TRANSPORTATION RESEARCH RECORD 958

Issues in Air Transport

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Issues in Air Transport

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1984

Transportation Research Record 958
Price $7.80
Editor: Jane Starkey
Compositor: Lucinda Reeder
Layout: Betty L. Hawkins

mode
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Printed in the United States of America

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Issues in air transport.

(Transportation research record; 958)
Reports prepared for the 63rd annual meeting of the Transportation Research Board of the National Research Council.
Include bibliographies.
1. Aeronautics, Commercial–United States--Congresses. 2. Airports--United States--Congresses. 3. Aeronautics, Commercial--Law and legislation–United States–Congresses. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 958 380.5 s 84-22804 [HE9803.A4]
[387.7'0973] ISBN 0-309-03704-2 ISSN 0361-1981

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Some Probable Effects of Deregulation on Airline Industry Economics

JUAN C. O'CALLAHAN

ABSTRACT

The larger U.S. airlines will probably continue to face severe economic difficulties throughout this decade. The reason for this pessimistic projection is that the established carriers will face a prolonged erosion of their overall profits (in relation to their costs) from sustained low-fare competition by low-cost specialist carriers that entered the air transportation industry after deregulation. This erosion of profits could be exacerbated not only by the expansion of low-fare, new-entrant passenger carriers of various specialty categories, but also by the diversion of heretofore profitable belly cargo to the vertically integrated services of specialist freight, mail, and package-express companies. The conclusion drawn here is that the danger of deregulation in the longer term may be in producing the opposite of what it intended; for example, less competition, half a dozen mammoth air transportation companies, and few small- or medium-sized carriers above the regional carrier category.

The potential impact of the current challenges to the airline industry in the long term is the focus of the discussion in this paper.

The larger U.S. airline carriers will probably face further sustained erosion of profits during the 1980s from new competition targeting business traffic as well as discretionary travelers and new competition for large volume freight as well as packages, priority and express cargo, and mails.

The discussion in this paper focuses on

1. New-entrant passenger carriers,
2. Other low-fare and specialist passenger carriers,
3. Low-cost passenger carrier expansion,
4. New-entrant cargo carriers,
5. Other specialist cargo carriers, and
6. Potential U.S. mail contractors.

New-entrant passenger airlines are predominantly shorter-haul carriers for high-density markets, that provide high-frequency, low-fare, one-class service. These carriers are modeled after Pacific Southwest Airlines (PSA), the original short-haul carrier and Southwest, currently the largest supplier of short-haul service. The operating concepts of these carriers are well known, for example, modern, but often used, efficient equipment, high utilization, fast through and turn times, high employee productivity (through new reimbursement concepts and job descriptions), no-frill services, high-density seating, and simple fares coupled with low overhead. Southwest, in 1980, at an average stage length of less than 300 miles, achieved a total operating cost of $6.80 per mile (excluding interest expense) with 737-200 aircraft and an operating profit margin of 23 percent.

The cost savings achieved by new-entrant carriers are partly effected by

- Aircraft productivity, for example, 11 1/4 hours versus; 7 1/2 hours utilization reduces insurance rates, depreciation, and interest expense (or lease cost) accounts by more than 30 percent on an hourly basis;
- Flight crew and cabin attendant productivity; for example, fewer personnel per flight, more flight hours per month, added job responsibilities, less crew expenses, and lower wage scales can save up to 60 percent on these accounts versus equivalent pre-1980 trunk carrier costs on similar route stage lengths; and
- Moderate but cumulatively significant savings on maintenance labor and burden, aircraft and passenger handling, other passenger services, ticketing and sales, and general and administrative cost accounts.

The resultant cost levels permit point-to-point rate structures that are usually about 40 percent below the 1981 economy fare levels in existence before the start-up airlines entered the market. The rate structures are somewhat higher for new-entrant carriers if older and less cost-effective aircraft are used.

These low-cost airlines (established carriers like Southwest, new entrants, and proposed start-ups) have covered the obvious markets in the United States, and where gaps exist, additional new carriers will likely enter the market. Recently, starting a new domestic airline has been a remarkably simple exercise. All that is needed is an Official Airline Guide (OAG), basic Civil Aeronautics Board (CAB) origin and destination data, and Economic Regulation (ER) 586 and other Form 41 data. With a few months' work, an individual could formulate a corporate plan, prepare a CAB service application, and develop a prospectus background presentation for underwriters, lawyers, and banks. Readily available funds, however, have recently been more difficult to obtain, and several proposed start-ups may be unable to secure adequate capitalization and financing.

Meanwhile a new challenge is developing. Lower-cost specialist and former local airlines are moving into longer-range and medium-density markets with efficient twin-jet aircraft and with somewhat lower-cost structures as previously discussed. Examples might include Air Florida and Republic Airlines, which are operating in numerous longer-range markets between various quadrants of the United States. The airlines that were formerly supplemental carriers also operate low-fare scheduled services in certain major long-haul markets, although a proportion of these services are concentrated between secondary airports. Perhaps of equal significance is a new service concept proposed by Texasamerican. This concept consists of a medium, long-haul network extending from the fast growing, previously underserved (before mid-1981) areas comprising the south

Texas and Oklahoma basins with a marked concentration on first-class and full-fare higher-yield services.

Half a dozen carriers equivalent to Texasamerican--not necessarily all new entrants (Southwest, Federal Express, Air Florida, and several other carriers)--would readily employ the same concept on a larger scale. If, economically, these carriers were as efficient as Southwest in this different service-tier structure, they could force the larger airlines to compete with below-cost fares over a sizable portion of their medium-range systems. Besides capturing significantly higher yield traffic, a medium, long-haul low-fare (low economy fare and also low first-class fare) specialist industry comprising, for example, 100 aircraft by the mid-1980s, would exert even greater pressure on the larger airlines to reduce overall yields to generally unprofitable levels.

The U.S. air cargo industry, generally, has not witnessed dramatic change in terms of growth, new service concepts, or marketing techniques (with certain specific exceptions). During the decade of 1971-1981, cargo ton-mile growth by the former trunk carriers and the all-cargo carriers was only 4 percent per annum--higher, of course, in belly cargo than in freighter aircraft. Since the deregulation of cargo in late 1977, average annual cargo ton-mile growth to 1980 has been even lower, whereas cargo yields have increased at almost the same level as passenger yields.

In short the potential impact of cargo deregulation has yet to demonstrate any significant breakthrough. Some adverse economic effects, however, may appear earlier than expected. What of the future? The large forwarders are acquiring or beginning to contract for their own aircraft fleets. Vertically integrated, surface-air transport is a frequently heard new buzzword. Yet the complexity of U.S. air cargo is little understood and virtually not studied in depth except by those in the freight forwarder field and a few cargo-oriented airlines, such as Flying Tigers and Northwest. Cargo appears to be the step-child of the air transport industry.

In Europe Cargolux expanded its business based on an effective surface transfer fleet (contracted in part) in addition to a low-cost, quasi-charter planeload schedule structure. In consortium with certain major foreign forwarders and CSAs, it captured a freight market that had nothing to do with its own national country of origin or destination. Its traffic was and still is German, British, Dutch, French, Middle East, Far East, West African, United States, and Central and South American. It operates 747 freighters on its main routes at the lowest available ton-mile costs. Luxembourg is essentially a transfer hub the equivalent of Memphis for Federal Express, but for large volume freight instead of small express-service packages. Cargolux may have to struggle economically, particularly in the short term, but it is not difficult to perceive the losses its freight competitors will have to sustain in order to crush Cargolux.

What would be the impact on the larger U.S. carriers if a carrier similar to Cargolux emerged in the United States, or, taken a step further, a carrier that was corporately integrated with the major freight controlling forwarders? The probable answer is that the response (in the mid to late 1980s) of some of the more aggressive larger airlines would be to integrate vertically, acquire and operate many more freighter aircraft units, or incur further losses. This in turn could tend to reduce combination aircraft belly loads and lower the vital property yields on these aircraft that now make the difference between profit and loss.

The potential erosion of combination aircraft yields through diversion of freight will put new pressure on the larger airlines to increase passenger fares. At the same time, these airlines, as discussed previously, may be facing the challenge of widespread pressure from smaller, low-cost carriers.

In a specialist cargo category, Federal Express demonstrated a new concept which, in its field, was far more dramatic than Southwest's example in the passenger category. In 1981 Federal Express achieved an operating profit of more than $100 million despite its use of a large number of small, relatively high-cost aircraft. The current Federal Express economic cost structure, as a percent of gross, can be reasonably estimated as follows:

Cost Structure	Percent Gross
Flying operations	30
Field services and hub and spoke handling	35
Selling and marketing	5
Administrative and other	12
Operating profit	18

Federal Express, until now, has had little need to be concerned with lowest ton-mile cost aircraft: its parameters were lowest-per-mile costs because its break-even load factors (and probably its on board load factors) were remarkably low. Thus it had the advantage of being able to acquire used, former-generation, low-depreciation, and low interest-expense burdened aircraft. Recent departures from this principle include its acquisition of new 727-200 aircraft, instead of used DC8-60 series types, and relatively expensive DC-10-30s. However, even with the more expensive 110,000-lb payload DC-10-30 aircraft--as loads become significantly greater and average density decreases--Federal Express's remarkable profit-making capability can be illustrated by observing that its break-even load factor on this aircraft is probably less than 10 percent. A theoretical example (based on 1981 conditions) is as follows:

- DC10 coast-to-coast via Memphis operating cost: $55,000
- Flying operations and hub handling cost offset per piece (at 50 percent of average piece charge): $10
- Break-even number of pieces on board: 5,500
- Average DC10 on board break-even load tons (at 1.5 lb/piece): 4.13
- Average DC10 break-even load factor: 7.5 percent

What do all these factors have to do with current challenges to the airline industry? First, in retrospect, Federal Express's innovation is a concept that any major airline could have originated. However, new forms of cargo-related studies were not then being undertaken, and high-investment cargo concepts were anathema to major airline managements. Second, the CAB Sunset Act could encourage U.S. Postal Service contracting which--coupled with the example set by Federal Express--might lead the postal giant to develop a similar concept. Third, several relatively new participants in the express package field could develop central sorting hub structures thereby siphoning from the major airlines not only priority pieces but other categories of freight traffic as well.

U.S. Postal Service contracting authority could be a catalyst for extensive, full-planeload mail conveyance contracting similar to the military Logair and Quicktrans contracts. If planeload rates are attractive (preliminary indications are that they could be some 25 to 30 percent below equivalent 1981 CAB mail rates), the U.S. Postal Service could justify airlifting certain categories of surface-rated mails. This could mean more domestic mail being transported by air, but less being transported in scheduled service belly compartments. Once again, this could mean a further erosion of combination aircraft yields. The major carriers will undoubtedly bid for U.S. Postal Service contracts, which probably total more than $400 million annually, but not all carriers will necessarily get them, whereas all carriers will face continued and increased pressure on the profitability of their passenger operations.

If these challenges are real, the larger airlines will react in a number of ways to counter low-fare, short-haul specialists, medium long-haul low-cost specialists, express-package specialists, forwarder-cargo airline specialists, and other new-entrant carrier specialists. It could take a decade to wage a counter-strategy, and during those years the larger airlines could experience large and continued losses. (This conflict might well be similar to the decades-long battle of the large international scheduled airlines versus the charger carriers on the North Atlantic, where everyone lost.)

Domestically, some of the stronger major airlines, such as United, American, Delta, and Northwest, could eventually win this conflict and force a number of new entrants out of business. To do so, however, will require a sustained erosion of their potential profit base. Furthermore, some of the weaker major airlines will be caught in the middle and may not survive.

As part of the counter-strategy, some of the larger carriers will probably get far larger. They may effect further mergers, integrate with freight and other specialist concerns, possibly create specialist carriers of their own, and become giants if they can.

The so-called nationals, in order to be viable in the longer term, may also have to form liaisons, mergers, or acquisitions and formulate a difficult strategy of rapid growth without incurring large losses. Long-haul national carriers could merge with medium- and short-haul feeder carriers, for example, or vice versa, and become effective full-service airlines (e.g., Transamerica with Republic, World with Frontier). They also may have to integrate with freight specialists, if possible. There will be a number of failures, and these will not all be new entrants or smaller airlines.

The danger of deregulation in the long term is that it may produce, in the United States, the opposite of what was intended--for example, less competition, half a dozen mammoth air transportation companies, and very few small- or medium-sized carriers (above the regional category).

In the interim, the economic outlook for the larger established airlines during this decade is generally bleak except for a year or two of fair profits--but certainly nowhere near the sustained 15 percent return on investment the industry needs to reequip periodically and to provide effective growth and service. For some carriers the challenge to remain viable will be difficult. Long-range strategic planning and development of innovative concepts have never been more important.

Publication of this paper sponsored by Task Force on Economics of Air Transport.

Discount Fare Market Research, 1981-1983

DONALD J. BENNETT

ABSTRACT

In 1981 and again in 1982-1983 Boeing sponsored surveys of passengers flying on U.S. and Canadian airlines to determine their responses to various proposed discount fare plans. From analysis of these surveys, it is apparent that (a) passengers will use reduced fares, even for small savings, whenever it is convenient for them to do so; (b) passengers who did not use a discount fare listed fare restrictions more often than any other reason; and (c) the ability of passengers to meet restrictions varies greatly depending on the characteristics of the market being considered. Incorporation of these findings into the design of discount fare plans is critical for an airline with an objective of maintaining or increasing profit levels. Proposed discount fare plans must be carefully evaluated. Market research is necessary to determine discount levels that will stimulate additional travel without undermining profitability. Characteristics of travel in the targeted markets must be determined in order to design restrictions that effectively control the tendency of potential full-fare passengers to divert to discount fares.

Discount fares can have a significant effect on the profitability of an airline.[1] To understand this effect, it is necessary to evaluate the response of the marketplace to a proposed fare--from the point of view of both the traveling public and an airline's competitors. Boeing continues to sponsor research that attempts to characterize these responses and their effects on airline profits.

Although most publicity about deep discount pricing and fare wars has occurred since the Deregulation Act of 1978, the first Boeing studies began in the low traffic growth years of the early 1970s. With the cooperation of 18 airlines Boeing has surveyed more than 63,000 airline passengers since 1972 to gauge their response to different discount fares (Figure 1). In actual airline planning environments, many times that number of surveys may be needed annually; however, for the purposes of investigative research, all that is required is sufficient detail to ensure that results are statistically significant. Summaries of previous Boeing discount fare management research are available (1-4).

