changes or the commissioner declared that there were no major changes and closed the auction.

This scheme would get around the complicated "system" problem of the simultaneous distribution of priorities at more than one airport. Airlines need to know the priorities they would use in all their markets in order to set up a system of flights that conforms to a consistent business strategy. That is, to set up a Class 1 flight line, airlines need Class 1 priorities at all the airports on the line in order to preserve the full benefits of Class 1 operation.

Each round of bidding would increase the information available to the airlines and give each an opportunity to set up a business strategy based on market constraints. Some carriers might not be willing to bid much for high-priority slots, whereas other carriers would be willing to pay more for priorities, depending on their business strategy and their perceived value of that priority. No carriers could gain by overbidding or underbidding, because they might be forced to pay too high a price for a priority or they might not receive a priority at a price they found profitable.

This bidding system was tested by the FAA when they were considering its use in allocating slots (*8*). They simulated its use in the "Airline Management Game," with five airlines having varying marketing strategies and somewhat overlapping routes. They found that a competitive, efficient equilibrium was reached quickly and the market players received overall higher profits after the auction than before its use.

One of the reasons the repeated auction was not used to distribute slots was probably pressure from the airlines, which argued that being forced to buy slots that they previously received at no cost would result in higher ticket prices to the consumer. However, priorities cannot be given away to current holders, because they do not exist. They are created entities that have great value, but only if allocated to the most efficient users. [There is some debate whether an auction would guarantee the most efficient use of priorities (*6, 9*).] The priorities could, of course, be randomly allocated among current users on a weighted basis and the owners given property rights. That might eventually lead to their purchase from the current owners by the most efficient users, but that is not assured.

There is a solution to this dilemma that could satisfy both the airlines and the consumers. Congress could lower the current 8 percent tax on ticket sales by an amount corresponding to the revenue raised by a repeated auction. Although the average ticket prices should remain the same (or possibly be lower because of increased airline efficiency), the distribution of ticket prices would reflect the more efficient market. Prices would be more closely tied to congestion; that is, the more congested the time of day and the airport, the higher the ticket price would be. Discount fares would be lower for those willing to travel at off-peak times or to wait longer.

Unrestricted access to markets, one of the keystones of deregulation, and efficient use of priorities could also be ensured by holding the repeated auction every 6 months. Between auctions the owners could be free to buy and sell their priorities or the commissioner could anonymously accept offers to buy and sell unwanted priorities. Excess priorities would be distributed on a first-come, first-served basis. In addition, airlines could still be free to add more flights to a city, but these flights would be at the lowest priority level. This would give a crude approximation of the optimal amount of congestion in a given airport. When entering at the lowest priority, the added entrant receives a much greater share of the delay cost that his entry imposes on other users. Finally, the results of this auction would provide financial information that would allow the FAA to determine the optimal investment in additional capacity.

Commuter Flights: Where Do They Fit In?

If commuters were given a separate category of priorities and shielded from competition with other users, the gains from this plan would be significantly cut, if not permanently erased. Large jets would still be delayed, and small planes would operate on time. However, in a competitive environment, users with larger aircraft would inevitably bid up the price of most priorities above affordable levels for many commuter airlines. To compensate, these airlines might find it economical in all but the smallest cities to have a mix of service that would include at least one higher-priority flight. It would be hard to imagine that priorities would be bid for strictly in terms of the size of aircraft using the priority.

Even assuming that commuters would mostly fly on Class 4 flights, they would still receive some benefits from a strict priority scheme. Most important, if commuter airlines do not buy high-priced priorities, ticket prices should fall. Also, most of those commuters who fly into large airports intend to catch connecting flights to other destinations. Currently, connecting at a major hub is an extremely unpredictable affair. More accurate timetables under a priority system would make connections easier.

Commuter airlines would probably reschedule some of their flights to avoid major delays at many airports. Although impossible to simulate, such a change could significantly reduce the average delays for lower-priority service. Flyers would be better able to make decisions about how long to allow for making connecting flights. This benefit would extend not only to commuter passengers, but to all who travel by air.

What About Other Users?

Finally there is a concern about how to deal with other airport users, including those originating in foreign countries, not scheduled, and in essential service. International flights could be given automatic priority and be required to pay a prorated fee to operate at certain times or even required to purchase Class 1 service. Even though international flights are not charged, they still represent only a small proportion of flights at congested airports and often use aircraft large enough to require some priority for efficient operation. Unscheduled users, although representing a small percentage of flights at congested airports, could be treated like other users. When unscheduled flights file their flight plans, they could be required to choose a level of priority, pay a prorated fee for that priority, and be treated as any other user with the same priority. This would give them the same choices as others, also ensuring that they face the full cost of flying at a given time. Service that the FAA deems "essential" would travel at any priority to which it is assigned.

CONCLUSION

The Future

The potential gains from an administrative change to a priority system appear substantial compared with the costs involved in implementing the system, which seem relatively minor. This simulation found passenger time savings of over 55 percent, or $34 million a year, at a single airport. These savings have a perpetuity value of $680 million, a figure that would increase greatly if it included gains at all the airports in the system. On-time arrivals could increase by about 23 percent, meaning that 6 million more passengers would arrive as scheduled. Furthermore, these calculations appear to underestimate the savings, not taking into account savings to airlines, secondary shifts in passenger and airline behavior, and benefits from greater predictability. A priority system seems to have the potential to revolutionize the organization of the air traffic control system, benefiting all who fly. It could even reduce the average delay time by reducing the bunching of flights.

Additional Research

Additional research needs to be done, however, to get a better idea of the feasibility and potential gains from a priority system. A more detailed computer simulation would be required to determine the specifics about feasibility and the effects on current and future market participants. Further analysis should explain how the scheme might fit into an entire system as opposed to a single airport. It is also necessary to have some idea of what business strategies might be possible and profitable with a priority scheme, including how commuter airlines would operate. This analysis should include the effects on service for different-sized communities. Research might also determine the possibility of a spot market, in which airlines would be permitted to trade priorities between specific flights on a daily basis.

After all, as the *New York Times* noted in an editorial (*10*), "Even under the best of circumstances . . . it will take years for capacity to catch up with traffic. That is why it is essential to find market-based ways to make the existing system more efficient. . . . [The airline industry's] potential ought not be undermined by a Government that simply can't keep the planes moving."

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Deregulation and Labor Demand: Sources of Pilot Employment Variation, 1979–1985

DANIEL P. RICH

Since domestic airline deregulation, labor markets in the industry have experienced unprecedented turmoil. The purpose of this study is to identify primary sources of pilot employment variation over the 1979–1985 period. Labor demand is estimated to determine the separate influences of increased competition, route system expansion, hubbing, and fuel price shocks. Most of the observed variation in employment can be linked directly to elimination of Civil Aeronautics Board route authority. Labor market volatility in the years to come will be due primarily to traditional economic influences.

Since airline deregulation, labor market conditions have been exceptionally volatile. Several studies highlight the development of sharp contrasts in compensation between competing firms (*1*). Related observations include experimentation with two-tier pay scales (at American Airlines, for example), decertification of existing union representation (Continental Airlines), and even discussion of employee purchase of the firm (United Airlines). It is clear that labor relations in the airline industry are in the midst of fundamental change.

Nowhere is this volatility more evident or widespread than in the area of employment. Table 1 summarizes annual data on employment of pilots and copilots for the domestic operations of former trunk airlines. Observations have been excluded in cases of unreported data and strikes in excess of 100 days. Remaining employment fluctuations determine the coefficient of variation (standard deviation divided by the mean), which has been calculated for each firm over two distinct time periods. Employment variation under Civil Aeronautics Board (CAB) regulation (1972–1977) is exceeded in every case by employment variation within the deregulated era (1979–1985).

In this discussion these employment fluctuations will be explored. What are the primary sources of observed employment variation? To what extent is this a transitory adjustment to recent regulatory change? To what extent is it a response to more traditional economic influences? Is this the type of instability that can be expected continuously in an unregulated environment? These questions may be answered by understanding the employment decisions of airlines with respect to pilots and then identifying the determinants of 1979–1985 employment changes.

Labor demand provides a useful general framework for technical analysis of issues relating to employment levels. First firm-specific demand for the labor services of airline pilots is empirically evaluated. Second these results are used to illustrate the individual effects of actual regulatory and economic changes. Finally, the combined effects of these 1979–1985 changes are shown and conclusions are offered.

Department of Economics, Illinois State University, Normal, Ill. 61761.

TABLE 1 EMPLOYMENT OF PILOTS AND COPILOTS

	1972–1977		1979–1985	
Airline	Mean	Coefficient of Variation	Mean	Coefficient of Variation
American	2,685	.03	2,853	.09
Braniff	884	.06	725	.70
Continental	1,031	.13	1,249	.28
Delta/Northeast	3,001	.02	3,718	.03
Eastern	2,909	.04	2,828	.05
Northwest	1,448	.07	1,215	.09
Pan Am/National	559	.03	498	.37
Trans World	2,355	.09	1,560	.15
United	3,585	.03	3,517	.06
Western	1,296	.07	1,249	.12

LABOR DEMAND ESTIMATION

The demand for labor is a theoretical relationship between wages and the firm's profit-maximizing level of employment. Movement along the labor demand curve represents the response to alternative wages, holding all other influences constant. The firm will react to a wage increase, in general terms, by substituting other productive inputs for labor and decreasing its level of output. In this case, decreased employment will result from these combined "substitution" and "scale" responses (*2*). Substitution is determined primarily by relative input prices and technological considerations, whereas the scale decision is influenced by production costs and characteristics of the product market environment.

The demand for labor will serve as the framework for evaluating employment variation for pilots during the 1979–1985 period. Labor demand is a useful context because it describes the employment decisions of the firm. Here the employment effects of competitive and technological changes due to deregulation can be analyzed. By estimating labor demand the actual impact of various proposed influences can be statistically measured. It is also important to identify significant nonregulatory economic effects (*3*) such as fuel price variation. Estimating labor demand enables one to distinguish between regulatory and unrelated sources of employment variation.

This empirical strategy explicitly incorporates both substitution and scale decisions as well as the implications of nonprice competition (*4*). Service quality will influence both consumer demand and production costs in a number of industries (*5*). Excess capacity has long been recognized as a fundamental element of airline behavior (*6*). Convenience, enhanced by additional scheduled seating capacity, serves as an important consideration for consumer choice, and the level of seating capacity is a primary element in the firm's production decisions. Theoretical discussion from Rich (*4*) implies that this particular form of nonprice competition can be represented, for the purposes of labor demand analysis, in a simple fashion. Traditional measures of output are replaced by the relevant quality-enhancing variable, seating capacity.