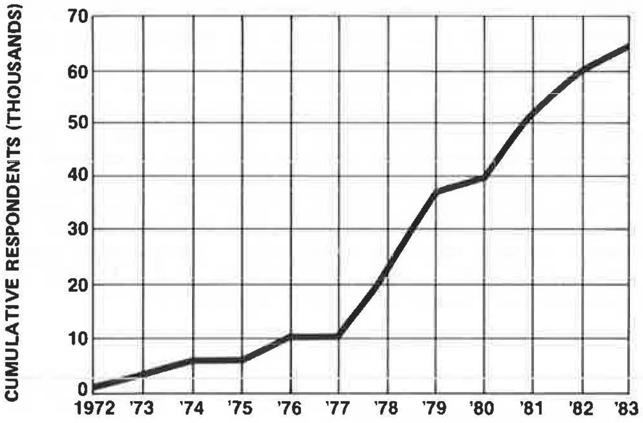


FIGURE 1 Boeing involvement in promotional fare surveys.

Boeing has recently analyzed two sets of passenger surveys of discount fares. The first surveys were conducted from August to November 1981; the second from September 1982 to March 1983. The two sets involved a total of 10 U.S. and Canadian airlines and 25,000 passenger responses (Figure 2).

The primary questions addressed by the 1981 and 1982-1983 survey were

1. How are passengers responding to the discount fare environment?
2. Will passengers accept degradation in quality of service in exchange for fare reductions?
3. What types of restrictions are effective in preventing the use of discount fares by travelers who would otherwise fly at full fare?

For proprietary reasons the survey results presented are composites of the individual airline and market results obtained; therefore, they may not apply to specific market situations. They are intended to be compared with proprietary individual market data and to indicate trends.

1981	1982/83
• AIR CAL	• AIR CAL
• AMERICAN	• AIR CANADA
• CONTINENTAL	• CONTINENTAL
• FRONTIER	• CP AIR
• USAIR	• PIEDMONT
• WESTERN	• REPUBLIC
	• WESTERN
13,000 PASSENGER RESPONSES	12,000 PASSENGER RESPONSES

FIGURE 2 Airline participants in surveys.

RESTRICTIONS ARE IMPORTANT ELEMENTS OF DISCOUNT FARE PLANS

One objective of the 1981 and 1982-1983 surveys was to evaluate consumer perception of airline pricing. Passengers were asked a series of fare-related questions designed to identify the type of fare they thought they were using for their current trip. The results reflect the types of fare plans available at the time the surveys were conducted (Figure 3).

In 1981 discounts in the U.S. approached 45 percent of the published full coach fares. Restrictions varied from none to a requirement for 2 weeks advanced booking combined with a Saturday night stay. During this period U.S. travelers were about evenly divided between those who thought they were paying full fare and those who thought they were paying less. Fifty-one percent of the U.S. respondents thought they were using a discount fare.

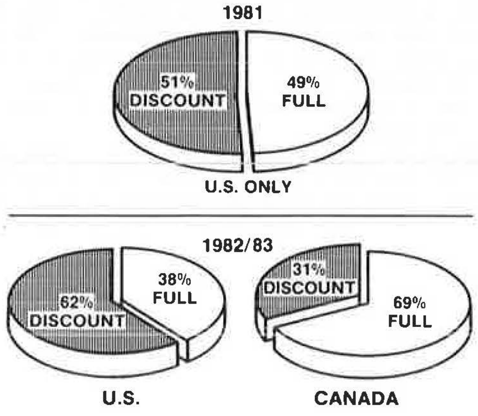


FIGURE 3 Passengers' perceived fare.

During the 1982-1983 surveys U.S. discounts approached 50 percent of published full coach fares and many markets had no restrictions on the lowest available fares. Accordingly the number of U.S. passengers who thought they were paying less than full fare increased from 51 percent in 1981 to 62 percent in 1982-1983. However, only 31 percent of the Canadian respondents thought they had obtained a discount in this same 1982-1983 time period. This difference in the number of perceived discount fare users is probably attributable to restrictions incorporated into the Canadian discount fare plans. In Canada typical fare restrictions required 2 weeks advanced booking combined with a "first Sunday" earliest return to qualify for discounts of approximately 45 percent.

Further evidence of the effectiveness of restrictions in limiting the use of discount fares was obtained when respondents were asked why they had not used a discount fare. Restrictions were the most frequently given reason why full-fare passengers did not use a reduced fare (Figure 4).

PASSENGERS ACCEPT TRAVEL INCONVENIENCES FOR SMALL SAVINGS

A second objective of the surveys was to gain some insight on how fares affect passenger behavior in

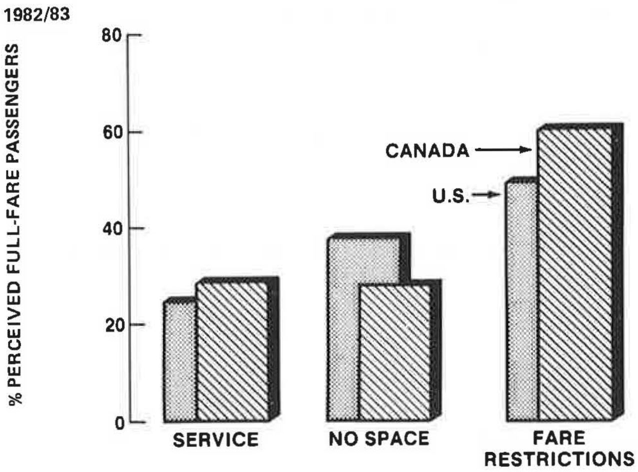


FIGURE 4 Why passengers did not use a discount fare.

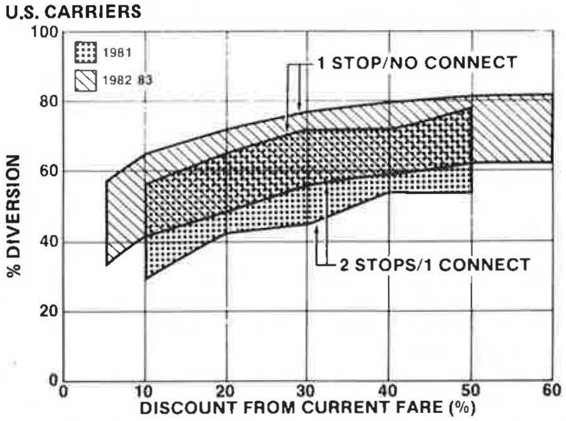


FIGURE 6 Diversion by percent discount.

the flight selection process. The issue addressed was the trade-off between level of discount and quality of service. Specifically, will passengers accept degradation in quality of service to obtain a fare reduction?

In both the 1981 and 1982-1983 surveys, 20 service quality versus discount fare scenarios were tested. Each respondent evaluated only one scenario (Figure 5). In 1981 the discount levels tested were 10, 20, 30, 40, or 50 percent lower than the current fare. In 1982-1983 the discounts were 5, 10, 30, 50, or 60 percent lower than the current fare. To obtain the discount, quality of service would be reduced by the addition of one or two stops. In some scenarios one of the stops required an airplane change (connect). Respondents were advised that each additional stop, whether through plane or connect, would increase their travel time by 1 hour. The airline and airplane type would remain the same.

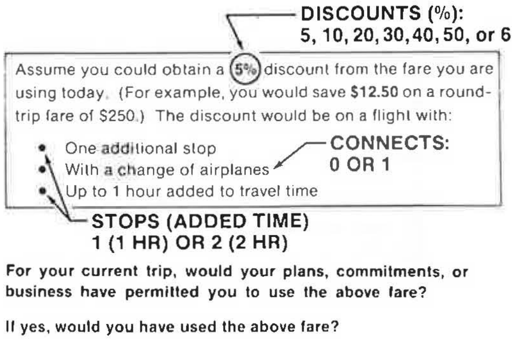
Results obtained from the surveys are expressed as diversion rates (Figure 6). This diversion rate for a given scenario is the fraction of passengers surveyed who said they would accept the proposed reduction in quality of service to obtain the discount fare. The top of each shaded band in Figure 6 represents the diversion rates associated with the scenarios that require one additional stop. The bottom of each band represents scenarios that require one through-plane stop and one connect (i.e., two stops). Diversion rates for the one-stop/one-connect and through-plane two stop scenarios are bounded by these limits.

In 1981 more than half the passengers surveyed said they would accept the reduced service and use the discount fare. A large proportion of the respondents indicated they would use the fare even at small reductions. As the discount increases, the increase in diversion rate is disproportionately small. Comparisons of 1981 with 1982-1983 measured diversion rates show that the 1982-1983 respondents were even more willing to divert.

The 1982-1983 survey was expanded to examine diversion rates as a function of dollar savings, in addition to a percent reduction from the current fare. The results provide an even stronger indication of passenger willingness to sacrifice quality of service for small reductions in fare (Figure 7).

About 60 percent of all passengers said they would divert to a flight requiring an extra stop for savings of only $25 or less. For any amount greater than $25, the responses indicate more than 80 percent would be willing to divert. Even with the inconvenience of two extra stops, one of which entails an airplane change, and the addition of 2 extra hours of travel time, approximately 70 percent of the respondents said they would divert if the savings were more than $50. Further study is recommended to confirm these results because few data are available for some specific savings intervals. Similar data from Canadian carriers were not extensive enough to be statistically significant.

The implication of these results for the airline industry seems clear. Diversion is not so much a function of discount as it is of convenience. Passengers will divert, even for small savings, whenever it is convenient for them to do so. To minimize the diversion of passengers who would otherwise pay full fare, restrictions are necessary.



Assume you could obtain a 5% discount from the fare you are using today. (For example, you would save $12.50 on a round-trip fare of $250.) The discount would be on a flight with:

- One additional stop
- With a change of airplanes
- Up to 1 hour added to travel time

For your current trip, would your plans, commitments, or business have permitted you to use the above fare?

If yes, would you have used the above fare?

FIGURE 5 Service quality versus discount fare scenarios.

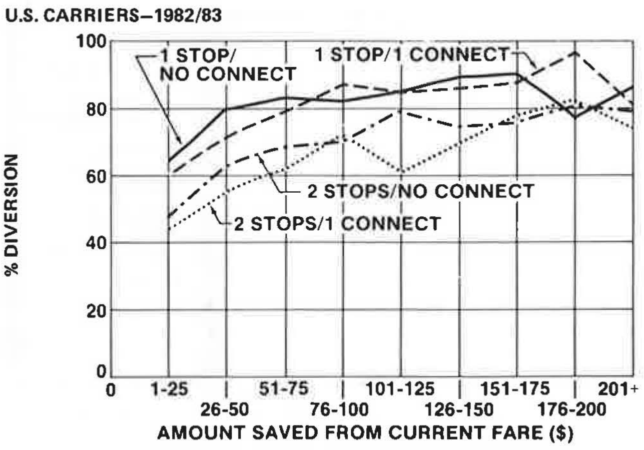


FIGURE 7 Diversion by amount saved.

BUSINESS VERSUS PLEASURE CLASSIFICATION IS A INSUFFICIENT RESTRICTION

A third objective of the survey was to evaluate the extent to which restrictions reduce the diversion of full-fare passengers to a discount fare. The evaluation of a passenger's ability to meet restrictions was based on the characteristics of the trip being taken when the survey was conducted. Passengers were questioned about the advance planning and duration of their current trip as well as whether they would be away over a weekend (Figure 8). Passengers were also asked the primary reason for the trip (Figure 9), their perceived fare type, and who paid for their ticket.

Analysis of the survey results revealed widely varying ability to meet restrictions. To obtain more meaningful results, it was necessary to group the respondents into homogeneous groups instead of attempting to evaluate all of the responses together. To group the respondents, analysis of variance was performed on the advance trip planning, advance reservations, and trip duration responses. Validation of these classifications was based on responses detailing perceived fare type, who paid for the ticket, and primary trip purpose.

Results indicate that the traveling public can be more accurately grouped into four categories (i.e., discretionary business, discretionary personnel, nondiscretionary business, and nondiscretionary personal travelers) than into the often used business versus pleasure definitions (Figure 10). Roughly one-third of the responses fell in each of the nondiscretionary business, discretionary business, and discretionary personal categories. The names are somewhat arbitrary labels for groups of passengers who exhibit similar trip characteristics. Although not necessarily indicative for all travelers within each category, the names generally reflect the predominant trip purpose.

How long before your departure from home did you decide to make this trip?

days

How long will you have been away by the time you return home?

days

Between the time you left home and your return will you have been:

Away over a Friday night?
☐ Yes ☐ No

Away over a Saturday night?
☐ Yes ☐ No

FIGURE 8 Trip planning questions.

Why are you taking this trip? (Please check all items that apply.)

☐ Business appointment
☐ Business conference/convention/meeting
☐ Government/military
☐ Accompanying family member
☐ Vacation/sightseeing
☐ Visiting friends/relatives
☐ Personal emergency
☐ Moving/attending school/research
☐ Other

FIGURE 9 Reasons for travel.

The ability to meet restrictions easily varied greatly among categories (Figures 11-14). Nondiscretionary personal travelers were the least able to meet advanced booking restrictions. Little attempt was made to analyze results from this category because it involved such a small proportion (about 4 percent) of the responses. Nondiscretionary business travelers were also frequently unable to meet potential fare restrictions. At the other end of the spectrum, the discretionary personal travelers were best able to qualify for discounts; and discretionary business travelers fell between the other two major categories.

The percentage of passengers who satisfy any particular combination of conditions is probably a minimum that could divert if really given a chance to pay a lower fare. The data reflect only what passengers actually did with regard to trip planning and duration for their current trip. No comparable data were collected to determine passenger willingness to compromise travel plans to obtain fare reductions.

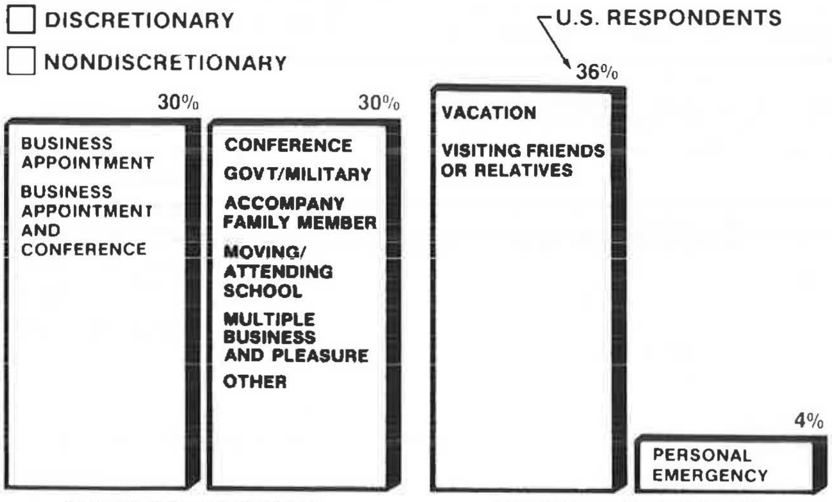


FIGURE 10 Reason for travel grouped by similar characteristics.

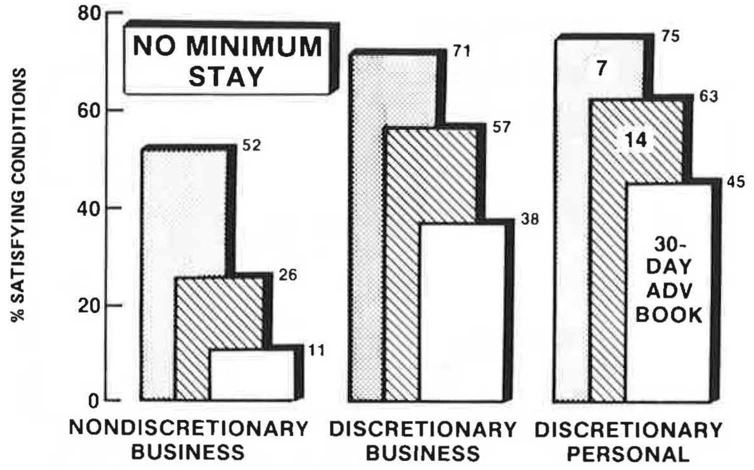


FIGURE 11 Ability to meet fare restrictions—U.S. carriers 1981, no minimum stay.

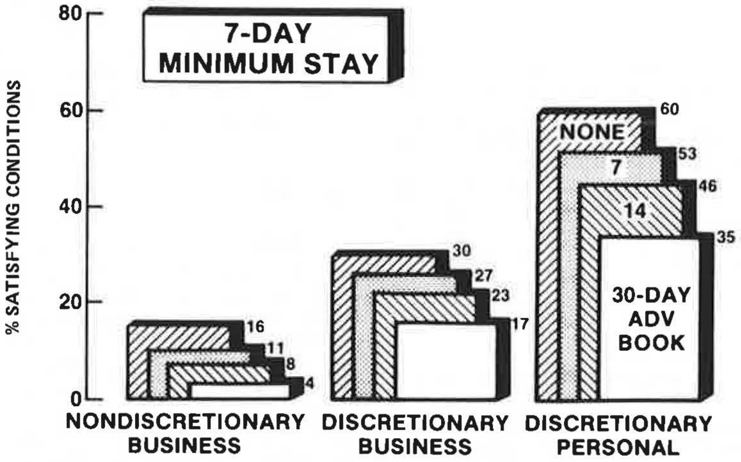


FIGURE 12 Ability to meet fare restrictions—U.S. carriers 1981, 7-day minimum stay.

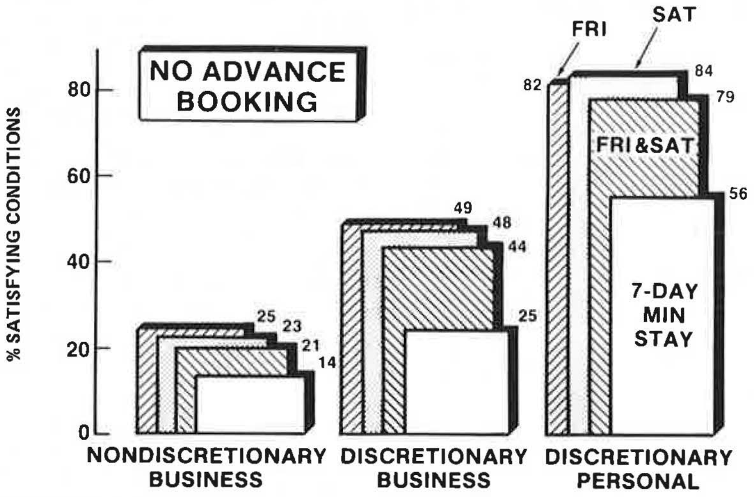


FIGURE 13 Ability to meet fare restrictions—U.S. and Canada 1982-1983, no advance booking.

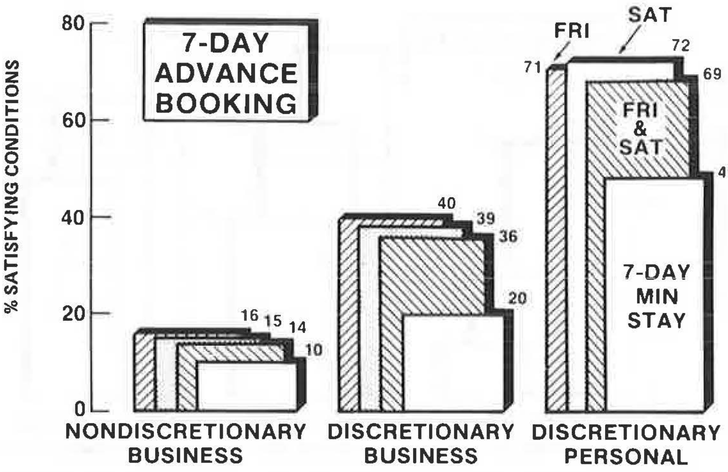


FIGURE 14 Ability to meet fare restrictions—U.S. and Canada 1982-1983, 7-day advance booking.

HALF OF ALL BUSINESS TRAVELERS MAY REACT LIKE VACATIONERS

The characteristics of discretionary business travelers may be more like those of discretionary personal (pleasure) travelers than to nondiscretionary business passengers (Figure 11). Therefore, advance booking restrictions alone are likely to be effective for only the nondiscretionary business third of U.S. passengers. Even for that group, more than 50 percent made reservations at least 7 days in advance of their flight. This suggests that if prebooking is the only restriction, it probably needs to be significantly longer than 1 week to be effective in controlling diversion from higher fares.

COMBINATIONS OF RESTRICTIONS FURTHER REDUCE DIVERSION

Adding a 1-week minimum stay condition to an advance booking requirement significantly reduces the number of passengers who can easily comply (Figure 12). This is especially true for the business traveler. When a 1-week stay is required, discretionary business passengers show characteristics closer to nondiscretionary ones than they did without that condition. If only one type of restriction is to be used, a 1-week minimum stay is probably a more effective diversion control than a 1-week prebooking requirement.

Questions about weekend overnights were included in the 1982-1983 series of surveys. For nondiscretionary business travelers, a weekend-stay requirement is almost as restrictive as a full-week stay requirement (Figure 13). The other two major categories of passengers are more likely to be able to comply with a weekend stay than a full-week requirement. The passenger's ability to satisfy restrictive conditions is further reduced if a 1-week advance booking is added to weekend overnights (Figure 14).

These results emphasize that an airline should evaluate a targeted discount market carefully before implementing a proposed fare plan. Because different segments of the traveling public exhibit a wide variety of travel characteristics, market composition must be determined to develop an effective set of restrictions. Based on the aggregated data, a 7-day minimum stay requirement was an effective restriction; however, it could be prohibitive or useless in individual markets. For example, in the Los Angeles-Las Vegas market, a 7-day minimum stay would probably eliminate almost all travelers. At the other extreme, a long-range vacation market such as Chicago-Honolulu might be largely unaffected by a week's minimum stay requirement. To prevent diversion effectively and still encourage additional air travel, discount fare restrictions must be developed and applied on an individual market basis.

DISCOUNT FARES MAY RESULT IN LOSS OF PROFIT

An airline must strengthen its traffic base before introducing discount fares to improve profitability, because a reduction in yield (revenue per passenger-mile) unavoidably accompanies discounts. Ideally the desired increase in traffic will result from new passengers. That is, people who would not have traveled at all, or would have used some alternate mode of transportation, will be induced to fly by attractive discount fares. From an airline's perspective, this is highly desirable. The marginal cost of carrying an additional passenger is low. Even though the discount fare is less than the published full fare, the potential for increased profit exists.

As demonstrated by the results of the 1981 and 1982-1983 surveys, passengers who otherwise would have flown at full fare will also attempt to use the reduced fare. From these passengers, the airline receives less revenue than they would have without offering the discount--with a negligible corresponding reduction in costs. Because of the high likelihood that competitors will match the lowest fares, an airline cannot depend on enticing passengers from competitors. Therefore the question becomes, Will profit increases resulting from carrying new traffic be sufficient to offset profit losses that result from full-fare passengers who switch to the reduced fare?

At a minimum, an analysis of stimulation and diversion rates is required. The stimulation rate is the number of passengers who will fly only with a discount (expressed as a percentage of potential full-fare passengers). The diversion rate is the percent of potential full-fare passengers who will try to use a reduced fare. These concepts are significantly different from the generation and dilution rates used some times. Generation is the percent of on-board passengers flying at reduced fare and dilution is the percent reduction in average yield after introducing the discount fare.

In its simplest form, the percent net revenue change that results from the introduction of a discount fare plan is

[% net revenue change] = [% revenue increase due to stimulation]
less [% revenue decrease due to diversion]
= [stimulation rate x (1 - % discount)]
less [diversion rate x % discount]

U.S. AND CANADIAN DISCOUNT FARES IN 1982-1983 WERE UNPROFITABLE

Using the results from the 1982-1983 surveys, it is possible to quantify this simplified model of the effect of discount fare plans on net revenue. Some assumptions are used that limit the validity of the model.

- Stimulation and diversion rates for both the United States and Canada are from the 1982-1983 survey estimates. These results are composites resulting from the various discount levels available during the survey.

	U.S.	Canada
Stimulation (%)	25	15
Diversion (%)	67	34

- Sufficient capacity is available to accommodate all full-fare and discount passengers.

The first assumption, relying on composite data, implies that stimulation and diversion rates are independent of discount level. Although probably realistic for diversion, this assumption is reasonable for stimulation only at moderate levels of discount, say 20 to 40 percent (2,3). It is also assumed that respondents were representative of their nation as a whole. The second assumption implies that there is no rejected demand on the flights under consideration. This is generally not true. Variability of demand, alone, results in the requirement to turn away passengers occasionally. This phenomenon may be exacerbated by the implementation of poorly designed discount fare plans. Often prebooking restrictions are a condition for obtaining reduced fares. If capacity management techniques are not used, the early booking characteristics of discount-fare travelers may result in the displacement of potential full-fare travelers.

It is likely that these simplifying assumptions are technically invalid for many actual markets. Nevertheless, this simplified example clearly depicts the danger of poorly designed discount fare plans. The United States exhibited both higher stimulation and diversion rates than Canada, resulting in greater revenue increases due to stimulation, but also greater losses due to diversion (Figure 15). At discount levels in excess of 25 percent, the estimate of U.S. net revenue change is less than that for Canada (Figure 16). Estimated net revenue change is negative for both countries if the average discount exceeded 30 percent.

These results become more bleak when associated profit levels are considered. In actual operation, there are added costs associated with each new passenger, such as fuel, food, and advertising. There is also the probability that some full-fare demand will be turned away, reducing profit levels even further.

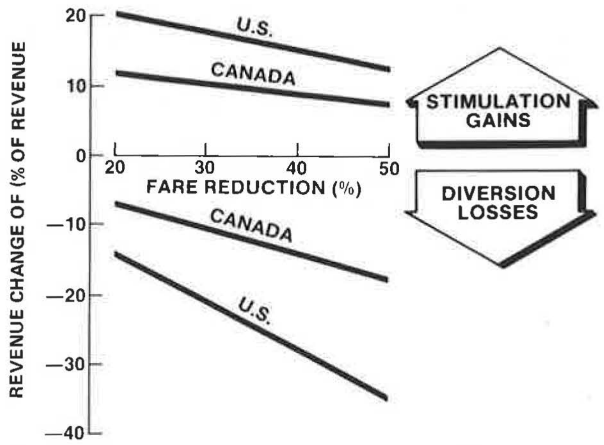


FIGURE 15 Stimulation and diversion impact, 1982-1983.

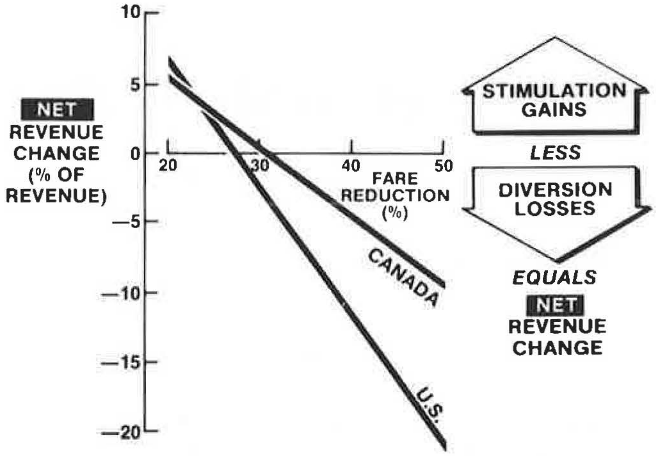


FIGURE 16 Net revenue impact, 1982-1983.

DETAILED ANALYSIS IS REQUIRED BEFORE IMPLEMENTATION

To maintain or increase profitability, proposed discount-fare plans must be carefully evaluated. Most successful discount-fare plans will exhibit stimulation rates that are somewhat lower than the associated diversion rates. However, care must be taken to foster stimulation while controlling diversion and protecting full-fare demand from displacement. Market research is necessary to determine discount levels that will stimulate additional travel without reducing profits. Characteristics of the targeted markets must be determined before restrictions can be designed to effectively control diversion. Also, capacity management is required to determine appropriate discount capacity to protect full-fare demand.

SUMMARY

1. Fare is a major variable in the flight selection process of an airline passenger.
2. Passengers will divert to flights that require longer transit times for a small saving.
3. Restrictions help minimize diversions. The effectiveness of a restriction is dependent on the characteristics of the passengers in each market.
4. It is highly probable that the discounts offered in the United States and Canada in 1982-1983 reduced profits.

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Publication of this paper sponsored by Task Force on Economics of Air Transport.

Airline Cost Trends as Viewed by an Airframe Manufacturer

G. RUSSELL MORRISSEY

ABSTRACT

Aircraft price trends and aircraft operational costs are presented. It is shown that compared with other airline costs, the investment cost per seat for commercial transports has been a bargain. Operational costs per seat mile declined by 75 percent between 1936 and 1971. Trends in investment cost per seat are analyzed, beginning with the introduction of turbine-powered transports. The cost impact of applying advanced technology to commercial transport airframes is also reviewed. The average annual rate of technology improvement is estimated at 2.5 percent. It is shown that the technological sophistication of commercial transport aircraft has more than doubled in one generation. But because of a decline in cost weight per seat in successive models of families of aircraft, constant dollar investment cost per seat for turbine-powered transports has risen only modestly. Airline labor costs for profitable carriers will increase at or above increases in the consumer price index, whereas labor settlements less than this index may be the pattern for unprofitable carriers. Aircraft productivity, measured by annual seat miles per aircraft, increased at an average annual rate of almost 8.5 percent between 1957 and 1979. Future increases in productivity are most likely to occur by increasing aircraft utilization. Design-to-cost procedures and computer-assisted design and manufacturing techniques will minimize the cost of future commercial transport aircraft, and future jet aircraft will continue to be a bargain.