The distinction between input substitution and scale determination motivates the "two-step" approach to labor demand estimation. Input substitution is the primary focus of the conditional labor demand equation

$$L = g(w, r, S) \qquad (1)$$

where

L = pilot employment,
w and r = input prices, and
S = scheduled seating capacity.

The particular specification for Equation 1 is obtained from Diewert (*7*) with route system characteristics included as proposed by Kim (*8*). The determination of seating capacity,

$$S = h(MRs, MCs) \qquad (2)$$

where MR is marginal revenue and MC is marginal cost, serves as the firm's relevant output decision under nonprice competition. Output is determined jointly by marginal revenue and marginal cost considerations; therefore, scheduled seating capacity will be influenced by input prices, technological considerations, and significant aspects of the product market in which the airline operates. Previous empirical studies of airline market behavior, including those by DeVany (*9*) and Trapani and Olson (*10*), have influenced the particular specification of Equation 2 employed in this study.

Data

Data for this study consist of the annual observations on the domestic operations of a dozen airlines. Firms were selected on the basis of CAB regulatory classification. The 12 former U.S. trunk airlines (American, Braniff, Continental, Delta, Eastern, National, Northeast, Northwest, Pan Am, Trans World, United, and Western) shared a regulatory history quite different from that experienced by any "nontrunk" airline (*1*). The full sample contains 118 observations during the period 1972–1985; however, the unregulated subsample (1979–1985) will be referred to frequently. Table 2 contains definitions of variables and means. Insufficient data, firm bankruptcies, and strikes in excess of 100 days led to the deletion of additional observations.

The two dependent variables required no calculation. Employment (L) is limited to pilots and copilots engaged in the firm's domestic operations. Data represent annual observations on full-time equivalent employees. Available seat miles (S) is the total number of seat miles carried by the firm, whether filled or unsold, in domestic operations.

The price of the labor input (*Wage*) is calculated as total pilot and copilot expenses to the firm divided by employment. The price of fuel (*Pfuel*) is similarly derived from the firm's reported expense accounts. *Pfuel* is total fuel expense divided by gallons of fuel consumed in all domestic operations.

The nature of the market competition facing the firm is an important element of the analysis. Industry aggregate measures of concentration are useless because competition occurs at the "city-pair" level and not all firms serve all city pairs. For this study a unique firm-specific measure of airline competition has been devised. First, an annual Herfindahl index of market concentration is calculated for each of 250 domestic city pairs. This index is based on passenger shares for all firms (trunk or nontrunk) that provide passage (nonstop or other) between those two cities. Second, a weighted average of these city-pair values is constructed for each firm in which the relative importance of that city pair in the firm's route system is used as a weight. The resulting variable (*Herf*) is an annual measure of actual competition facing the firm across its individual route system.

Cities is simply a count of the domestic destinations served by the airline. *Hub* is calculated as the number of departures from the firm's three most active airports divided by the firm's total departures.

Results

Conditional labor demand is estimated for the full sample to obtain information on long-run factor substitution. The seat

TABLE 2 VARIABLE DEFINITIONS AND MEANS

Variable	Definition	Mean 1972–1985	Mean 1979–1985
L	Employment of pilots and copilots	1,986.83	2,086.88
S	Available seat miles (in 10,000,000s)	25,884.23	30,891.83
Wage	Wages of pilots and copilots ($)	52.25	72.47
Pfuel	Price of fuel ($)	50.72	82.60
RK	User cost of capital ($)	23,485.35	28,767.50
Dist	Average stage length (miles)	696.46	756.91
Hub	Concentration of flight operations	0.35	0.39
Cities	Number of cities served	52.21	56.55
Incrl	Real income of consumers ($)	105.71	112.39
Herf	Index of market concentration	0.44	0.38
Dens	Average market density	45,130.48	57,641.60
TICO	Texas International-Continental merger		
NAPA	National-Pan Am merger		

equation is estimated only for the unregulated subsample to reflect scale decisions in the absence of regulated price or barrier-to-entry constraints.

Conditional labor demand is estimated as follows:

$$L = Sx\Bigg[\underset{(-0.578)}{-0.012} - \underset{(-0.586)}{0.011(^1\!/\!_2)}\left(\left|\frac{Pfuel}{Wage}\right|\right)^{1/2} + \underset{(2.010)}{0.004(^1\!/\!_2)} \times \left(\left|\frac{RK}{Wage}\right|\right)^{1/2} - \underset{(6.303)}{0.045}\left(\left|\frac{Dist}{Wage}\right|\right)^{1/2} + \underset{(7.800)}{3.306(^1\!/\!_2)}\left(\left|\frac{Hub}{Wage}\right|\right)^{1/2}\Bigg] \quad (3)$$

where the sample size is 118, the F-statistic is 674.075, and t-statistics are shown in parentheses. Available seat miles is estimated as follows:

$$\begin{aligned} \ln S = {} & \underset{(-1.596)}{-18.837} + \underset{(6.403)}{1.056} \ln Dist - \underset{(1.998)}{0.058} \ln Hub \\ & + \underset{(12.464)}{1.634} \ln Cities + \underset{(0.265)}{0.357} \ln Incrl - \underset{(-1.216)}{11.846} \ln Herf \\ & + \underset{(2.269)}{0.430} \ln Dens - \underset{(-0.044)}{0.010}\, TICO + \underset{(1.243)}{0.255}\, NAPA \\ & + \underset{(0.573)}{0.688} \ln Wage + \underset{(1.204)}{1.353} (\ln Wage \times \ln Herf) \\ & + \underset{(1.411)}{1.904} \ln Pfuel + \underset{(1.404)}{2.205} (\ln Pfuel \times \ln Herf) \\ & - \underset{(-0.214)}{0.197} \ln RK - \underset{(-0.336)}{0.286} (\ln RK \times \ln Herf) \end{aligned} \quad (4)$$

where the sample size is 60, the F-statistic is 58.367, $\bar{R}^2 = .931$, and t-statistics are shown in parentheses.

Calculated elasticities of interest may be found in Table 3. Detailed methods of estimation have been described by Rich (*4*).

From the conditional labor demand results in Table 3 it is clear that the firm's choice of seating capacity is the primary determinant of pilot employment. A 1 percent increase in available seat miles leads to an approximate 1 percent (1.014) increase in employment. Conditional labor demand elasticity with respect to wage (–0.587) indicates a significant substitution response. Wage increases induce the firm to select less labor-intensive modes of production.

Results from the seat equation reveal a variety of important influences. The initial objective is to determine the scale response to a wage change. After route system differences, determinants of firm-specific demand, disequilibrium effects of mergers, and regulatory influences have been controlled for, the predicted response to marginal costs can be identified. The elasticity with respect to wage (–0.616) indicates that increased marginal costs lead to reduced seating capacity.

The full response of employment to a wage change is then a combination of both substitution and scale responses. Figure 1 shows estimated labor demand. Here one may observe the full employment response, implied by the estimation results, to representative wage variations. Figure 1 is obtained with all other variables held constant at their mean values for the unregulated subsample. This gives a picture of average firm-specific demand for airline pilots isolated from regulatory and nonregulatory external influences.

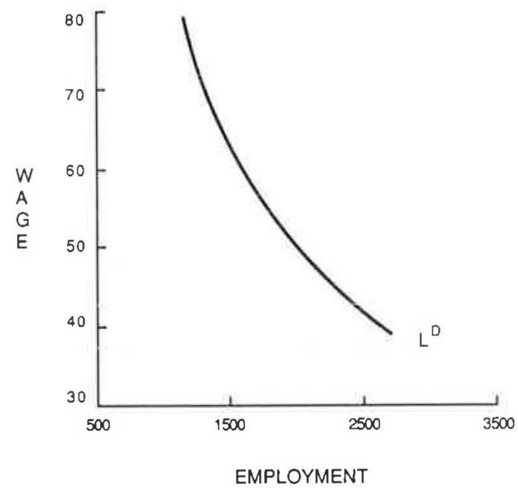

FIGURE 1 Estimated labor demand.

SOURCES OF EMPLOYMENT VARIATION

In this section four important labor demand influences were reviewed. From the results of preceding technical analysis, it is clear that these are the primary sources for increased variation in pilot employment as shown in Table 1. First, the most commonly cited by-product of deregulation—increased market competition—is examined. Elimination of CAB route authority led to other changes during the 1979–1985 period as well. Expansion by incumbent firms into new markets and increased hub system utilization will be discussed in the context of labor demand. In addition to regulatory transition, 1979–1985 has

TABLE 3 SELECTED RESPONSE ELASTICITIES

Condition Labor Demand	*T*-Statistic	Elasticity	Available Seat Miles	*T*-Statistic	Elasticity
Available seat miles	11.687	1.014	*Wage*	–1.395	–0.616
Wage	–3.959	–0.587	*Wage* × *Herf*	1.204	1.353
Pfuel	–0.586	–0.037	*Pfuel*	–0.902	–0.221
Hub	7.800	0.852	*Hub*	–1.998	–0.058
			Cities	12.464	1.634

been marked by substantial fuel price fluctuation. The implications for pilot employment of all of these potential influences will be explored.

Competition

One of the goals of airline deregulation was to create a more competitive market environment. The data presented in Figure 2 clearly indicate that competition has increased for the firms in this study. Figure 2 presents annual average values of *Herf*, the firm-specific measure of market concentration. From 1972 to 1977 trunk airlines operated in highly concentrated markets with extremely limited opportunities for increased competition. Removal of CAB barriers to entry opened the door for other trunks, nontrunks, and even new entrants. Market concentration generally declined following deregulation, giving the 1979–1985 pattern for *Herf* in Figure 2.

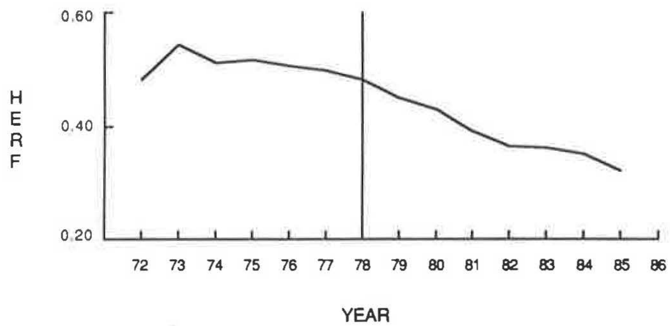

FIGURE 2 ***Herf*: measure of market concentration.**

Estimation results in Table 3 (*Wage* × *Herf*) suggest that this trend has a unique impact on the firm's demand for labor. Faced with a greater number of air travel alternatives, the consumer is more responsive to price or quality changes. The firm must now be more responsive, in terms of output and employment, to any variation in marginal costs. Increased market competition will lead to an increased scale response and therefore more elastic labor demand.

In Figure 3 the effects of changing *Herf* are simulated. Labor demand is calculated as before but with *Herf* set alternatively at the 1977 level (.50) and the 1985 level (.32). The individual impact of increased competition is a flatter or more elastic labor demand curve. For pilots this means a more severe trade-off between wages and employment. Under a given contract this should produce short-run employment loss. In the long run, elastic labor demand serves as a deterrent to wage increases. Changes in competition have been at the heart of labor market volatility during 1979–1985.

It is doubtful that market concentration, as measured here, will continue to decline at such a rapid pace. Some recent mergers, such as Trans World with Ozark, have tended to increase concentration. The 1979–1985 changes in *Herf* should be viewed as resulting from a historic period of regulatory transition.

Route System Expansion

Deregulation not only opened the door to increased competition but permitted incumbent firms to expand into additional

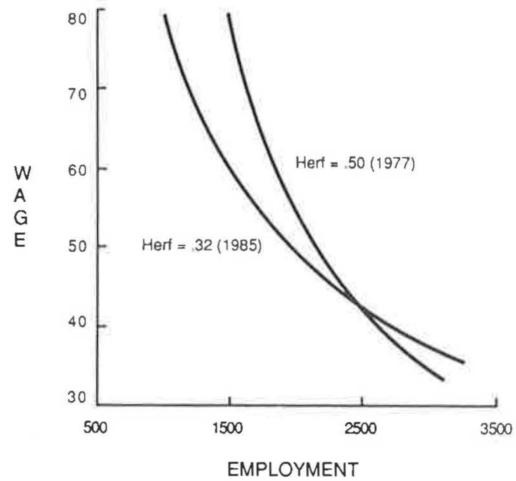

FIGURE 3 Simulated effects of market concentration.

markets. in 1938, at the inception of CAB regulation, all firms were strictly regional carriers (*1*). After 40 years of CAB route authority, the route systems of trunk carriers retained much of their regional flavor. One of the most striking trends of the deregulated era has been route system expansion beyond the firm's traditional regional territories, which is shown in Figure 4. Very little change is evident during the 1972–1977 period. Route system expansion was severely restricted during this period of CAB regulatory control. During 1979–1985 a general increase may be seen in the number of cities served on average by the firms in this study. This trend is slowed by recession initially and reversed at the end because of the experiences of a few firms that dramatically curtailed operations.

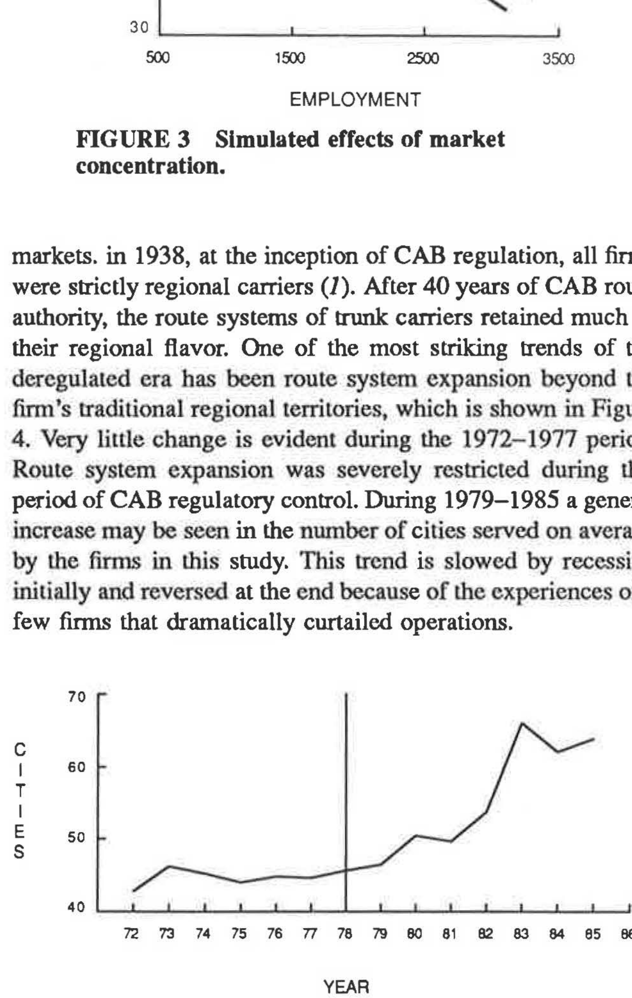

FIGURE 4 ***Cities*: measure of route system expansion.**

The estimated impact of *Cities* in the seating-capacity equation (1.634) reveals route system expansion as a very significant determinant of pilot employment during the period. Figure 5 shows the simulated effect of expansion on the demand for labor. Labor demand is derived with *Cities* set at the 1977 average (44.7) and then at the 1985 average (63.7). As firms increase the number of cities served in their route system, labor demand increases.

For pilots this expansion has more pleasant implications than the previously discussed increase in competition. The resulting labor demand shift leads to expanded wage and employment opportunities.

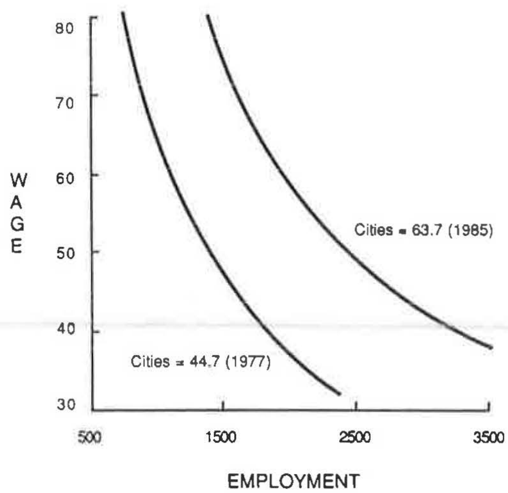

FIGURE 5 Simulated effects of route system expansion.

Ten years of deregulated airline behavior have not yet erased 40 years of regulation. Airline route systems remain somewhat regionally biased. The general trend toward expansion has resumed since 1985 but through a different method. Some mergers, such as Delta with Western, were primarily regional expansions. How will employment in the merged entity compare in the long run with the combined employment of the two separate firms? With a measured elasticity in excess of 1, these results suggest that a merger between two firms with completely distinct route systems would increase pilot employment.

Hub System Utilization

With the removal of CAB route authority, airlines were permitted to rearrange route systems. Combining diverse city-pair passenger flows through traffic centers allows the firm to enjoy economies of scope (*11*). Consumer preferences for nonstop travel limit airline hubbing activity. Although the hub concentration of Federal Express is a model for cost minimization, it is not a blueprint for passenger airline profit maximization.

Figure 6 shows that hubbing has increased substantially during 1979–1985. This trend should be interpreted as a move from CAB route assignments toward optimal hub system utilization.

Estimation results presented in Table 3 revealed conflicting effects of this trend. In the seat equation the negative elasticity (–0.058) reflects more efficient use of seating capacity. Higher load factors are in part due to hubbing activity. The positive elasticity with respect to *Hub* (0.852) in the conditional labor demand equation indicates that hub concentration leads to more pilot labor-intensive production. For a given number of seat miles, hubbing requires shorter hops and more frequent departures.

The combined impact during 1979–1985 has led to increased labor demand. Figure 7 shows the simulated effects of hubbing. Pilots will enjoy greater wage and employment opportunities with hub concentration at the 1985 level (0.44) as opposed to the 1977 level (0.35).

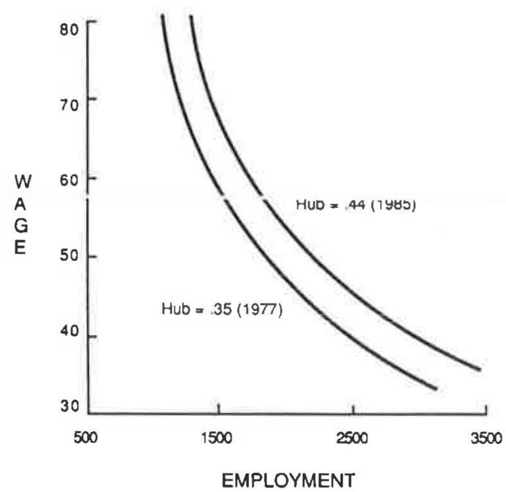

FIGURE 7 Simulated effects of hub system utilization.

It is important to note that increased hub utilization may have a very different impact on other labor groups. Centralization of ground activities may decrease demand for employees not involved in flight operations.

It is difficult to imagine increased use of primary hubs by the firms in this study. Movement toward new secondary or regional hubs and exploration of profitable nonstop opportunities are trends that will very likely dominate in the foreseeable future.

Fuel Prices

Several potential sources of pilot employment variation during 1979–1985 are independent of industry deregulation. Fuel

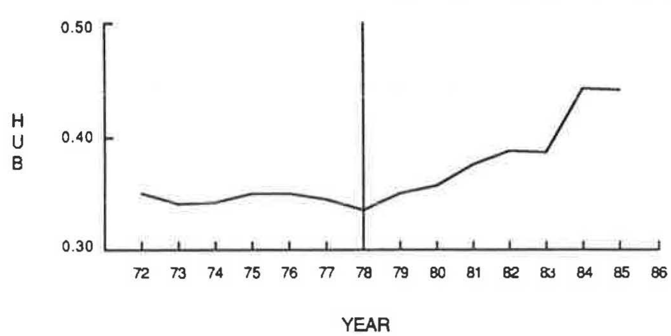

FIGURE 6 *Hub*: measure of hub system utilization.

price shocks, recessions, and changes in the cost of acquiring capital equipment have come and gone regardless of the regulatory environment faced by airlines. It was decided to focus on fuel prices because of their relative significance during this period (*12*).