Aircraft price trends are reviewed in this paper. Constant-dollar investment cost per seat of turbine-powered transports rose at a modest average annual rate of 0.5 percent in the 1960s and 1970s. These prices do not reflect the advanced technology that has been incorporated into them. The approach used to measure improvements in technology was to compute the rate of change in constant dollars per pounds of aircraft cost weight. This rate far exceeded the increase in investment cost per aircraft seat. This investment in technology brought about a significant decline in direct operating costs between 1947 and 1971. More recently labor and fuel have caused an increase in direct operating costs. Current wage settlements are about 9 to 10 percent and it is not clear at this time whether organized labor will adapt its goals to the new deregulated environment. Jet fuel prices in 1982 dollars are not currently forecasted to surpass 1981 levels until the late 1980s.

Potential increases in aircraft fleet fuel efficiency, attributable to improvements in airframes and engines, are expected to average 2.7 percent between 1981 and 1992. When U.S. domestic trunk operational costs from 1967 to 1980 are unitized on a cost per flight hour basis, it is evident that maintenance costs have not risen in proportion to the increases in airframe size, technological complexity, and Federal Aviation Administration requirements.

Although there have been only modest increases in investment cost per seat, annual seat miles per aircraft increased at an average annual rate of almost 8.5 percent between 1957 and 1979. System-related airline costs remain high, and automation of the air traffic control system to reduce flight delays is the probable solution. There will be continued efforts on the part of the commercial

TABLE 1 McDonnell Douglas Aircraft Prices

AIRCRAFT	DATE INTRODUCED	PRICE (MILLIONS OF DOLLARS) CURRENT	CONSTANT 1982	SIGNIFICANT TECHNOLOGY EVENT
DC-3	6/7/36	0.110	1.300	ALL-METAL CANTILEVER RETRACTABLES
DC-4	1/18/46	0.363	3.400	4 ENGINES, OVERWATER
DC-6	3/28/47	0.640	4.800	PRESSURIZED CABIN
DC-6B	4/11/51	1.068	6.000	
DC-7	11/4/53	1.790	9.300	TURBOCHARGED ENGINES
DC-8-10	6/3/59	4.800	19.400	TURBOJET ENGINES
DC-8-50	4/3/61	6.000	23.400	FANJET ENGINES
DC-10-10	7/29/71	19.000	49.600	HI-BYPASS FANJET ENGINES

airframe manufacturers to hold down the cost of designing and manufacturing new aircraft.

AIRCRAFT PRICE TRENDS

Table 1 gives the current and constant-dollar cost of seven McDonnell Douglas commercial transports that were successively introduced over a period of 35 years. The DC-3, the most successful airliner of its era to enter airline service, was introduced in 1936. It carried 21 passengers at a cruising speed of 180 miles per hour, for a range of 1,380 statute miles. The 803 aircraft manufactured commercially carried 95 percent of all civilian air traffic. In 1936 dollars, the price per seat was $5,000. In constant 1982 dollars, however, the price per seat was $62,000. When the DC-8 Series 10 was introduced in 1959, its price per seat was $36,000 in 1959 dollars and $145,000 in constant 1982 dollars. Gains in seat-mile productivity between the DC-3 and DC-8 Series 10 were gigantic when compared with the 134-percent increase in constant-dollar seat price.

Price per seat, in 1982 dollars, increased from $62,000 in 1936 for the DC-3 to $162,000 in 1971 for the DC-10 Series 10. This is an absolute increase of only $100,000 per seat for immense advances in speed, comfort, service, reliability, and safety, not to mention sharply lower fares. For example, between 1939 and 1976, constant-dollar fares (New York-London) fell 72 percent or at an average annual rate of 3.5 percent (1).

Investment cost per seat for turbine-powered transports is shown in Figure 1 in both current and constant 1982 dollars. A series of regression analyses was performed using these two sets of data. In both cases, the best fit was a geometric straight line or the logarithmic form of a least-squares trend line. Between 1960 and 1980 the investment cost in current dollars per seat for turbine-powered transports rose at an average annual rate of 5.8 percent. On a constant-dollar basis, however, the cost per seat rose at a modest average annual rate of only 0.5 percent. The constant-dollars series was developing by using a weighted deflator composed of the Standard Industrial Classification 3721 (aircraft hourly earnings) of the Bureau of Labor Statistics and the U.S. Producer Price Index--Code 10 (metal and metal products).

The quality or technological sophistication of

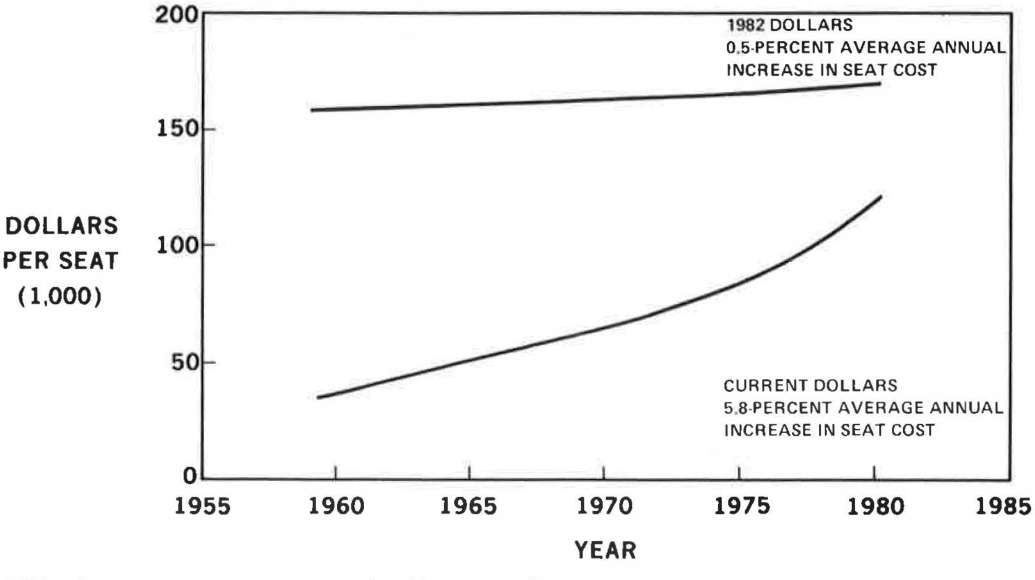


FIGURE 1 Investment cost per seat of turbine-powered transports.

jet transports increased significantly between 1960 and 1980, particularly in the areas of propulsion and avionics. Also, the data for investment cost per seat were taken from manufacturer list prices. The prices do not reflect manufacturer concessions, which have been higher than usual in the last several years. If this factor is taken into account, investment cost per seat rose less than the rates presented.

THE IMPACT OF TECHNOLOGY

Figure 2 shows the amount of new technology (and its associated cost) that has been incorporated into commercial transport aircraft since the end of World War II. Aircraft prices from the same data base used for Figure 1 were adjusted by removing the prices associated with engines and rolling assembly to produce airframe price. Airframe price, in turn, was divided by cost weight (aircraft weight less engines and rolling assembly) to produce dollars per pound of cost weight. Price per pound was used as a surrogate for cost per pound because the data were more readily available. It should be noted, however, that commercial aircraft manufacturing has not been remarkably profitable since the commercial jet age came into being in the late 1950s, therefore, the possibility that rising profit margins have distorted data can be dismissed.

Inflation was removed from the current-dollar data by the same method used to deflate data for the current-dollar investment cost per seat. The rate of change in constant dollars per pound of cost weight is a measure of the impact of technology. Advanced technology is incorporated into new aircraft designs for several reasons. First and foremost, the airframe manufacturer combines desirable technical characteristics (particularly in engines) in a way that produces successive generations of aircraft with lower operating costs per seat mile. Second, technology is also incorporated to comply with new Federal Aviation Administration regulations. This type of technology application is not necessarily reflected in lower aircraft-mile or seat-mile cost. Third, the airframe manufacturer adds features to meet new airline requirements. Accommodating the airline customer in these situations definitely adds to product cost.

A regression analysis was conducted on both the current- and the constant-dollar series, and a geometric straight line was the best fit in both instances. Price per pound of cost weight in current dollars increased at an average annual rate of 7.5 percent between 1947 and 1980. This same series, measured in constant dollars, increased at an average annual rate of 2.5 percent between 1947 and 1980. The impact of technology over this period had two effects. Aircraft productivity was vastly increased but at a price of a 2.5 percent average annual increase in constant dollars per pound of cost weight.

As previously noted, constant-dollar seat prices on turbine transports--the price that the airline customer actually pays--has been rising at an average annual rate of only 0.5 percent. These two series of data have to be reconciled. Airframe manufacturers have generally tended to introduce aircraft with design allowance margins that will ultimately enable the introduction of higher-capacity and longer-range derivative models when market conditions warrant.

Within given families of aircraft, cost weight per seat of successive derivative aircraft models declines as preexisting design margins are utilized. This is the explanation in this instance. For one family of aircraft, cost weight per seat declined at an average annual rate of 2.2 percent between the initial version and the latest derivative version.

In summary, the technological sophistication of commercial transport aircraft has more than doubled in the span of one generation as measured by the increase in constant dollars per pound of cost weight. Because of a decline in cost weight per seat in successive modes of families of aircraft, constant-dollar investment cost per seat for turbine-powered transports has risen modestly. Compared with other airline costs, the investment cost per seat for commercial transports has been a bargain.

DIRECT OPERATING COST TRENDS

Figure 3 shows what the application of advanced technology has done to reduce direct operating costs since the introduction of the DC-3 in 1936. It should be noted that the DC-3, a wider and stretched

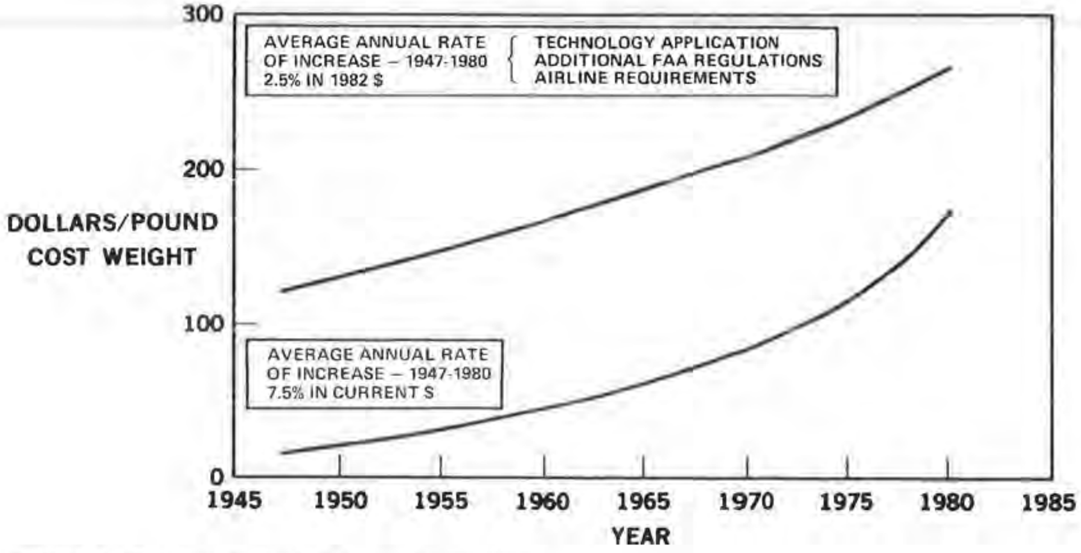


FIGURE 2 The impact of technology–price per pound.

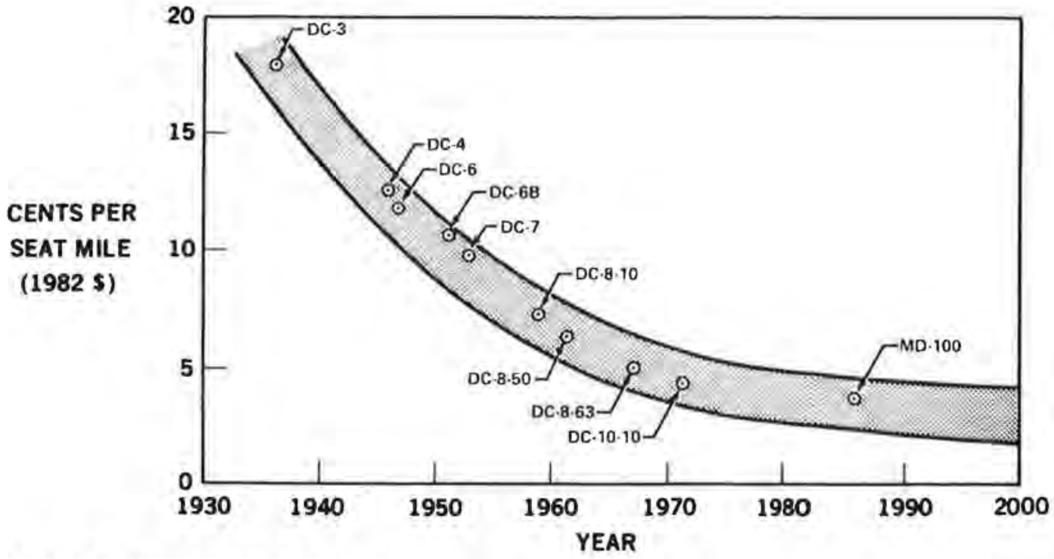


FIGURE 3 Direct operating cost trends.

version of the DC-2, featured a 52-percent reduction in direct operating costs from the DC-2. The DC-4, which was introduced 10 years later in 1946, offered a 28-percent reduction in direct operating costs from the DC-3. A further 8-percent reduction in direct operating costs was secured with the introduction of the DC-6 in 1947. When the DC-7 was introduced in 1953, direct operating costs declined an additional 17 percent.

The commercial jet age was launched in June 1959 when the DC-8 Series 10 was introduced, and direct operating costs were reduced by a remarkable 26 percent compared with the DC-7. Further progress was achieved when the DC-8 Series 50, an aircraft equipped with fanjet engines, was introduced in 1961: direct operating costs dropped by an additional 23 percent. More recently, the wide-body DC-10 Series 10 trijet with its high-bypass fanjet engines, introduced in 1971, reduced direct operating costs more than 21 percent.

Between the introduction of the DC-3 in 1936 and the introduction of the DC-10 in 1971, direct operating cost per available seat mile dropped more than 75 percent or at an average annual rate of 3.9 percent. Further improvements in the McDonnell Douglas commercial aircraft family are being studied, and the proposed MD-100 trijet offers a potential reduction of more than 10 percent in available seat-mile cost. This advanced-technology aircraft will offer a further reduction in direct operating cost per available seat mile through the use of advanced engines and aerodynamic improvements.