Figure 8 shows *Pfuel* rising continuously from 1972 through 1981 and then falling through the end of the sample. Fuel price increases are particularly substantial during the early days of deregulation, with an observed 164 percent increase from 1978 through 1981. Again, this fuel price increase is independent of airline deregulation. For example, a 147 percent increase may be observed over a comparable time span beginning in 1973.

The estimation results confirm the belief that pilot employment, in the long run, is affected adversely by high fuel prices. Labor and fuel are complements in both the conditional labor demand and seating capacity equations. Higher fuel prices increase costs, leading the firm to reduce scheduled seating capacity (–0.221), which will result in less employment. The firm will also respond by altering its input mix. Long-run fuel-saving decisions regarding route systems and aircraft fleets appear to be labor saving (–0.037) as well. These estimates suggest that a 1 percent increase in fuel prices will lead to a combined 0.25 percent decline in pilot employment. Although this would appear to be a relatively inelastic response, it becomes significant in light of the tremendous fuel price fluctuations observed.

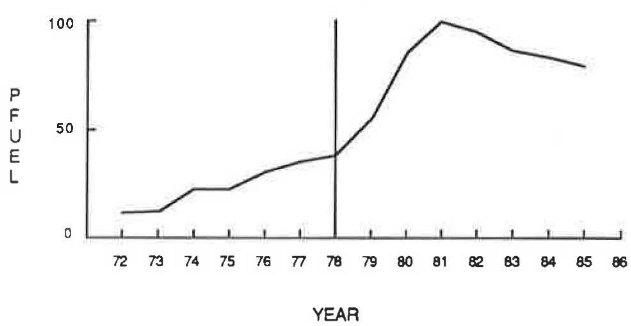

FIGURE 8 ***Pfuel*****: cost of fuel per gallon.**

Figure 9 shows the simulated effects of a representative fuel price change. As *Pfuel* increases from the 1979 value (56.4) to the 1979–1985 mean value (82.6), labor demand declines. Thus, fuel price increases during the initial years of deregulation had a depressing effect on pilot wages and employment levels. Subsequent fuel price declines expanded the demand for labor.

It should be noted at this point that the firm's ability to react to fuel price and other exogenous shocks is enhanced by the elimination of route restrictions and price regulation. The response shown here, though limited, is greater than the response to equivalent fuel price changes experienced before deregulation (*4*). As for the future, continued surprises from fuel price movements should be expected and corresponding inverse movements of pilot employment levels predicted.

CONCLUSION

Employment variation during the deregulated era has been caused by a variety of forces. These influences are shown to

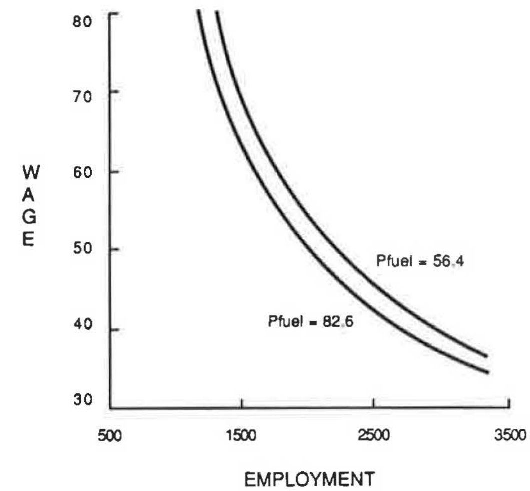

FIGURE 9 Simulated effects of fuel price variation.

have conflicting effects. Figure 10 shows the combined impact of the sources of employment variation. Representative labor demand curves are obtained by setting all variables in the analysis at annual mean values for 1979, 1982, and 1985. The overall increase in labor demand over the period is primarily a result of route system expansion, increased hub utilization, and 1982–1985 reductions in the price of fuel. The overall flattening observed is primarily the result of increased market competition.

FIGURE 10 Simulated labor demand in the deregulated era.

During 1979–1985 a tremendous change has been observed in the determinants of pilot labor demand and significant adjustment in pilot employment. The long-run impact of the labor demand shifts shown in Figure 10 has been increased employment at only a few firms. American, Continental, and Delta are the only former trunk carriers to increase pilot employment relative to the regulated period. It is not surprising that employment growth is observed at the firm with the greatest expansion (American), the firm with the most aggressive wage strategy (Continental), and the firm that has been exposed to the least new competition (Delta). Pilot employment over the same period for all other former trunk carriers has declined.

Pilots with the airlines studied have, for the most part, taken the potential gains from increased labor demand in the form of wages. These wage increases initially exceeded the rate of inflation; however, the effects of increased market competition have continued to increase the employment cost of this wage choice relative to earlier periods. In the last 2 years of this sample, wages fail to keep pace with inflation, leaving real earnings as of 1985 only slightly better than they were in 1978.

Estimation of labor demand has identified separate sources of employment variation. Removal of route restrictions produced multiple regulatory effects during 1979–1985. Fuel prices served as an example of labor demand influences independent of regulatory change. Most of the employment variation during this period apparently represents transition to a deregulated environment. Although there will continue to be changes in competition, hub utilization, and route systems, the magnitude of changes observed here is unique to the 1979–1985 period. Nonregulatory influences such as fuel price variation, recession, and technological change will certainly continue to arise. Some continued labor market volatility should be expected, but in the future it will be primarily in response to these traditional economic influences.

Predictions regarding the future course of events in airline labor markets must be made with a note of caution. Although all carriers have faced low-cost competition in some limited percentage of markets, the impact of a full-service carrier with a significantly different cost structure and extensive nationwide route system has yet to be observed. An increase in competition of this sort at this time would flatten labor demand without creating conflicting expansion and hubbing effects. This would put unprecedented wage or employment pressure on the high-cost firm. The success or failure of Texas Air in achieving its apparent long-term goals is quite significant in this context.

Finally, it is important to note the limited scope of this study. First, it focuses on pilots and copilots only. Employment variation for other groups has exceeded the employment variation observed here. Labor demand for workers not involved directly in flight operations will be determined by a different set of considerations. Second, the analysis is limited to former trunk carriers. Extension of this research to other airlines may provide interesting contrasts and additional insight.

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Uses and Misuses of Risk Metrics in Air Transportation

CARMEN TERESA VILLARREAL

In air transportation the use of different statistics to measure risk (henceforth referred to as "risk metrics") yields different perceived levels of safety. The perception of risk, in turn, affects the framework within which thresholds for risk acceptability are set. Therefore, it is important to carefully consider the characteristics of several risk metrics before deciding to use a particular one. In this paper the strengths, limitations, uses, and potential misuses of seven commonly used risk metrics are examined. The risk metrics analyzed are (a) fatalities per hour of exposure to air transportation, (b) passenger fatalities per 100 million scheduled passenger-mi, (c) fatal accidents per 100,000 flights, (d) probability of being killed in an air carrier accident, (e) total accidents per 10 million system flying hours, (f) miles flown between successive accidents, and (g) mean time between failures. The conclusion is that there is no "unique" or "correct" way of measuring risk in air transportation. Therefore, air transportation risk studies should include a statement of the applicability, spectrum, and limitations of the chosen risk metrics.

The statistics used to measure risk (henceforth referred to as "risk metrics") play an essential role in evaluating the safety of the air transportation industry as well as in the comparison of the safety levels of different airlines, different modes of transportation, and different risk-generating activities. Risk metrics also play a crucial role in analyzing the effect of introducing changes in the air transportation system. For example, use of a particular metric may influence decisions such as whether to fly with two engines over the Atlantic or to increase the number of operations at an airport.

The use of different metrics yields different perceived levels of safety, which in turn affect the framework within which thresholds for risk acceptability are set. Because there is no "unique" or "correct" way of measuring risk in air transportation, it is important to explore the strengths and limitations of some frequently used risk metrics within the context of their use before deciding to use any one of them.

In this paper the following seven risk metrics are examined:

- Fatalities per hour of exposure to air transportation,
- Passenger fatalities per 100 million scheduled passenger-mi,
- Fatal accidents per 100,000 flights,
- Probability of being killed in an air carrier accident,
- Total accidents per 10 million system flying hours,
- Miles flown between successive accidents, and
- Mean time between failures.

Boston University Law School, 13 Potter Pond, Lexington, Mass. 02173.

These metrics were selected because they were considered representative of those that have been used and those that could be used in the air transportation industry.

The metrics studied in this paper have different mathematical interpretations and derivations, as well as different spectra of applicability. For example, four of the seven are built by dividing a mishap parameter (fatalities or accidents) by an activity parameter (hours of exposure, passenger miles, flights, or flying hours). Metrics built in this way acquire the shape of the parameter with the higher variance. Figures 1–3 show that the trend of the metric *passenger fatalities per passenger mile* closely resembles that for *passenger fatalities*, which is the high-variance parameter shown in Figure 1.

To examine the spectra of applicability of the aviation risk metrics, they are classified into three categories: wide spectrum, medium spectrum, and narrow spectrum. Wide-spectrum risk metrics are used to measure the risk posed by the air transportation system as a whole. Medium-spectrum risk metrics measure the risk posed by air transportation subsystems such as air traffic control, airline, airplane type, airplane maintenance schedule, and operational condition. Narrow-spectrum risk metrics measure the risk posed by characteristics or components of a subsystem such as human error, avionics, engines, and power plants.

DATA BASE

The data base contains the necessary parameters to build the metrics of interest. The actuarial data gathered reflect the accidents and fatalities of the U.S. domestic scheduled air carriers (Table 1) and the activity levels measured by passenger emplanements, passenger miles, load factors, aircraft miles flown, aircraft hours flown, and number of flights (Table 2). The data base covers the period from 1970 to 1985. U.S. domestic scheduled air carrier operations were chosen because they constitute a subgroup of the air transportation industry for which consistent data are readily available.

Military, nonscheduled carrier (typically represented by charter flights), cargo, general aviation, and international operations of U.S. air carriers were not considered in this analysis. The operations excluded constitute about 50 percent of the total U.S. air traffic activity (*21*). This exclusion does not limit the usefulness of the analysis, because the purpose of this paper is to illustrate the uses and misuses of different risk metrics in air transportation and not to evaluate the safety of the air transportation industry as a whole.