The MD-100 is planned for operational use in 1986, a half-century after the introduction of the DC-3. During this period, direct operating cost per available seat mile will have declined at an average annual rate of 3 percent. Figure 4 shows some factors in reducing direct operating costs that have occurred to date as well as some that are expected to occur in the 1980s. This figure traces the technical development of commercial transport aircraft and identifies the technical improvements that can

1930'S	1950'S	1970'S
• ALL-METAL AIRCRAFT • RETRACTABLE LANDING GEAR • IMPROVED POWER PLANTS • FIRST PROFITABLE AIRCRAFT	• JET ENGINES – SPEED – ALTITUDE – COMFORT – ECONOMY • SWEPTBACK WING • SAFETY/RELIABILITY	• WIDE CABIN FUSELAGE • HIGH-BYPASS-RATIO TURBOFAN ENGINES – ADDITIONAL FUEL EFFICIENCY • LOWER NOISE LEVELS
1940'S	1960'S	1980'S
• CABIN PRESSURIZATION • SUPERCHARGED ENGINES • IMPROVED WING FLAPS • INCREASED PAYLOAD/RANGE	• LOW-BYPASS-RATIO TURBOFAN ENGINES – FUEL EFFICIENCY • STRETCHED FUSELAGE	• SUPERCRITICAL WING • ACTIVE CONTROLS • COMPOSITE MATERIALS • DIGITAL AVIONICS

FIGURE 4 Evolution of commercial air transport.

be expected to be incorporated into aircraft designs during the 1980s. The commercial air transportation industry grew rapidly until the late 1960s because of technical improvements and reductions in direct operating costs which, in turn, were attributable to the judicious application of new technology and appropriate design changes in successive generations of aircraft.

AIRLINE COST TRENDS

Six elements make up direct operating cost: fuel, maintenance, crew, landing fees, insurance, and depreciation. However, to place airline cost trends in their proper perspective, a number of statistical series have been compared for a 22-year period. These data are shown in Figure 5.

From 1960 to 1982, the cost of jet fuel rose tenfold. The major increases, however, occurred in 1974, 1979, and 1980. The average price paid in 1982 could show a drop of up to 6 percent from 1981 levels. Average compensation per airline employee, the other major component of airline total cash operating expenses, is up 8 percent (second quarter of 1982) from last year. From 1960 to 1982, average compensation per airline employee rose at an average annual rate of 7.7 percent. During this same period the widely used consumer price index rose at an average annual rate of 5.5 percent.

Until 1978 airline employees often secured wage increases above consumer price inflation. Before airline deregulation in 1978 a disproportionate share of the benefits of increased aircraft productivity went to labor. This occurred because airlines are a service industry whose products are time and convenience. Civil Aeronautics Board route franchises limited competition and regulated ticket prices. Revenue passenger miles lost because of employee strikes were totally lost, and market share was difficult to recover. Over the long run, average compensation per airline employee increased faster than other employee groups with a similar mix of skill. Also, restrictive work rules were gradually codified in labor agreements (2).

Table 2 gives a comparison of the percentage of annual change in airline employee compensation (using two different price indices) and U.S. industry compensation. The last column in the table shows by how many percentage points airline employee compensation deviated from changes in the consumer price index. At the bottom of the table there is a comparative summary for the 5 years preceding deregulation and for the 5-year period following it (1982 is estimated). Airline compensation exceeded consumer inflation by an average of 1.8 percent a year during the 1973-1977 period but fell below it by 0.3 percent a year during the 1978-1982 period.

These straightforward comparisons may be useful in determining future trends even though the 1978-1982 period can hardly be considered normal. The domestic airline industry has been challenged by two recessions and the OPEC petroleum price increase, which followed the fall of the Shah of Iran; nonetheless, the negotiating climate has changed. As USAir Chairman and President Edwin I. Colodny recently told graduates of the University of Pittsburgh Graduate School of Business (6), "Somehow, we must explain the need [to employees] for lowering our cost of providing the service in order to be competitive." It is necessary to be cautiously optimistic in this respect because labor represents 36 percent of total airline cash operating expenses.

Figure 6 shows what has happened to airline total operating cost, which includes both direct and indirect operating cost, from 1968 to 1981. Before the OPEC petroleum price increase in the fourth quarter of 1973, fuel was not a dominant component of total operating cost. For example, in 1968 fuel constituted 13 percent of the total. By 1980 it had risen to nearly 31 percent and remained at this figure in 1981. In the second quarter of 1982, fuel was 28 percent of total cash operating expenses, whereas labor was 36 percent. This data base confirms that labor and related costs have been and continue to be the single largest element of the total operating cost of the U.S. trunk airlines. Fuel will decline as a proportion of these costs in 1982 and 1983.

A decrease in the share of fuel as a proportion of total operating cost will increase the labor

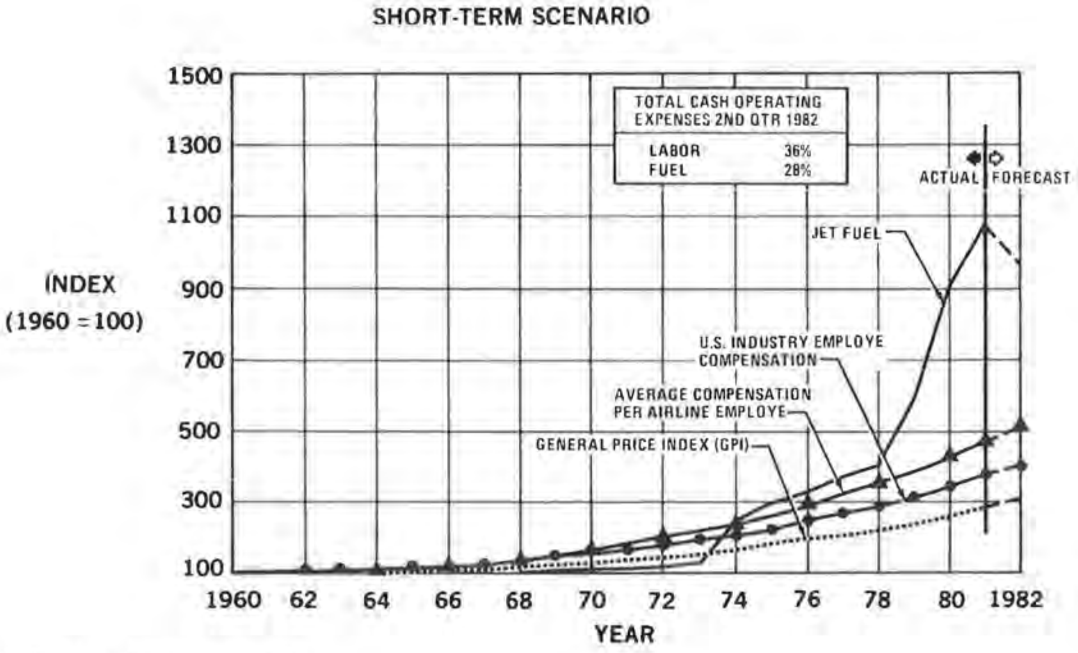
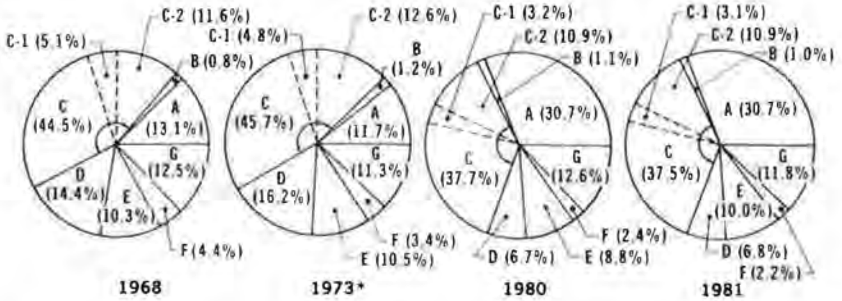

SHORT-TERM SCENARIO

FIGURE 5 Airline cost trends.

TABLE 2 Airline Cost Trends--Percentage of Annual Change

YEAR	① CONSUMER PRICE INDEX[a]	② GENERAL PRICE INDEX[a]	③ U.S. INDUSTRY COMPENSATION[b]	④ AIRLINE COMPENSATION[c]	⑤ COL 4 LESS COL 1
1973	6.2	5.7	6.1	7.7	1.5
1974	11.0	8.7	8.2	8.0	(3.0)
1975	9.1	9.3	9.7	9.6	0.5
1976	5.8	5.2	7.8	10.6	4.8
1977	6.5	5.8	8.0	11.6	5.1
1978	7.7	7.3	7.8	10.2	2.5
1979	11.3	8.5	8.8	6.9	(4.4)
1980	13.5	9.0	8.7	11.7	(1.8)
1981	10.4	9.2	8.9	10.9	0.5
1982	6.6E[d]	6.6E[d]	7.0E[d]	8.2E[d]	1.6E[d]
1973-1977 AVERAGE	7.7	6.9	8.0	9.5	1.8
1978-1982 AVERAGE	9.9	8.1	8.2	9.6	(0.3)

[a] See Reference (3).
[b] See Reference (4).
[c] See Reference (5).
[d] Estimated.



*OPEC PRICE RISE — 4TH QTR
SOURCE: CAB FORM 41

A — AIRCRAFT FUEL
B — TAXES
C — LABOR AND RELATED COST; C-1 MAINTENANCE LABOR, C-2 FLYING LABOR
D — DEPRECIATION, RENTAL, AND INSURANCE
E — PURCHASED GOODS AND SERVICES, EXCLUDING FUEL
F — MAINTENANCE MATERIAL
G — LANDING FEES, COMMISSIONS, ETC.

FIGURE 6 Total operating cost for U.S. trunk airlines.

share automatically. However, on a unit cost basis, labor is the second fastest growing component of U.S. airline cash operating expenses (second quarter, 1982). Wages can be increased and the number of airline employees controlled, as labor and aircraft productivity are increased. Several major airlines have obtained improvements in productivity from employee groups by pointing out that the alternative was to "shrink the airline" in spite of overall growth in public demand.

In Europe, where airlines must contend with landing fees up to seven times higher than in the United States and jet fuel up to one-third higher in many stations, this alternative is already being put into effect. British Airways, which was ranked by International Air Transport Association (IATA) airlines as number six in passenger kilometers in 1981, is a case in point. Airline manpower peaked at more than 58,000 in 1979. It stood at 41,000 in the fourth quarter of 1982 and is projected to decline to 35,000 by the end of the airline's fiscal year on March 31, 1983 (7). This represents a 40 percent reduction in manpower. By contrast, overall IATA airline employment remained level between 1979 and 1981. British Airways, whose current liabilities exceed net assets, is an extreme case.

Over the past several years, U.S. airline labor negotiations have exhibited a mixed pattern. Labor has worked hard to help airlines with current and potentially continuing operating losses. Although many wage settlements are at 9 to 10 percent now, a reasonable midterm forecast for the future is that airline compensation at or somewhat above increases in the consumer price index will continue to be the pattern for profitable carriers, whereas settlements just under changes in the consumer price index will predominate for unprofitable carriers. Profitable national carriers can, to some extent, offset potentially higher labor costs by substituting efficient two-engined aircraft for older-technology trijet aircraft of roughly the same seating capacity.

Two additional factors may affect labor costs:

1. Over the long term, the U.S. faces a zero population growth. This has already occurred in some areas of the country. Currently families are opting for fewer children, and steady or declining reproduction rates are expected to continue.

2. Although the majority of wives and a near-majority of mothers hold paying jobs, and higher family incomes and fewer children will mean more air travel, the post-1960 baby bust will mean declining numbers of young adults, and later, of the entire adult population.

TABLE 3 U.S. Domestic Jet Fuel Price Forecast

YEAR	PETROLEUM PRICE[a] (CURRENT $/BBL)	KEROSENE PRICE (CURRENT CENTS/GAL.)	PERCENT CHANGE	KEROSENE PRICE (1982 CENTS/GAL.)	PERCENT CHANGE
1981	35.24	102.2	—	109.2	—
1982	33.08	96.0	-6.1	96.0	-13.1
1983	33.66	100.1	4.3	94.3	-1.8
1984	38.04	113.5	13.4	100.3	6.4
1985	42.00	125.7	10.8	103.6	3.3
1986	46.33	139.0	10.6	106.8	3.1
1987	50.67	152.3	9.6	109.8	2.8
1988	55.17	166.2	9.1	112.7	2.6
1989	59.67	180.1	8.4	115.9	2.8
1990	64.56	195.3	8.4	123.1	6.2

[a] U.S. REFINER ACQUISITION COST (DOMESTIC/IMPORTED WEIGHTED AVERAGE)

At the end of the 1980s wages may rise because of dwindling number of workers (8).

More capital investment in automated plants and in other labor-saving equipment will be necessary to improve productivity. The proposed MD-100, an advanced trijet, is being designed for introduction in 1986 for long overwater stages. It would have a two-man cockpit. Over the long term, then, airline management will have to work with employee groups to increase productivity and cooperatively lower the cost of airline service.

Table 3 gives a forecast of U.S. jet fuel prices. In this connection it is well to remember what the late Carl H. Madden had to say about forecasting accuracy during a speech before the Economics Club of Pittsburgh on April 17, 1975 (9):

> The art of forecasting the future will remain imperfect; only fools and charlatans claim otherwise. In a mind-boggling universe everywhere fraught with real novelty, the demand for 'accuracy' in forecasts easily slides over into absurdity while the claim of accuracy slithers into dishonesty. Forecasting never has had for its prime purpose the achievement of accuracy but rather its purpose is to improve the quality of current decisions.

In constant 1982 dollars, jet fuel prices are expected to rise at an average annual rate of 1.4 percent between 1981 and 1990. These prices, however, are not expected to surpass 1981 levels until 1987. Moreover, if constant-dollar jet fuel prices are expressed in terms of cents per available seat mile, there will be a decline of nearly 8 percent in price per unit because of potential improvement in fuel efficiency. This is a surprisingly favorable forecast, given that the authors of the World Integrated Model concluded only a few years ago that oil and substitutes for oil will be among the three greatest constraints to world economic growth (10).

AVAILABLE SEAT MILES PER GALLON

Figure 7 shows a forecast of available seat miles per gallon between 1981 and 1992. As new-generation aircraft are phased into the U.S. airline fleet, advances in technology are expected to produce a potential 2.7 percent average annual improvement in fuel efficiency between 1981 and 1992. It should be noted that the introduction of an aircraft with advanced engines such as the McDonnell Douglas D-3300 or the Airbus Industrie A320 was postulated in this forecast. In any event, available seat miles per gallon are expected to rise from 45 in 1981 to 60 in 1992. If these data are used in conjunction with the constant-dollar jet fuel forecast in Table 3, it is apparent that cents per available seat mile will decline between 1981 and 1990 (2.43 cents in 1981 versus 2.23 cents in 1990). The 1990 available seat miles per gallon figure was interpolated from the data in Figure 7.