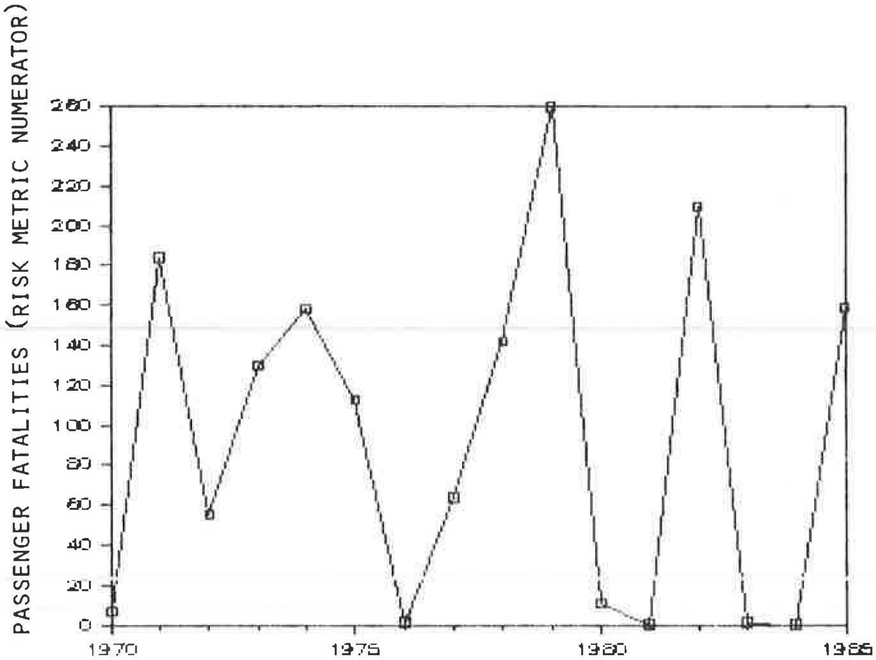

FIGURE 1 Composition of a risk metric: passenger fatalities.

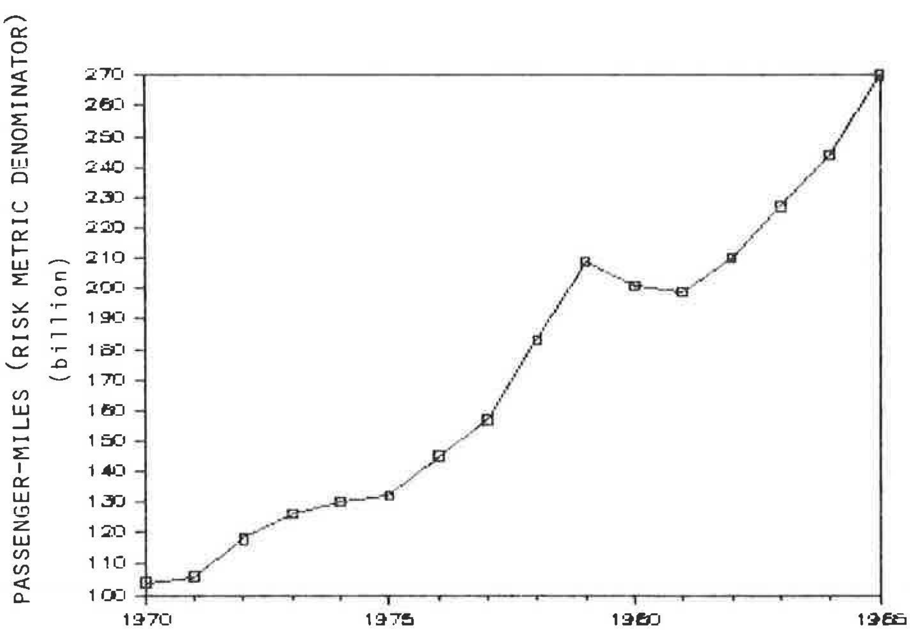

FIGURE 2 Composition of a risk metric: passenger miles.

USING ACTUARIAL DATA TO MEASURE RISK IN AIR TRANSPORTATION

Risk metrics derived from actuarial data can introduce two main types of bias: leveling of distinctions and omissions. "Leveling of distinctions" refers to the blending of data so that distinctions among individual data points are lost. Although this blending is the basis of statistical sampling, it can work against accurate reflection of the facts. An example is a metric that has fatalities in the numerator but does not distinguish among crew, passenger, and ground fatalities. This distinction is critical in many cases, for example, when the parameter of interest is willingness to undertake risk.

Omissions occur when relevant factors are not considered when a metric is built. For example, the metric *passenger fatalities per 100 million scheduled passenger-mi* considers only those passenger injuries that result in dealth within 7 days of an accident, omitting any accident-related casualties occurring more than 1 week after the accident.

Two additional problems arise from using actuarial data to measure risk in air transportation. One is that accidents are rare events; thus perceived variations in risk might be due to

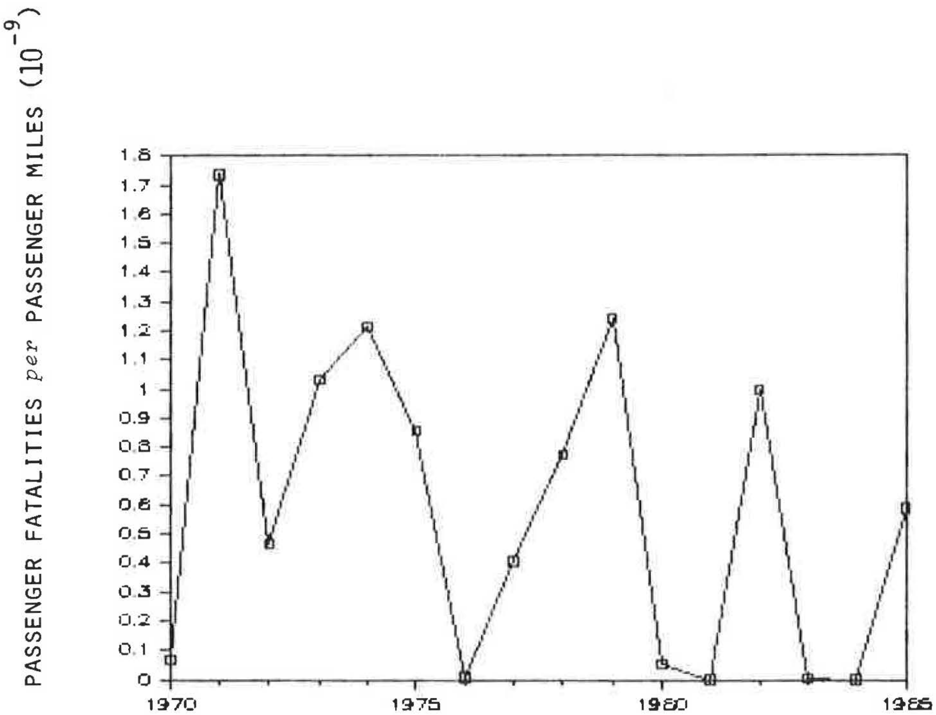

FIGURE 3 Composition of a risk metric: passenger fatalities per 100 million scheduled passenger-mi.

TABLE 1 ACCIDENTS AND FATALITIES OF THE U.S. DOMESTIC SCHEDULED AIR CARRIERS

	ACCIDENTS (1)		FATALITIES (2–17)			
	TOTAL	FATAL	TOTAL	PASSENGER	CREW	GROUND
1970	31	1	9	7	2	0
1971	33	4	201	184	16	1
1972	37	6[a]	65	55	9	1
1973	27	5[b]	139	130	9	0
1974	31	3	168	158	10	0
1975	21	2	122	113	9	0
1976	17	1	1	1	0	0
1977	15	2	75	64	2	9
1978	18	4	164	142	9	13
1979	14	3	278	260	16	2
1980	8	1	13	11	2	0
1981	13	0	0	0	0	0
1982	14	3	233	210	11	12
1983	22	2	2	1	0	1
1984	11	0	0	0	0	0
1985	39	2	172	159	13	0

a Includes 05/30 & 12/15 accidents resulting in crew fatalities only

b Includes 08/30 accident resulting in one passenger fatality only

TABLE 2 ACTIVITY INDICATORS OF THE U.S. DOMESTIC SCHEDULED AIR CARRIERS

	PASSENGER MILES (18) (billion)	AIRCRAFT MILES (19) (billion)	AIRCRAFT HOURS (19) (million)	NUMBER OF FLIGHTS (20) (million)
1970	104	2.0	6.0	5.0
1971	106	2.0	4.9	4.7
1972	118	2.0	4.9	4.7
1973	126	2.0	5.0	4.8
1974	130	1.9	4.7	4.5
1975	132	1.9	4.7	4.5
1976	145	2.0	4.9	4.7
1977	157	2.1	5.1	4.8
1978	183	2.1	4.7	4.8
1979	209	2.2	5.1	5.0
1980	201	2.5	6.1	5.1
1981	199	2.4	5.9	4.9
1982	210	2.4	5.8	4.7
1983	227	2.5	6.0	4.8
1984	244	2.8[e]	6.8[e]	5.1[e]
1985	270	2.9[e]	7.0[e]	5.1[e]

e estimate

chance. The other is that actuarial data do not take into account the cause of accidents. In the following section, uses, strengths, limitations, and potential misuses of the selected metrics are presented.

AIR TRANSPORTATION RISK METRICS

Fatalities per Hour of Exposure to Air Transportation

The metric numerator *fatalities* is defined by the FAA as injuries that result "in death within 7 days of the accident" (*22*, p. 170). The types of fatalities in air transportation can be broadly classified as on-board fatalities (passengers and crew) and ground fatalities.

The metric denominator *hour of exposure* can acquire different meanings. For example, if the metric is used to measure the safety of the whole flying population, it refers to the number of hours that passengers or crew, or both, fly during a given period of time. If the metric is used to pertain to nonpassengers as well, it refers to the time when there is a danger of an airplane's crashing into people.

The risk metric numerator *fatalities* has some intrinsic strengths and limitations regardless of the choice of denominator. This characteristic will allow a discussion of fatalities as an independent parameter later. This is followed by a discussion of the potential misuses of the entire metric within the framework of specific applications. This approach was chosen because the limitations of the denominator are easiest to recognize when specific uses of the metric are studied.

Uses of the Metric

In 1969 Chauncey Starr published in *Science* his now often-cited article (*23*) Social Benefit versus Technological Risk. In this article Starr used the metric *fatalities per person-hour of exposure* as a wide-spectrum metric to determine the social acceptability of risk. He compared the risks and the benefits derived from hunting, skiing, flying on airliners, flying on general aviation planes, driving, using electric power, and smoking (*3*). *Fatalities per hour of exposure* can also be used as a medium-spectrum metric to compare the safety record of different airlines.

Advantages and Limitations of Fatalities as Numerator

Fatalities as a metric numerator offers some advantages that should not be overlooked. It is an often relevant measure and it is generally reliable in that deaths are always reported. The metric numerator *fatalities* can be easily used in comparisons of the safety performance of different airlines or different modes of transportation.

This metric numerator, however, has a number of intrinsic limitations. Circumstantial factors such as load factors, terrain at the accident site, weather conditions at the time of the accident, and time of day at which the accident happened may impinge dramatically on this measure. The fluctuations of the parameter that may in some cases be attributable to circumstantial factors are shown in Figure 1.

Fatalities as a numerator introduces leveling-of-distinctions and omission bias. Omission occurs because the parameter is not sensitive to severe injuries or to the causes of the different accidents. This lack of sensitivity could have serious consequences, particularly in areas such as the legal determination of compensations and liabilities.

Leveling-of-distinctions bias occurs with respect to life expectancy, willingness to be exposed to risk, airplane size, load factor, and kind of death.

Life Expectancy Before a fatal accident, a 3-year-old passenger has a much longer life expectancy than an 80-year-old; yet *fatalities* overlooks this distinction by simply counting the number of dealths. A legal scholar interested in aviation tort law could not use *fatalities* as a metric numerator because reduction in life expectancy and loss earnings are key elements of wrongful death cases.

Willingness To Be Exposed to Risk *Fatalities* as a metric numerator makes no distinction among the deaths of a crew member, a passenger, and a person on the ground. These three events are quite different in terms of the level of voluntary acceptance of exposure to risk. Crew members constitute the group who subject themselves to the highest risk. Delta Air Lines pilots, for example, fly 75 hr a month and are very much aware of the risks involved in their profession. Passengers are somewhat aware of the risks, and they undertake them on a voluntary basis. Except in those cases in which accidents involve those working at airports, ground fatalities affect those who did not undertake the risk voluntarily.

According to Starr, "the public is willing to accept voluntary risks roughly 1,000 times greater than involuntary risks" (*23*). On the basis of Starr's rule of thumb, one could assume that each ground fatality counted as much as 1,000 passenger fatalities. Under this assumption, from 1970 to 1985 there would have been 41,000 "equivalent ground fatalities," which would surpass the 1,380 actual passenger fatalities (Table 1).

Airplane Size *Fatalities* accounts for a nonsurvivable accident of a fully loaded DC3 in the same way as a survivable accident of a fully loaded L1011 in which 90 percent of the passengers survived. In both cases, the parameter *fatalities* only records the fact that there were 30 casualties.

Load Factors Given two nonsurvivable accidents involving identical airplanes with 100 seats each, one with a 90 percent load factor and the other with a 40 percent load factor, the metric numerator *fatalities* would count 90 fatalities in one case and 40 in the other. The metric numerator *accidents*, however, would regard both events as identical.

Kind of Death The numerator *fatalities* does not distinguish between an instantaneous death and a prolonged agony due to third-degree burns affecting a large percentage of the body. It counts only those deaths that took place within 7 days of a given accident.

Potential Misuses of the Metric

If the metric *fatalities per hour of exposure* were used to compare risks posed by different transportation modes, it would show its leveling-of-distinctions bias by not differentiating between fast and slow modes of transportation. It would discriminate against air transportation by failing to consider the reduction in time of exposure while traveling achieved by the higher speeds of airplanes.

To illustrate how this bias works against air transportation, consider a comparison of the safety levels displayed by National Railroad Passenger Corporation (Amtrak) and Eastern Airlines (EAL) in their Boston–Washington, D.C. (BOS–DC) market. The Amtrak trip lasts approximately 8.5 hr, whereas the EAL trip lasts 1.25 hr. Assuming that both means of transportation produced the same number of fatalities in a given period of time, an individual comparing the safety of Amtrak with that of EAL in the BOS–DC market via the metric *fatalities per hour of exposure* could falsely conclude that Amtrak is 7 times safer than EAL. Using this metric clearly penalizes Eastern Airlines for being a faster means of transportation.

Note that the metric does not consider some important differences between the two modes of transportation in the BOS–DC market, including the number of passenger carried daily, the frequency of departures, and the load factors. Amtrak carries about 8,000 passengers a day, whereas EAL only carries 3,000. Therefore, Amtrak is exposing more than twice the number of people to the risk of traveling seven times longer than on EAL. Amtrak carries an average of 400 passengers per trip, and EAL carries an average of 105 passengers per trip. If it were assumed that the risk was a function of the number of departures, Amtrak would be exposing almost four times as many to the risk of traveling than would EAL. Last, Amtrak offers 20 daily departures in the BOS–DC market, and EAL offers 26. Although the excluded factors are not fundamental in every study, an analyst using the metric *fatalities per hour of exposure* should decide whether those omissions would make a difference in the results.

If one wanted to compare the safety performance of two airlines, one would be better off using another metric, such as a passenger fatalities per 100 million passenger-mi or fatal accidents per flight, because the denominator of the metric *fatalities per hour of exposure* is not optimal in capturing the difference in size and volume of operation of different airlines.

Passenger Fatalities per 100 Million Scheduled Passenger-Mi

If used within aviation, the wide-spectrum metric *passenger fatalities per 100 million scheduled passenger-mi* reflects how many passengers die on average in airplane crashes during the interval in which an airline (or the air transportation system) covers 100 million passenger-mi. The denominator *passenger* *miles* measures travel output as a function of how many passengers fly how far. The numerator of this metric does not consider crew or ground fatalities, which together constituted 9 percent of the total fatalities resulting from the accidents of the U.S. domestic scheduled air carrier operations from 1970 to 1985 (Table 1).

The intrinsic limitations of using *fatalities* as a numerator were discussed earlier. Here the limitations of choosing *passenger miles* as a metric denominator will be examined within the framework of the applications of the risk metric as a whole.

Uses of the Metric

The FAA and the National Safety Council use the metric *passenger fatalities per 100 million scheduled passenger-mi* to compare trends of the normalized accident data of cars, taxis, buses, railroad passenger trains, and domestic scheduled air transport planes (*24*).

The International Civil Aviation Organization (ICAO) compares the safety records of the airlines of the world by using *fatalities per 100 million passenger-km*, which is essentially the same metric.

Potential Misuses of the Metric

A risk analyst must always question the applicability of a particular risk metric for a prescribed use. For example, when comparing airlines, the analyst must be aware that the risk in air transportation is concentrated in the takeoff and landing phases. Data in Table 3 reveal that of the 37 U.S. domestic scheduled air carrier accidents involving passenger fatalities between 1970 and 1985, 27 (73 percent) took place during take-off or landing and 10 (27 percent) took place during cruise. On this basis, it would seem that perhaps a better metric denominator to capture the "exposure" to air transportation risk would be *number of flights* rather than *number of passenger miles*.

In addition, when comparing airlines using *fatalities per 100 million passenger-mi* as a medium-spectrum metric, one has to be aware that the metric favors the larger airlines, which usually have larger airplanes carrying a larger number of passenger for longer distances.

Large airlines complete fewer flights than small airlines to reach 100 million passenger-mi. For example, in 1983 it took United Airlines approximately one day to cover 100 million passenger-mi in its domestic scheduled market. In contrast, it would have taken Mid-South, a middle regional airline, 12.5 years to fly 100 million passenger-mi. During December 1983, United had an average of 1,367 departures a day (or 100 million passenger-mi), whereas Mid-South would have had 119,475 departures in 12.5 years (the required time to perform 100 million passenger-mi). That is, every United takeoff would correspond to 87 Mid-South takeoffs. If one believes that risk in air transportation resides in the takeoff and landing phases rather than in the en-route phase, the last statistic could be interpreted to mean that Mid-South has to undergo a risk 87 times larger than that undergone by United when *100 million passenger-mi* is used as a metric denominator.

Using the metric *fatalities per 100 million scheduled passenger-mi* as a wide-spectrum metric to compare different modes of transportation poses some problems because the differences in speed, passenger-carrying capacity, load factor, and level of service are not accounted for. For example, air transportation is much faster than ground transportation; therefore the time of exposure required to achieve the same number of miles is much less for air transportation than it is for ground transportation. Trains carry roughly 3.5 more passengers per trip than air carriers and 5 times more than a bus. Last, the frequency of departure and availability of service of the different modes of transportation vary considerably depending on the market studied.

Fatal Accidents per 100,000 Flights

The metric *fatal accidents per 100,000 flights* focuses only on those accidents in which human life was lost within 7 days of an air carrier accident. From 1970 to 1985 the U.S. domestic scheduled air carriers completed 100,000 flights in approximately 1 week. This metric represents a good attempt to use a denominator that captures the activity in which the risk resides in air transportation.

Uses of the Metric

Fatal accidents per 100,000 flights is used by the FAA as a wide-spectrum metric to measure the probability of having a fatal accident as a function of the number of takeoffs. The FAA uses this metric in its handbooks of aviation statistics as a safety-trend indicator. It can also be used as a medium-spectrum metric for comparing the safety standards of different airlines.

Advantages and Limitations of Fatal Accidents as Numerator

Fatal accidents is a reliable parameter, because all accidents resulting in loss of human life are reported. One of its limitations, however, is that fatal accidents are rare events. From 1970 to 1985 the U.S. domestic scheduled air carriers experienced 61 fatal accidents. Because of these relatively low numbers, analysts sometimes prefer to use total reported accidents; according to *Flight International*, there were 351 reported accidents for U.S. domestic air carriers from 1970 to 1985.

Fatal accidents as a metric numerator incorporates some leveling-of-distinctions bias because it does not differentiate between a TWA nonsurvivable accident (Dec. 1, 1974) in which 92 lives were lost because of a premature descent (*6*) and a World Airways accident (Sept. 20, 1981) in which there were 345 people on board and only a stewardess trapped in the galley was killed (*14*).

Potential Misuses of the Metric

If cast as fatal accidents per 100,000 departures, *fatal accidents per 100,000 flights* could be used as a wide-spectrum metric to compare different modes of transportation. However, the strong correlation between risk and number of departures is only present in air transportation; other modes show a higher correlation between risk and number of miles traveled.