COSTS PER FLIGHT HOUR

So far, the major contributors to airline operational costs have been identified and analyzed. Except for the discussion of trends in airline employee compensation, the functional area of maintenance has not been addressed. Figure 8 contains U.S. domestic trunk airline operational costs from 1967 to 1980 unitized on the basis of cost per flight hour. These data, from the Civil Aeronautics Board, have been expressed in constant 1982 dollars. As indicated in Figure 8, maintenance costs have not risen in proportion to increases in airframe size, technological complexity, and requirements of the FAA. The commercial jet age began in the late 1950s, but in terms of its impact on maintenance, the period covered here is more representative.

AIRCRAFT PRODUCTIVITY IN THE U.S. AIRLINE INDUSTRY

Figure 9 traces aircraft productivity in the U.S. airline industry from 1957 through 1981. The individual elements of aircraft productivity are also included in this figure. Productivity peaked in 1979, principally as a result of a decline in aircraft utilization. Between 1957 and 1979, however,

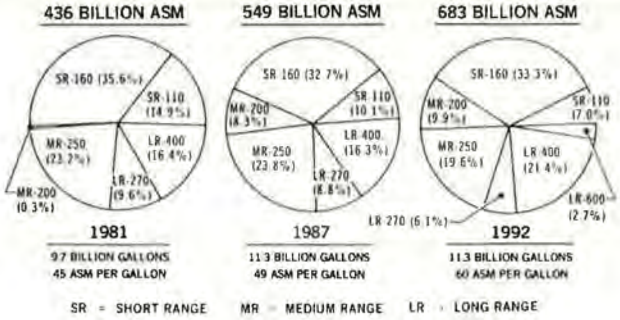
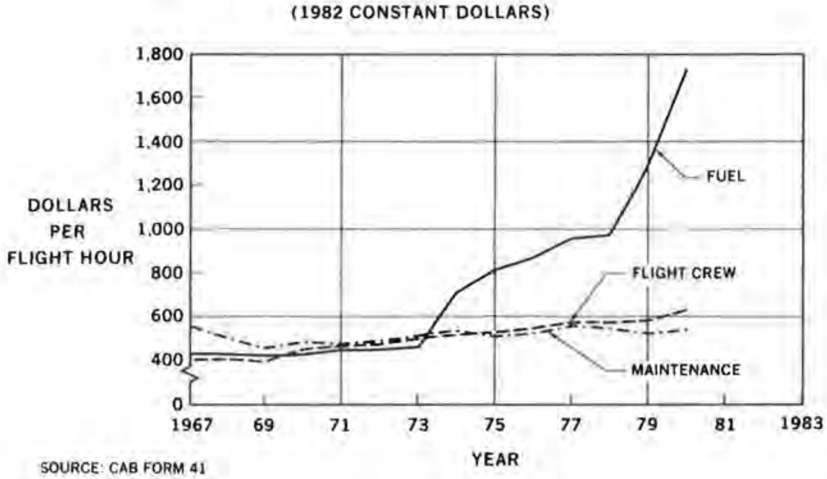


FIGURE 7 Available seat miles per gallon.



SOURCE: CAB FORM 41

FIGURE 8 Cost per flight hour.

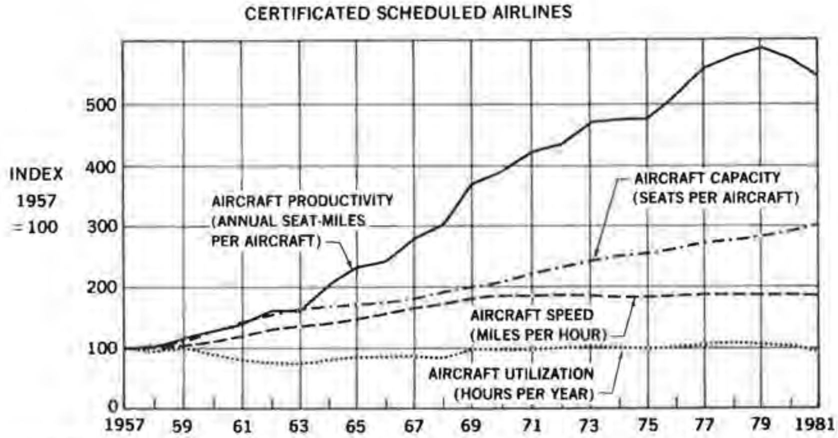


FIGURE 9 Aircraft productivity in the U.S. airline industry.

seat miles per aircraft increased at an average annual rate of nearly 8.5 percent. Future increases in aircraft productivity are most likely to occur by increasing aircraft utilization. The FAA expects the restrictions on capacity imposed as a result of the controllers' strike to end soon. The current target data for restoring the aviation system to full capacity is September 1983. This target may not be met because of problems such as employee training. Once the system is returned to full capacity, however, aircraft utilization should increase.

SYSTEM-RELATED AIRLINE COSTS

Figure 10 shows estimates from the FAA on the systemwide cost of flight delays. In the 14 years between 1967 and 1981, the current-dollar cost of flight delays rose from $73 million to $1.4 billion. In constant 1982 dollars, this means that the cost of flight delays increased from $200 million in 1967 to $1.5 billion in 1981, or at an average annual rate of 15.5 percent. Obviously, something will have to be done to solve this problem. The FAA is hoping to alleviate this situation through increased automation.

Complete automation has been delayed because of the financial investment required. The air traffic control system will be automated gradually over the next two decades. As an example of the potential benefits of such a system, the FAA could phase in a computer service after 1990 that would analyze individual flight plans and select routes that have the least conflicts with other airborne aircraft and are the most fuel efficient. Under current conditions, airline pilots are often forced to waste fuel because traffic controllers require them to deviate from efficient flight plans. The benefits of computerized flight planning include integrated flow management, conflict-free route clearances, fuel-efficient climb and descent paths, and direct routing between major terminals (11).

1967	$ 73 MILLION
1973	$219 MILLION
1977	$800 MILLION
1980	$ 1.4 BILLION
1981	$ 1.4 BILLION

NO NEW AIRPORTS ANTICIPATED

BY 1990, 32 U.S. AIR CARRIER AIRPORTS WILL BECOME MORE THAN 90 PERCENT SATURATED

SOURCE: FEDERAL AVIATION ADMINISTRATION

FIGURE 10 Cost of flight delays.

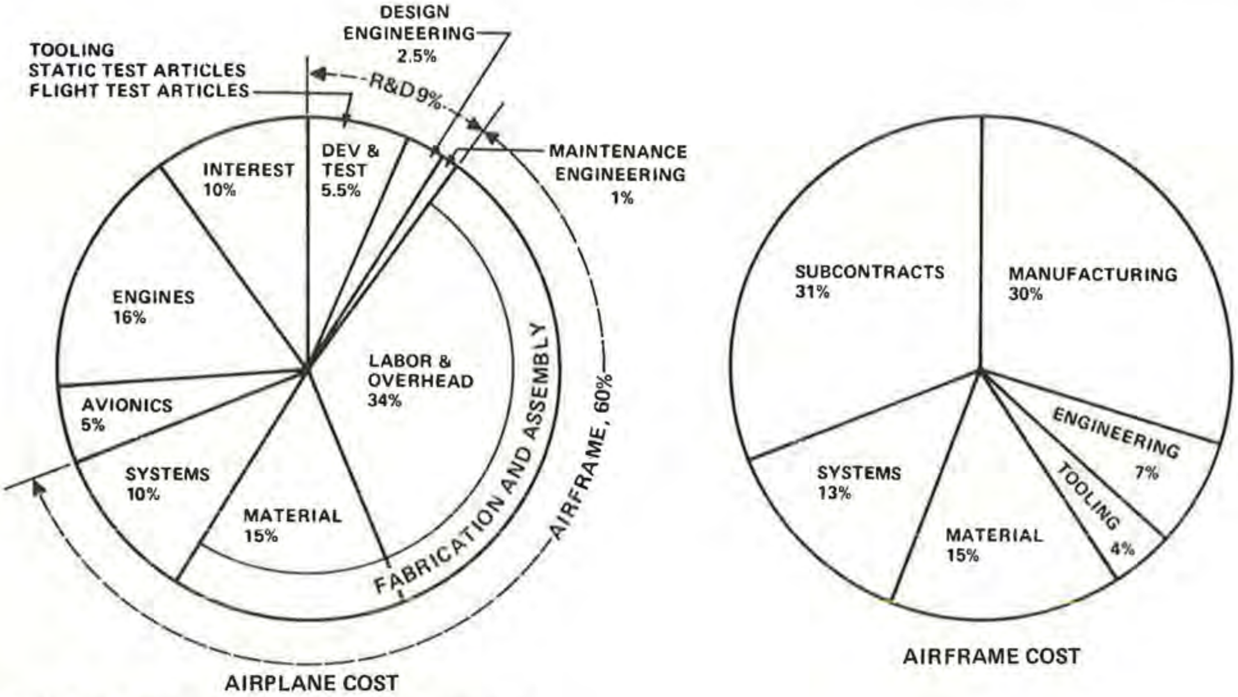


FIGURE 11 Cost breakdown for new aircraft program.

MINIMIZING COSTS

Airline designers will continue working to hold down the cost of new equipment as shown in Figure 11. This figure is based on a hypothetical production program of 700 aircraft. The total research and development cost is 9 percent of total cost. Design engineering, per se, is only 2.5 percent of total cost but the skill with which this critical task is carried out affects the entire manufacturing process as well as the expense of the engines, equipment, and avoinics.

Cost minimization can be achieved through design-to-cost procedures, computer-assisted design and computer-assisted manufacturing techniques, and aircraft standardization that permits the purchasing airline to customize a standard aircraft design by choosing from a large group of features contained in a Configuration Guide. These techniques are in addition to the ongoing task of determining the life-cycle cost-effectiveness of certain airline requirements (12).

CONCLUSIONS

Airline cost trends have been reviewed in this paper and the midterm outlook for each of the major airline operational costs presented. It was noted that the constant-dollar investment cost per seat of turbine-powered transports rose at a modest average annual rate of 0.5 percent between 1959 and 1980. This low rate of increase would have been still lower if the manufacturer's price concessions, which were higher than normal, of the past several years had been included in the analysis.

Aircraft prices do not reflect the substantial amount of advanced technology that has been incorporated into them through manufacturer's initiative, compliance with new FAA regulations, and airline-proposed supplemental requirements. Between 1947 and 1980, commercial transport aircraft benefited from the incorporation of advanced technology. It is estimated that the average annual rate of technology improvement was 2.5 percent. The rate of change in constant dollars per pound of aircraft cost weight was used as a yardstick to measure improvement in technology.

From 1947 to 1971 this investment in technology permitted direct operating cost to decline at a 4-percent average annual rate. Passenger fares declined correspondingly during this period as cost savings were passed on to the airline passenger. This process led to the rapid growth of the air transport industry and its dominance over all other competing common carrier transport modes.

It is characteristic of regulated industries, especially those with a perishable product like air transport with unused aircraft seats, to be faced with inflated labor wage settlements. This situation has changed somewhat since deregulation. Although current wage settlements are at 9 to 10 percent, it is expected that settlements at or above increases in the consumer price index may be the pattern for profitable carriers while settlements under the consumer price index will predominate for unprofitable carriers. In general, however, it is not yet known whether organized labor will adapt its goals to the new deregulated environment. There is, however, every indication that a new spirit of cooperation is developing in many sectors of U.S. industry where labor and management have long maintained adversarial relationships, and it is hoped that this will also be true for the airline industry. The movement toward a two-member flight crew for all except long overwater operations and increased automation will help to offset rising labor costs.

Jet fuel prices in 1982 dollars are not currently forecasted to surpass 1981 levels until 1987. If constant-dollar jet fuel prices are restated in terms of cents per available seat mile, potential increases in fuel efficiency suggest that there will be a fall in jet fuel prices per available seat mile amounting to nearly 8 percent between 1981 and 1990. Potential increases in fleet fuel efficiency, attributable to improved technology, are on the order of an average annual rate of increase of 2.7 percent between 1981 and 1992. Available seat miles per gallon are expected to rise from 45 in 1981 to 60 in 1992.

Despite only modest increases in investment cost per seat, annual seat miles per aircraft increased at an average annual rate of almost 8.5 percent between 1957 and 1979. Future increases in aircraft productivity are most likely to occur by increasing aircraft utilization; however, such increases have been delayed by the controllers' strike. System-related airline costs are very high. The estimated cost of flight delays in 1981 was $1.4 billion. The last hope for alleviating this serious problem is through automation.

Commercial airframe manufacturers are currently attempting to minimize the cost of designing and manufacturing new aircraft by using design-to-cost procedures, computer-assisted design and manufacturing techniques, and aircraft standardization techniques. These efforts should ensure that the investment cost per seat for future generations of jet aircraft will continue to be a bargain.

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Publication of this paper sponsored by Task Force on Economics of Air Transport.

Economic Impact of General Aviation in Florida: Suggested Method of Analysis

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ABSTRACT

The absence of a standard methodology to determine the regional economic impact of airports has caused difficulties in (a) evaluating economic impacts, (b) comparing economic impacts of airports in different regions, and (c) comparing the economic impact of airports with other economic activities. The input-output approach is generally regarded as the most appropriate method for determining regional impacts; however, the use of input-output analysis has been limited because of its high cost. The problem of high cost has recently been overcome by the Regional Input-Output Modeling System (RIMS II) developed by the U.S. Department of Commerce. The Florida Department of Transportation conducted a study of the economic impact of general aviation on Florida's economy. Using the RIMS II procedure, a method was developed to assess the impact of a specific general aviation airport on its community and the impact of statewide general aviation on the total Florida economy. The methodology was developed to minimize data requirements and hence survey costs. The Florida study indicated that in 1981 general aviation employed 9,752 and generated $157 million in total earnings. The methodology and results presented in the Florida General Aviation Economic Assessment study are highlighted and an example of the use of the RIMS II tables is presented. The methodology is concluded to be applicable throughout the United States and it is recommended that the RIMS II approach be used as a standard to evaluate the regional economic impact of aviation and other transportation activities.

During the past two decades there has been tremendous growth in the number and variety of economic impact analyses being performed. This is true of impact studies in general and aviation activities in particular. Increasingly, the lack of a standardized methodology has made it difficult to compare the results of an impact study for one airport with the results of similar studies for airports in other regions, or even to compare impacts for one airport for different periods of time. Consequently, numerous recommendations have been made in the literature and at transportation research meetings to standardize methodologies for measuring the economic impact of aviation activities.

The most frequently criticized area of economic impact analysis has been the development of multipliers for measuring the effect of aviation activity on the community and region. Although input-output analysis is recognized as the most intellectually rigorous method of developing multipliers, its use in economic impact studies has been limited by the high costs associated with developing the transactions matrix, the vast data requirements, and the inappropriateness of using the coefficients developed for one region to calculate the impacts of an activity in another region (1). Since the mid-1970s, all of these objections to using input-output analysis to obtain local or regional multipliers have been overcome by the Regional Industrial Multiplier System (RIMS) and the Regional Input-Output Modeling System (RIMS II) developed by the Regional Economic Analysis Division of the Bureau of Economic Analysis (BEA), U.S. Department of Commerce (2,3,4).