TABLE 3 FATAL ACCIDENTS OF THE U.S. DOMESTIC SCHEDULED AIR CARRIERS (2–17)

		FLIGHT	TOTAL	F A T A L I T I E S		
		PHASE	ABOARD	PASSENGER	CREW	TOTAL
01/28/70	TAG	E	9	7	2	9
05/06/71	APACHE	E	12	10	2	12
06/06/71	HUGHES AIRWEST	E	51	44	5	49
06/07/71	ALLEGHENY	L	31	26	2	28
09/04/71	ALASKA	L	111	104	7	111
02/22/72	AIR HAWAII	E	8	7	1	8
06/29/72	NORTHCENTRAL	E	5	2	3	5
06/29/72	AIR WISCONSIN	E	8	6	2	8
12/08/72	UNITED	L	61	40	3	43
07/24/73	OZARK	L	45	37	1	38
07/31/73	DELTA	L	88	83	5	88
08/30/73	TWA	L	141	1	0	1
09/27/73	TEXAS	E	11	8	3	11
11/04/73	NATIONAL	E	128	1	0	1
09/11/74	EASTERN	L	82	69	2	71
12/01/74	TWA	L	92	85	7	92
12/11/74	KEY WEST	E	5	4	1	5
06/24/75	EASTERN	L	124	106	6	112
08/30/75	WIEN ALASKA	L	32	7	3	10
04/05/76	ALASKA	L	50	1	0	1
04/04/77	SOUTHERN	E	85	60	2	62
05/16/77	NEW YORK	L	25	4	0	4
03/01/78	CONTINENTAL	T	197	2	0	2
05/08/78	NATIONAL	L	58	3	0	3
09/25/78	PSA	L	138	129	7	136
12/28/78	UNITED	L	189	8	2	10
02/12/79	ALLEGHENY	T	25	1	1	2
03/10/79	SWIFT AIRE	T	7	1	2	3
05/25/79	AMERICAN	T	271	258	13	271
06/12/80	AIR WISCONSIN	L	15	11	2	13
01/13/82	AIR FLORIDA	T	79	70	4	74
01/23/82	WORLD AIRWAYS	L	208	2	0	2
07/09/82	PAN AM	T	145	138	7	145
01/09/83	REPUBLIC	L	36	1	0	1
10/11/83	AIR ILLINOIS	L	10	7	3	10
08/02/85	DELTA	L	163	128	8	136
09/06/85	MIDWEST	T	36	31	5	36

En route (E); Landing (L); Take-off (T)

Fatal accidents per 100,000 flights could also be used as a medium-spectrum metric to compare two airlines. However, problems may arise if one of the two airlines compared has a significantly larger number of departures or much larger airplanes, or consistently travels with much higher load factors than the other.

Probability of Being Killed in an Air Carrier Accident

The odds of being killed in an airline accident are obviously of interest to the passengers. In this paper, the metric was derived by using statistics on the U.S. domestic scheduled air carriers from 1970 to 1985 (Tables 1 and 2). The fatality quotient was defined as the fraction of passengers who did not survive a given flight; it was set to zero for all the flights that landed safely. The fatality quotient was derived by dividing the total number of passenger and crew fatalities by the total number of passengers on a given flight (Table 4). After all the positive fatality quotients had been calculated, they were summed on a yearly basis. The normalized quotient was derived by dividing the cumulative yearly fatality quotients by the annual number of flights. The normalized quotients reflect the probability that a passenger or crew member will be killed in a U.S. domestic scheduled air carrier accident during a particular year. The odds of being killed in an air carrier accident are shown in Table 4 as the inverse of the normalized quotient.

The metric takes into account the number of survivors of a given accident but not the mileage flown. Figure 4 shows the fatality quotients for each fatal flight of the U.S. domestic (scheduled and unscheduled) air carriers from 1970 to 1985. The fatality quotients take values close to either 0 or 1, which can be easily approximated by a Poisson process. The major limitations of this metric reside in its measurement of risk in terms of the fatality quotients, which depend on the number of fatalities. These limitations were discussed earlier.

Uses of the Metric

The probability of dying in an air carrier accident was used as a risk metric by Barnett et al. (*25*) to compare the safety records of 58 major world airlines.

Potential Misuses of the Metric

Probability of being killed in an air carrier accident could be misused if the limitations of using fatalities as a risk-measuring parameter were not realized. Furthermore, if it were modified to be used as a wide-spectrum metric for comparing the safety of air transportation with that of other modes of transportation, it would lose one of its major attractions, namely, the Poisson process approximation. This would occur because typically a high percentage of passengers survive train and bus accidents, thereby making it inaccurate to assume a 0-1 process. Last, this

TABLE 4 DERIVATION OF PROBABILITY OF BEING KILLED IN AN AIR CARRIER ACCIDENT

	FATALITY QUOTIENT (2–17)	YEARLY FLIGHTS (20) (million)	NORMALIZED QUOTIENT (10^{-7})	ODDS OF BEING KILLED ON A FLIGHT (denominator in millions)
1970	1.00	5.0	2.00	1 in 5.0
1971	3.86	4.7	8.22	1 in 1.2
1972	3.70	4.7	7.88	1 in 1.3
1973	2.86	4.8	5.96	1 in 1.7
1974	1.87	4.5	4.14	1 in 2.4
1975	0.90	4.5	2.01	1 in 5.0
1976	0.02	4.7	0.04	1 in 235
1977	0.89	4.8	1.85	1 in 5.4
1978	1.11	4.8	2.32	1 in 4.3
1979	1.51	5.0	3.02	1 in 3.3
1980	0.00	5.1	0.00	1 in ∞
1981	0.00	4.9	0.00	1 in ∞
1982	1.95	4.7	4.14	1 in 2.4
1983	1.03	4.8	2.14	1 in 4.7
1984	0.00	5.1	0.00	1 in ∞
1985	2.00	5.1	3.92	1 in 2.6

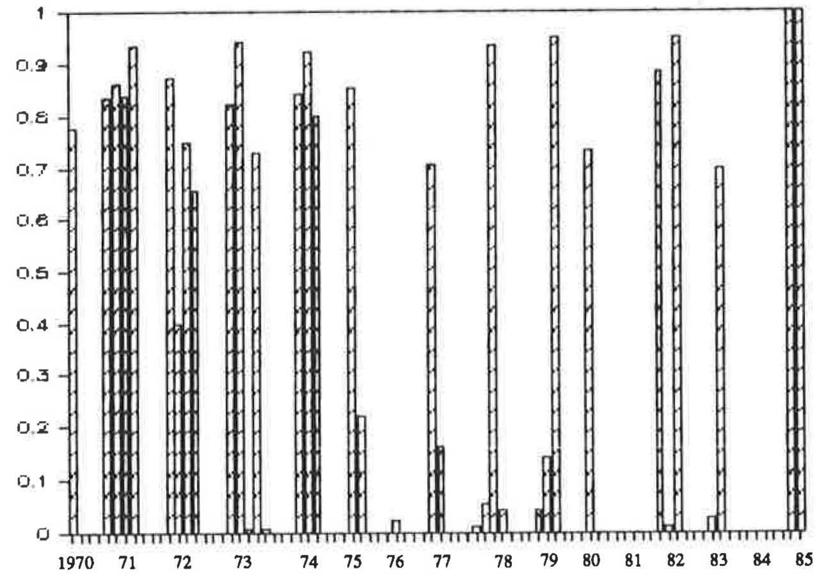

FIGURE 4 Yearly fatality quotients.

metric should not be used if mileage flown is assumed to be a parameter affecting air transportation safety.

Total Accidents per 10 Million System Flying Hours

The metric *total accidents per 10 million system flying hours* records all the air transportation mishaps that resulted in human injuries or damage to airplanes in intervals of 10 million flying hours. During the period studied (1970 to 1985) the U.S. domestic scheduled air carriers flew 10 million hr approximately every 2 years, and there were 351 reported accidents, of which 61 (17 percent) were fatal. This measurement is often used as a medium-spectrum metric for air traffic control purposes. It can be applied to wide-spectrum purposes if it is cast as total accidents per 10 million travel hours.

Uses of the Metric

The North Atlantic System Planning Group (*26*) used the metric in the mid-1960s to set target levels of safety in the North Atlantic region. In its safety trends, the FAA uses a narrower-spectrum metric: *accident rate per 100,000 system hours flown* (*21, 22, 24*). Both these metric denominators (*10 million system flying hours* and *100,000 system flying hours*) encompass a longer time period than 100 million passenger-mi. An attractive feature of *total accidents per 10 million system flying hours* is that it contains a relatively large number of data points.

Advantages and Limitations of Total Accidents as Numerator

Using *total accidents* as a metric numerator represents an effort to include all instances in which something "went wrong" in air transportation. *Total accidents* as a metric numerator incorporates leveling of distinctions because it assigns equal weight to an accident in which an airplane veered off a runway and there were no casualties (Ozark, March 16, 1980) (*28*) and to one in which 273 lives were lost (American Airlines, May 25, 1979) (*11*). Another problem is that the data on total accidents are not completely reliable because not all accidents are reported. Using 10 million system flying hours as a normalizing parameters presents similar problems as using hours of exposure, namely, that faster modes of transportation are discriminated against.

Potential Misuses of the Metric

Total accidents per 10 million system flying hours incorporates serious leveling of distictions by not differentiating between fatal and nonfatal accidents. An analyst interested in loss of life or property should avoid this metric. It should also be avoided if one wants to compare airlines of very different sizes or airlines operating in very different weather conditions.

Miles Flown Between Successive Accidents

To derive the metric *miles flown between successive accidents*, the fatal accidents suffered by both the scheduled and unscheduled U.S. domestic air carriers from 1974 to 1983 were considered. The number of days between successive accidents was counted and then translated to the number of miles flown. This was done by assuming that U.S. domestic air carriers flew the same number of miles every day. The yearly miles flown was divided by 365 (or 366 for leap year) to obtain the daily number of miles flown. The daily mileage was then multiplied by the number of days from one accident to the next (Table 5). When the interaccident time spanned two consecutive years, the number of days corresponding to each year was counted and multiplied respectively by the daily mileage of each of the two consecutive years in question.