The RIMS II procedure provides regional-specific multipliers for a single county or group of counties and industry-specific multipliers for any of the 496 industrial sectors contained in the 1972 BEA national input-output table. These multipliers are obtained by a standard and consistent methodology at a reasonable cost. Such multipliers permit a comparison of the impact of aviation activities on different industries and a comparison of the impact of aviation expenditures for different categories of airports. RIMS II provides earnings multipliers, which may be used to estimate how aviation-related expenditures affect employment (4). The model also provides a table of direct coefficients and a table from which output multipliers can be calculated for each industry. However, for most public decision purposes, the effects on earnings and employment are the more appropriate indicators of economic activity.

Although RIMS II multipliers have been used in various parts of the United States to assess the regional economic impact of other industries, they have not been used previously to assess the impact of aviation-related economic activity. The RIMS II multipliers offer a technically sound, relatively easy to use, inexpensive, and regionally flexible methodology that may be used in conjunction with standardized data obtained from local areas and the U.S. Department of Commerce to conduct an aviation/airport economic study for any region of the country with a minimum of direct surveying.

In the summer of 1982, the Florida Department of Transportation (FDOT) let a contract to devise a methodology that would determine the economic impact of Florida's general aviation (GA) airports. The results were reported in the Florida General Aviation Economic Assessment (5). This paper highlights the methodology and results presented in that study, presents an example of the use of the RIMS II multipliers, and concludes that the methodology has excellent potential for use throughout the United States.

METHODOLOGY FOR ECONOMIC ASSESSMENT OF FLORIDA GENERAL AVIATION

The methodology encompassed three major phases: identifying airports to be studied, an economic survey of those airports, and analysis of primary and secondary data.

Phase I: Identifying Airports

Surveying each business at each airport to obtain primary economic data was considered impractical. Consequently, a methodology was needed to reduce the number of airports surveyed while still retaining the diversity of airport categories represented in the total Florida GA system.

To identify a small, yet representative, group of airports, simple and multiple regressions were performed to establish influential relationships between the 17 FAA variables used to categorize airports and to determine which variables were most closely related to airport activity (6). The results of this analysis indicated that the strongest relationship existed between aircraft based at the airport and total annual operations. Therefore the mean and standard deviation of the these two elements was determined for each airport category. A similar analysis was performed for all Florida GA airports combined to obtain a ranking of GA airports on a statewide basis. The results produced a ranking of airports as they centered about the mean for each airport category. Those airports situated most closely to the mean became candidates for detailed economic analysis. Nine airports representing different classification categories were selected (5). Hereafter these airports will be referred to as target airports.

Phase II: Economic Survey of Target Airports

The RIMS II analytical model allows the analyst to devote a larger share of his resources to the phase of the study that is most critical: collecting primary economic data by means of a survey. The accuracy of the survey data is of utmost importance for sound conclusions to be drawn. Consequently, a great deal of attention was given to designing the survey, data reliability, and formulating analysis techniques. Because of this effort, approximately 90 percent of the on site businesses and organizations and 100 percent of the direct suppliers answered the surveys. Approximately 90 percent of the answered surveys were of sufficient quality to be used in the economic analysis. Thus, the total success rate of the surveys was more than 80 percent. An extensive description of this phase of the study is contained in the Florida General Aviation Economic Assessment (5).

Phase III: Economic Analysis

The State of Florida was divided into six metropolitan regions, three rural regions, and a region representing the entire state. FDOT purchased a complete set of RIMS II multipliers for each of the identified regions.

To determine the economic impact on the community or region of each target airport, the individual firms surveyed were assigned to a Standard Industrial Classification (SIC) category based on principal products or services. Firms listed in the 1982 Directory of Florida Industries (8) were assigned the SIC code identified by that reference. Those firms not listed in the directory were assigned SIC codes from the Standard Industrial Classification Manual (9) based on knowledge of each firm's principal product and the judgment of the researchers. To aid in administration of the survey, firms were then assigned to one of four categories: airport management, field-based operation (FBO), aviation-related businesses, and nonaviation-related businesses. Most activities including airport management, FBO categories, and a number of aviation-related firms were assigned to SIC 45 (air transportation). However, a number of firms were assigned to other categories, such as SIC 76 (avionics repair).

Sales figures were not available for the airport management category. Consequently, total payroll plus total purchases were used as a proxy for sales in that category. The total sales attributed to airport management, FBO, and aviation-related businesses located at each target airport were aggregated by SIC code and used as the measure of aviation-related final demand at that airport. Because sales activity attributed to nonaviation-related firms was not dependent on general aviation, the impact from these firms on total earnings and employment was excluded from this analysis.

The appropriate RIMS II regional multiplier was then applied to the sales of each aviation-related firm to estimate total earnings. However, the multipliers are based on the six-digit numbering system of the 1972 national input-output model (10) and must be translated to appropriate SIC categories. For example, SIC 45 (air transportation) corresponds to RIMS II code no. 650500. Using BEA personal income data provided by the Florida Department of Commerce, effects on employment were then estimated by dividing the total earnings from general aviation activities by the average annual earnings per employee for each SIC category (7). The total earnings and employment for each target airport are reported in the Florida General Aviation Economic Assessment (5).

ECONOMIC IMPACTS OF FLORIDA GENERAL AVIATION

The use of input-output multipliers to estimate statewide economic impacts of general aviation airports required the development of statewide general aviation airport sales figures. Sales data from the nine target airports were regressed against several airport characteristics. Results from these experiments were much better than had been initially expected. The coefficient of determination (r^2) was 0.81, meaning that approximately 81 percent of the variation in airport sales was explained by the total number of civilian aircraft based there. The "y" intercept was -$630,221, and the slope of the curve was 37,189. This suggests a strong relationship between the number of civilian aircraft based at a general aviation airport and the dollar volume of sales generated at that airport. In 1981 there were 6,720 civilian aircraft based at the state's general aviation airports. A confidence test was conducted for the slope coefficient, which was found to be successful at the 0.0005 level. Standard error of the slope was ±1,382. The resultant regression relationship estimated statewide sales to be $249,281,400 among the 82 general aviation airports offering no known scheduled commercial service. This figure did not include the sales by nonaviation businesses located on airport property.

Total estimated earnings from general aviation for each Florida industry are given in Table 1. Table 1 is derived by applying the statewide earnings multiplier coefficient (not shown in Table 1) for each industry times estimated statewide sales ($249,281,400). Because most activities associated with general aviation can be assigned to SIC 45 (air transportation), only one comparable set of RIMS II multipliers (air transportation, code no. 650500)

TABLE 1 Statewide Impacts by Industry from General Aviation Airport Sales of $249,281,400 (1981 Dollars) and Pensacola Earnings Multipliers

Industry	Statewide Total Earnings ($)	Statewide Total Employment	Pensacola Earnings Multiplier[a]
1. Agriculture	1,221,500	114	0.0011
2. Forestry and fishing	74,800	5	0.0002
3. Coal mining	–	–	0.0000
4. Crude petroleum and natural gas	–	–	0.0001
5. Other mining	49,900	3	0.0001
6. New construction	–	–	0.0000
7. Maintenance and repair construction	2,218,600	148	0.0069
8. Food and kindred products and tobacco	1,884,700	125	0.0022
9. Textile mill products	99,700	9	0.0000
10. Apparel	872,500	96	0.0022
11. Paper and allied products	598,300	28	0.0006
12. Printing and publishing	2,044,100	141	0.0039
13. Chemical and refined petroleum	473,600	23	0.0006
14. Rubber and leather products	324,100	28	0.0001
15. Lumber and furniture products	299,100	23	0.0002
16. Stone, clay, and glass products	124,600	7	0.0001
17. Primary metals	24,900	1	0.0000
18. Fabricated metals	324,100	20	0.0001
19. Nonelectrical machinery	199,400	11	0.0002
20. Electrical machinery	897,400	50	0.0009
21. Motor vehicles	49,900	4	0.0000
22. Other transportation equipment	2,517,700	116	0.0028
23. Instruments	99,700	7	0.0001
24. Miscellaneous manufacturing	249,300	21	0.0006
25. Transportation, local government and transit	91,785,400	4,657	0.3408
26. Communications	2,916,600	140	0.0089
27. Utilities	772,800	34	0.0022
28. Wholesale trade	6,257,000	347	0.0103
29. Retail trade	8,675,000	816	0.0282
30. Eating and drinking establishments	4,761,300	676	0.0159
31. Finance	4,013,400	264	0.0102
32. Insurance	2,941,500	181	0.0045
33. Real estate	872,500	69	0.0025
34. Lodging and amusements	1,171,600	122	0.0034
35. Personal service	1,969,300	188	0.0056
36. Business services	8,749,800	589	0.0246
37. Health services	3,041,200	192	0.0104
38. Other services	4,287,600	422	0.0140
39. Households	598,300	75	0.0020
Total	157,461,200	9,752	0.5064

[a] RIMS II earnings multiplier for code no. 650500 (air transportation) for the Pensacola metropolitan area.

was used to derive impacts statewide. As might be expected the largest earnings are by transportation, local government, and transit industries, which accrue $91,785,000 in total earnings annually. The next-largest earnings sector is the business service sector, generated by airport operations, which reaches $8,749,800. Following that is retail trade with earnings of $8,675,000. Wholesale trade is next with earnings of $6,257,000, followed by eating and drinking establishments, other services, finance, and health services. The total statewide earnings from general aviation are $157,461,200.

The effects on statewide employment were estimated by dividing the earnings of each industry from general aviation by the average annual earnings per employee for that industry. The transportation, local government, and transit sector also have the largest number of employees associated with general aviation. The second largest impact on employment was on the retail trade sector with 816 employees, followed by the eating and drinking establishments with 676 employees, the business service sector with 589 employees, other services with 422 employees, and wholesale trade with 347 employees. In total the $249 million in sales at general aviation airports resulted in employment for 9,572 persons.

Because this is a study of the economics of general aviation in Florida, nonaviation-related businesses were not included in the statewide impact estimates. Among target airports all classifications except the smallest had nonaviation businesses present. The impact of the nonaviation businesses is potentially far greater than that of aviation businesses.

RIMS II TABLES--USE AND SAMPLE CALCULATIONS

The RIMS II tables are described in this section, which explains how they are used, and a sample set of calculations for determining impacts on earnings is presented.

Two levels of industry aggregation tables are available: a 39-row by 39-column set and a 39-row by 476-column set. In this study the 39-by-476 tables were used. The industrial identity of each row is described by a two-digit number and an industry description. These codes and industry descriptions were used to describe the impact of air transportation on the employment of specific industries shown in Table 1. Each column in the table is described by a six-digit code which corresponds with the numbering system of the 1972 national input-output model (10). In this sample set of calculations code no. 650500 (air transportation) was used.

The RIMS II earnings multiplier table for each region of Florida is used to determine the total impact of a given change in final demand on earnings. Also the multiplier table can be used to determine how a change in demand for any one of the 476 industries affects the earnings of any one of the industries represented in the 39 rows.

The final demand figure for a target airport was used as the entry to the appropriate regional RIMS

II multiplier table. The fourth column of Table 1 gives the air transportation column extracted from the earnings multiplier table for the Pensacola metropolitan area. Sales from aviation-related businesses at Destin Airport, which is in the Pensacola metropolitan area, amounted to $1,897,348 in 1981. The total impact on earnings is calculated by multiplying these aviation-related sales by the total of the earnings multiplier column: $1,897,348 x 0.5064 = $960,817.

If the impact of aviation activity on a particular industry is desired, it may be obtained by multiplying the aviation-related sales demand by the appropriate industry's multiplier coefficient. For example, suppose the impact of aviation activity at Destin Airport on the printing and publishing industry in the Pensacola metropolitan area is desired. The earnings multiplier coefficient is 0.0039 for this industry (10). Therefore, aviation-related sales of $1,897,348 at Destin Airport result in total earnings of $7,400 ($1,897,348 x 0.0039) by the printing and publishing sector.

CONCLUSION

The study design developed for the Florida General Aviation Economic Assessment Study provides a practical alternative to the disparate approaches currently employed in estimating the economic impact of aviation activities. The study design employs a recognized input-output approach, RIMS II, for generating multipliers, which ensures that multipliers derived from a common methodology are available for any region of the United States at a modest cost. The field work required to collect primary economic data is minimized because the primary economic variables specified by the RIMS II model, sales and payroll, are easily and reliably collected.

ACKNOWLEDGMENT

Special recognition is given to Joseph V. Cartwright (U.S. Department of Commerce) for his guidance in the use of the RIMS II input-output model, Larry Bauman (FDOT Project Manager), and Jack Karibo (ESE Senior Aviation Planner).

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The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Florida Department of Transportation.

Publication of this paper sponsored by Committee on State Role in Air Transport.

Estimating Aircraft Activity at Nontowered Airports: Results of the Aircraft Activity Counter Demonstration Project

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ABSTRACT

The findings and conclusions of the Aircraft Activity Counter Demonstration Project are reported and data obtained at 24 of the airports studied are used to evaluate alternative methods of estimating aircraft activity from sample data. The counter project used acoustical aircraft activity counters to obtain periodic samples of activity at selected Northwest airports throughout a full year. The paper analyzes the use of independent measures of variation for expanding sample counts and develops a sampling plan for use at nontowered airports when reliable independent measures are not available. Analysis of independent measures of variation includes operations data from related towered airports, weather data, and record of fuel sales. The paper concludes that tower data are not a reliable source for estimating nontowered airport activity because the variations in operations over the year at towered and nontowered airports are not sufficiently similar. Fuel sales data will probably prove to be a more useful indicator of variation, but more research is needed. The paper recommends the use of seasonally stratified, systematic samples of aircraft activity for estimating operations at nontowered airports. This type of sample data may be used to estimate the seasonal distribution of operations and peak loadings and to estimate total annual operations.

Insufficient knowledge of activity at nontowered airports has been a concern of state and federal aviation agencies as well as local airport sponsors. Until recently there was no accurate alternative to visual observations for determining aircraft activity. This means that where there is no tower, estimates of operations are often no better than guesses. This is especially true of small general aviation facilities which often are without full time managers or fixed-base operators.

The Aircraft Activity Counter Demonstration Project was conducted from November 1980 through April 1982 (1). During the project operations data were gathered at 37 nontowered airports in Oregon, Washington, and Idaho by using acoustical aircraft activity counters. These counters record the sound of departing aircraft on cassette tapes which are then audited and the activity is classified by time and date. The sounds of departing aircraft can often be classified into several aircraft types; however, results of the project indicate that the most reliable data are based on total fixed-wing departures. Usually a single counter was used to make periodic counts at several airports throughout a 1-year period.