Uses of the Metric

This measurement is widely used as a medium-spectrum metric by those concerned with airplane maintenance. It can be cast as *miles traveled between successive accidents* and used as a wide-spectrum metric to compare different modes of transportation. The metric *miles flown* (or traveled) *between successive accidents* has the probabilistic interpretation of "interarrival time" for a stochastic process. On the basis of this notion, a policy maker might want to set safety standards using this metric so that there is a probability not greater than a prescribed target level of having an accident in an interval of a predetermined duration.

TABLE 5 DAYS ELAPSED AND MILES FLOWN BETWEEN ACCIDENTS OF THE U.S. DOMESTIC SCHEDULED AIR CARRIERS

	CARRIER (2–17)	DAYS	MILES (million)
03/13/74	SIERRA		
09/11/74	EASTERN	171	700
12/01/74	TWA	80	425
06/24/75	EASTERN	186	992
04/05/76	ALASKA	302	1638
04/04/77	SOUTHERN	363	2065
05/16/77	NY AIRWAYS	41	243
12/13/77	NATIONAL	221	1308
03/01/78	CONTINENTAL	77	470
05/08/78	NATIONAL	67	413
09/25/78	PSA	139	856
12/28/78	UNITED	93	573
02/12/79	ALLEGHENY	45	303
03/10/79	SWIFT AIRE	25	169
04/18/79	NY AIRLINES	38	257
05/25/79	AMERICAN	36	244
06/12/80	WISCONSIN	383	2611
09/07/81	AMERICAN	451	3058
01/13/82	AIR FLORIDA	127	850
01/23/82	WORLD AIRWAYS	9	60
07/09/82	PANAM	166	1111
08/11/82	PANAM	32	214
01/09/83	REPUBLIC	150	1006
10/11/83	AIR ILLINOIS	274	1915

Potential Misuses of the Metric

The main problem with this metric derives from the differences in severity of aviation accidents. The measured interarrival time may be misleading because it may reflect the time elapsed between events that are very different in nature. An analyst concerned about total levels of air transportation safety may be more interested in total number of fatalities than in the relative frequency of accidents. The media, however, seem to abuse this metric by reporting "new" accidents.

Mean Time Between Failures

This metric is similar to *miles flown between successive accidents* and it is the most commonly used narrow-spectrum metric. To derive the mean time between critical failures, analysts must decide which failure to count, for how long, and during which phases. Once analysts have decided which parameter to measure, they must decide how to measure it. Broadly speaking, avionics tests can be divided into destructive and nondestructive ones. Within these two major groups, one can then classify the tests as environmental, physical, and electrical. Once a testing setup is working, analysts have only to count failures during a predetermined period of time and average the interfailure times to obtain the mean time between failures.

A difficult challenge is to understand how the narrow-spectrum metrics relate to wider-spectrum metrics. Ideally, one should be able to translate risk quantitatively among the different sectors of the air transportation industry. Such translations would aid in understanding how narrow-spectrum risks contribute to the aggregate air transportation industry risk.

An example of a probabilistic model that would translate the probability of a critical failure into the expected number of fatalities follows. This model was suggested by B. B. Myers of Transport Canada.

$$E = NP_{F|A}P_{A|CF}P_{CF} \tag{1}$$

where

E = expected number of fatalities,
N = number of occupants (crew and passengers),
$P_{F|A}$ = probability of fatalities given an accident,
$P_{A|CF}$ = probability of an accident given a critical failure, and
P_{CF} = probability of critical failure.

$$P_{CF} = P_s + P_e + P_c \tag{2}$$

where

P_s = probability of a system's contributing to failure,
P_e = probability of the environment's contributing to failure, and
P_c = probability of crew's contributing to failure.

The stochastic quantities involved in Equations 1 and 2 are difficult to estimate. However, any attempt to quantify the probabilities in these equations would prove useful, because it would put things in perspective.

Uses of the Metric

This metric is often used to measure and forecast the reliability of aircraft subsystems, especially that of avionics. According to Bird and Herd (27), avionics accounts for 40 percent of the problems of all aircraft types. *Mean time between failures* is often used in the testing and operational stages of avionics. However, there are limitations in that the reliability of avionics depends on numerous factors, including the complexity and quality of the design, use of state-of-the-art technology, avionics-aircraft interface, resources allocated for avionics development, intensity of monitoring and quality control during manufacturing, training of service personnel, maintenance standards, and test facilities (*28*).

Potential Misuses of the Metric

Mean time between failures might present problems if a careful record of the test conditions and the responses to the test is not kept. Furthermore, this metric should not be used as a deterministic parameter, but rather as a probabilistic parameter with confidence intervals.

COMPARISON OF RISK METRICS EXAMINED

In the previous section the strengths, limitations, uses, and potential misuses of seven commonly used aviation risk metrics were examined. The metrics of interest include fatalities per hour of exposure to air transportation, passenger fatalities per 100 million scheduled passenger-mi, fatal accidents per 100,000 flights, probability of being killed in an air carrier accident, total accidents per 10 million system flying hours, miles flown between successive accidents, and mean time between failures.

Comparing these metrics is difficult because their duration spans are very different. For example, the U.S. domestic scheduled air carriers fly 100 million scheduled passenger-mi in less than 1 day, 100,000 flights in 1 week, and 10 million flying hours in 2 years. One way of avoiding the duration-span incompatibility is to modify the metrics so that they can be expressed as yearly parameters. Figures 5 and 6 show the risk levels displayed by the U.S. domestic scheduled air carriers as measured by the following modified metrics: yearly probability of being killed in an air carrier accident (Parameter A in Figure 5), yearly total fatalities per yearly system flying hours (Parameter B in Figure 5), yearly total accidents per yearly aircraft miles flown (Parameter C in Figure 6), yearly passenger fatalities per yearly passenger miles (Parameter D in Figure 6), and yearly fatal accidents per yearly flights (Parameter E in Figure 6).

One can see that different metrics yield different perceived levels of safety, and the information derived from these tables can be conflicting. For example, from 1972 to 1974, Parameter A in Figure 5 leads one to believe that safety is improving, whereas Parameter B gives the opposite impression. From 1976 to 1985, Parameters C, D, and E in Figure 6 present inconsistent information regarding the relative levels of safety.

To avoid confusion, aviation safety studies should be conducted using several metrics. An understanding of the effects of using different risk metric numerators and denominators is crucial.

CONCLUSION

In this paper an attempt has been made to show that there is no "correct" or "unique" way of measuring risk in air transportation and that the risk metric selected for any study involving risk appraisal may influence the perception of risk. Because of the potential introduction of biases by a particular metric choice, one should always question the applicability and limitations of risk metrics. When possible, aviation risk analyses should be conducted using several risk metrics and should state the applicability, strengths, and limitations of each metric.

One of the weaknesses of this study is that none of the numerators of the risk metrics deal with the underlying cause of the accidents or the fatalities. The metrics make no distinction between accidents caused by weather and accidents caused by pilot error or faulty maintenance. Determining and accounting

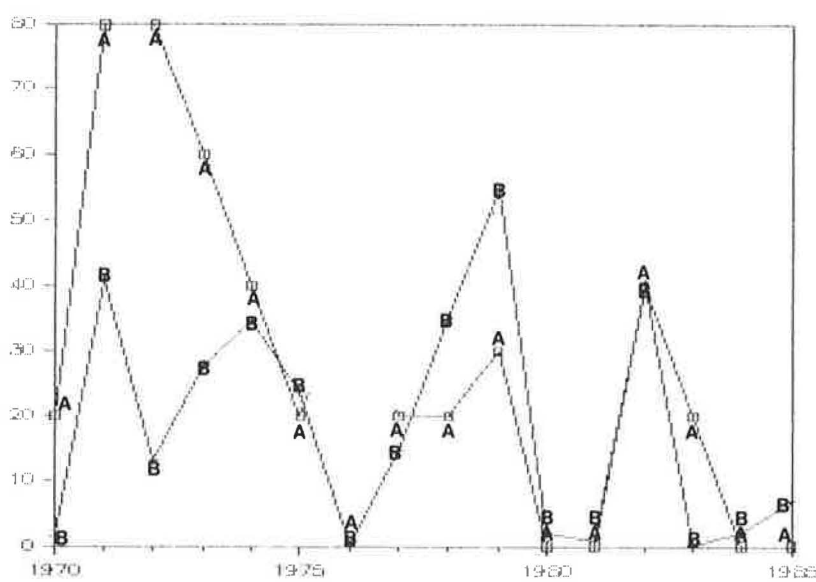

FIGURE 5 Comparison of risk metrics: *A*, yearly probability of being killed in an air carrier accident; *B*, yearly total fatalities per yearly system flying hours.

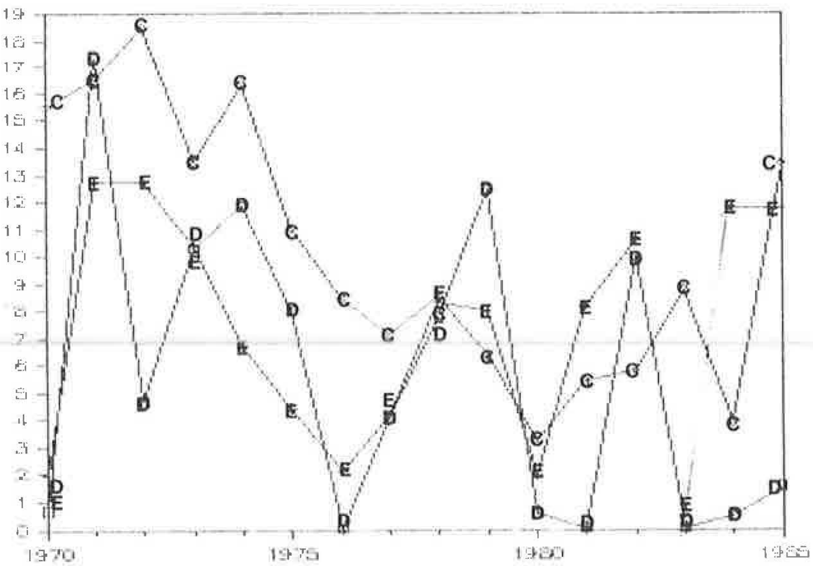

FIGURE 6 Comparison of risk metrics: *C*, yearly total accidents per yearly aircraft miles flown; *D*, yearly passenger fatalities per yearly passenger miles; *E*, yearly fatal accidents per yearly flights.

for the different accident causes is a difficult task. However, it seems desirable to incorporate this notion in order to conduct more equitable and balanced risk analysis studies.

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