The estimates of annual operations presented in Table 1 are based on sample data for 24 of the airports in the study. Data on the 13 other airports were not complete enough for use in evaluating alternative sampling and estimating methods. Although there was no attempt to obtain a proportional representation of general aviation airports in the study, a review of the operations estimates in Table 1 indicates a cross section of medium to small general aviation airports. The airports are widely distributed geographically throughout Washington and Oregon and represent a variety of general aviation uses.

Because data were obtained throughout a full year at each of the airports in the study, the data provide information on the seasonal variation of operations. These data were used to test the accuracy of independent data sources as measures of variation of operations at nontowered airports. Independent data sources analyzed include tower operations data, weather data, and fuel sales data. The project data also provide valuable information for designing sampling procedures when accurate independent estimates of seasonal variation are not available. Analysis of sampling procedures and project data demonstrates the use of sampling for estimating seasonal, daily, and hourly variations as well as total annual operations.

TABLE 1 Estimated Annual Total Fixed-Wing Operations at Selected Northwest Airports (based on accoustical counter data), 1981 *(1)*

Airport	Estimated Annual Total Fixed-Wing Operations	Approximate Sampling Error at 95 Percent Confidence Level (%)
Oregon		
Albany	30,272	23
Arlington	618	35
Ashland	16,460	12
Beaver Marsh State	630	36
Christmas Valley	3,232	19
Creswell	26,196	16
Hermiston	15,956	9
Hood River	11,174	15
Josephine County	22,498	15
LaGrande	5,940	21
Lebanon State	11,662	19
Medford-Jackson County	89,244	16
Newport	12,472	18
Pinehurst State	390	36
Seaside State	1,650	23
Siletz Bay State	4,146	27
Sunriver	10,138	16
Tillamook	8,242	25
Wasco State	3,954	36
Washington		
Hoquiam	13,810	26
Kelso	28,404	32
Omak	11,556	13
Richland	25,118	12
Wenatchee	31,938	13

USE OF INDEPENDENT DATA TO ESTIMATE OPERATIONS AT NONTOWERED AIRPORTS

Because of the high cost of obtaining complete visual counts of operations, independent data are often used in conjunction with a limited sample of observed operations to estimate annual operations at nontowered airports. The underlying assumption in the use of independent data is that they measure the variation in operations throughout the year. The measured variations then are used to extrapolate the limited sample into an estimate of annual operations. Estimates of operations based on independent data have always been suspect, because until recently there has been no means of testing the degree of error in such estimates.

Tower Operations Data

Airport operations data at towered airports are used currently to estimate operations at nontowered airports. An FAA publication (2) identifies five methods for estimating operations. Tower data are used to adjust nontower operations data obtained from a small (7- to 21-day) sample. Several different estimating equations are presented, but all are based on the ratio relationship of Equation 1.

$$\bar{y}/\bar{Y} = \bar{x}/\bar{X} \qquad (1)$$

where

$\bar{y}$ = average daily nontower operations during the sample period,

$\bar{Y}$ = average daily nontower operations during the year,

$\bar{x}$ = average daily tower operations during the sample period, and

$\bar{X}$ = average daily tower operations during the year.

Equation 1 assumes that paired towered and nontowered airports will have a similar distribution of operations over the year. The equation also assumes that towered and nontowered airports can be logically paired according to similarities in mix of operations, weather, and daily traffic variation.

Method of Comparing Towered and Nontowered Airports

To test these two assumptions, estimates of each quarter of annual operations at 23 nontowered airports were compared with quarterly operations data for the closest or otherwise best-paired towered airport. The Medford Airport was used as a control because both tower operations data and data gathered by acoustical counters were available. Tower operations data were obtained from unpublished FAA tower operations data for 1981. A total of seven towered airports in Washington and Oregon were used in the study. Only itinerant and local general aviation data for towered airports were used so that the data would be comparable to the type of data available from nontowered airports.

The quarterly distributions of operations at towered and nontowered airports were considered to be similar if they did not differ by more than 25 percent in any one quarter. A 25 percent difference was allowed because (a) it provides for a liberal but reasonable tolerance of variation and (b) the quarterly distribution of sampled operations data at Medford Airport differed by as much as 23 percent during a single quarter from the quarterly distribution of tower data for the Medford Airport. The difference in the quarterly distribution of operations between the Medford sample data and tower data may be due to (a) the difference between a sample and a complete count and (b) the fact that the sample estimate reflects all operations, whereas only general aviation statistics were used from the tower data.

Result of Comparison of Operations

The comparison of the quarterly distributions of operations at nontowered and nearby towered airports yielded few similar pairs (see Table 2). Of the 23 paired towered and nontowered airports studied, only six had similar distributions of operations. The other 17 towered and nontower pairs were not similar because of the wide fluctuation in the quarterly distributions of operations at nontowered airports.

Among nontowered airports, the proportion of annual operations that occurred in a single quarter ranged from a low of 7 percent to a high of 61 percent. Furthermore, among nontowered airports there was no consistent pattern in the distribution of operations across quarters. With few exceptions, each nontowered airport exhibited a unique distribution of quarterly operations.

By comparison, the distribution of operations among towered airports followed a much more consistent pattern across quarters. The proportion of annual operations that occurred in a single quarter ranged from a low of 14 percent to a high of 36 percent, less than half the range of nontowered airports. Generally the first and fourth quarters each accounted for about 20 percent of annual operations, and the second and third quarters each had about 30 percent of annual operations.

This relationship is more visible in pre-1981 tower data. The 1981 data were affected by the air traffic controller walkout and the recession, which lowered fourth quarter activity at towered airports.

This comparison indicates that the distributions of operations at towered airports are not sufficiently similar to paired nontowered airports for estimating purposes. Therefore, tower operations data should not be expected to provide reliable estimates of operations at nontowered airports.

This conclusion would hold even if nontowered airports were paired with different towered airports. Given the similarity in the quarterly distribution of operations among all towered airports, and the varied distribution of operations among nontowered airports, it is not probable that a better pairing of towered and nontowered airports could improve the estimating capability of tower operations data. Most of the nontowered airports are dissimilar to their paired towered airport and also dissimilar to all other towered airports in the study.

An example using the Josephine County nontowered airport illustrates how an overestimation of operations at Josephine County Airport could result from using Medford tower operations data. Josephine County Airport is about 25 miles from the Medford Airport. The two airports share the same weather and, therefore, the same flying conditions. Based on acoustical counter data Josephine County Airport was estimated to have 22,498 operations a year, which is 19 percent of the general aviation activity at the Medford Airport. Data reports for Medford tower show 122,961 general aviation operations in 1981. This number differs from the Medford operations estimate given in Table 1 because that estimate is based on a sample and does not include helicopters or missed approaches.

The two airports appear to be a good nontowered

TABLE 2 Quarterly Distribution of Operations at Selected Towered and Nontowered Airports, 1981

Towered Airport	Nontowered Airport	Percent of Annual Operations[a]			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
McNary (Salem, Oreg.)		24	34	28	14
	Newport	19	27	33	21
	Albany	22	29	32	17
	Creswell	18	31	34	17
	Lebanon State	19	35	32	15
	Siletz Bay State	9	36	36	19
Portland-Hillsboro (Oreg.)		24	29	29	18
	Tillamook	22	21	20	37
	Seaside State	9[b]	34	43	15
	Hoquiam	18	32	15	35
	Kelso	33	27	13	28[c]
Portland-Troutdale (Oreg.)		23	32	29	16
	Hood River	12	27	45	16
Kingsley (Klamath Falls, Oreg.)		22	30	33	14
	Sunriver	12	27	49	12
	Christmas Valley	23	25	38	14
	Beaver Marsh State	9	48	30	14
Medford-Jackson County (Oreg.)		22	29	31	19
	Medford-Jackson County	17	33	34	16
	Josephine County	35	30	28	7
	Ashland	26	27	34	13
	Pinehurst State	15	29	48	8
Walla Walla (Wash.)		25	36	22	17
	LaGrande	10[b]	26	52	12
Tri-Cities (Pasco, Wash.)		20	31	29	20
	Richland	21[b]	22	26	31
	Omak	29	24	28	18
	Wenatchee	22	29	27	22
	Wasco State	61	14	14	10
	Arlington	36	50	7	7
	Hermiston	20[b]	30	28	22

[a] Quarterly percentages may not sum to 100 because of independent rounding.

[b] Quarterly distribution is for the first quarter of 1982 and is not strictly comparable to 1981 first quarter tower data.

[c] Quarterly distribution is for fourth quarter of 1980 and is not strictly comparable to 1981 fourth quarter tower data.

and towered pair for the purposes of estimating nontowered operations. However, the quarterly distribution of operations at the two airports is not similar. If general aviation operations data from the Medford Airport were used to expand sample data from the first quarter at the Josephine County Airport, annual operations would be estimated at 38,390. This estimate was obtained by using the minimum change estimate (MCE) equation given by FAA (2).

The estimate of 38,390 annual operations is 71 percent higher than the 22,498 estimate of annual operations based on a more complete sampling of actual activity at Josephine County. This large discrepancy is due to the compounding of two errors in the estimating technique. First, the technique assumes that the proportion of annual operations that occur in the first quarter at Josephine County and Medford Airports are the same. This was not the case. Medford had 17 percent of annual operations occurring in the first quarter, whereas Josephine County had 35 percent of annual operations in the first quarter (Table 2). This difference in the distribution of operations accounted for 65 percent of the error in the estimate. Second, the technique relies partially on the use of previous activity estimates which, for Josephine County Airport, have been much higher than actual counts indicate. The use of a high estimate in the technique accounted for an additional 6 percent error in the estimate. The resulting 71 percent error is in addition to the sampling error.

The above example was based on first quarter operations to avoid any impacts on the distribution of operations caused by the air traffic controllers walkout in August 1981. Worse case examples are apparent in Table 2, such as the 205 percent difference in the proportion of first quarter operations at Tri-Cities and Wasco State Airports. Another example is the 136 percent difference between third quarter operations at Walla Walla and LaGrande Airports.

On the other hand, some paired towered and nontowered airports had similar distributions of operations in each of the four quarters. The Wenatchee and Tri-Cities Airports are the best example. Quarterly operations at these two airports differ by 10 percent or less in each quarter. In this case, estimating operations at Wenatchee by using Tri-Cities tower data would have a 10 percent or less error (plus the sampling error). The problem is that one does not know beforehand which nontowered airports can be successfully estimated from tower operations data, or in which quarter to sample operations, without more knowledge of seasonal operations at nontowered airports.

The difference in seasonal distributions of operations at towered and nontowered airports appears to result from a combination of factors, including the effect of weather and the types of uses that tend to concentrate at nontowered airports. General aviation activity appears to be more sensitive to weather conditions at nontowered airports. An obvious reason for this difference is the nature of the airport facilities. Towered airports provide for instrument approaches, whereas the majority of nontowered airports do not have this capability. Another reason for the varying impact of weather may be because business and commuter aircraft constitute a higher proportion of the operations at towered airports. Business aircraft tend to be better equipped for instrument flying and more likely to fly regardless of the weather. By contrast, training and recreational flying probably account for a larger proportion of operations at nontowered airports. This type of fair weather activity tends to be more sensitive to weather conditions.

The dissimilarity in the seasonal distribution of operations also may be due to different types of activities. At nontowered airports it is probable that a large portion of operations results from specialized activities. For example, the LaGrande Airport is used extensively by the U.S. Forest Service when fighting forest fires during the summer months. This activity results in an unusually high percentage (52) of annual operations occurring in the third quarter. At the Wasco State Airport 61 percent of annual operations occurred in the first quarter because of local crop spraying schedules. These types of local activities are not reflected in tower operations data.

Weather Data

During the Aircraft Activity Counter Demonstration Project weather data were gathered for most of the days on which aircraft departures were sampled. Daily comparisons indicate that there is a correlation between weather condition and departures. As a result, daily departures were generally higher in the second and third quarters (April through September), when flying conditions tended to be better, than in the fourth and first quarters (October through March). Furthermore, departures varied with weather conditions within each quarter.

If daily weather data for a sampled airport were available, they would be expected to help provide an estimate of variation in operations so that the size of the sample of operations could be reduced. Unfortunately, using weather data as an independent indicator of variation has several drawbacks. Weather data must be available for every day of the year, not just when flying activity is being sampled. Data collected by the National Weather Service do not include visibility and cloud ceiling, which are the most important weather factors affecting operations. Also, site-specific weather data are not available for many nontowered airports. Finally, use characteristics of individual airports result in different sensitivities to weather conditions; therefore, even if adequate weather data were available, it could not be expected to account for all variations that affect operations. Other components of variation, such as type of day (weekday, or weekend or holiday) and other nonweather seasonal variations would still have to be captured directly by sampling operations.

Fuel Sales Data

In Oregon retail sales of aviation gasoline and jet fuel are reported monthly by most retail dealers. A comparison of fuel sales data and number of departures was made for seven nontowered Oregon airports. Analysis was limited to the months that had both adequate samples of departures and complete fuel sales data. The correlation coefficient of gallons of aviation gasoline sold and number of departures was between 0.92 and 0.97 at five of the seven airports. The other two airports had coefficients of about 0.68. Jet fuel was also sold at three of the airports studied but inclusion of jet fuel sales in the analysis did not improve the coefficients. One of the airports with the lower correlation coefficient also had a very high ratio of departures per gallon, indicating that most users of this facility probably bought their fuel elsewhere.

To test the use of fuel sales data for estimating operations, a ratio of departures per gallon of aviation gasoline sales was calculated for each airport for each month in which complete data were available. In spite of the close relationship of fuel sales and aircraft activity, these data indicate that wide errors could result if fuel data were used to expand a single weekly count to an annual total. On the other hand, when the average departures for all months were used to estimate operations from fuel sales, the results were similar to those obtained by the direct survey, even for those airports with the lower correlation coefficients.

Extreme ratios of departures to fuel sales probably resulted from a combination of two factors. First, the data on departures actually consisted of week-long samples expanded to a full month. Although this sampling period provides a very good confidence interval over a several month period, it allows for wide deviation in a single month. Second, changes in types of aircraft and types of activity throughout the year may have affected the ratio of departures to fuel sales.

In response to this second concern, a check was also made to determine if variations in the ratio of departures to fuel sales followed a seasonal pattern. Although a pattern was not identified, it is interesting to note that the greatest variation in the measure of departures to fuel sales occurred in the first quarter at most airports.

The comparison of departures-to-fuel-sales ratios among airports also provides useful information on the relationship between fuel sales and operations. Although there was a high correlation between fuel sales and departures at most of the individual airports studied, there were significant differences in the ratios of departures to gallons of fuel sales among airports. Mean ratios of departures per gallon were tested for significant difference at a 95 percent confidence level using a one-tailed t-test with pooled variance. Of 21 possible pairings, 19 were significantly different.

Two studies are needed to confirm these general findings and determine the potential accuracy of methods relying on fuel sales as an independent indicator of variation. One is to conduct operations counts during periods that correspond exactly to the fuel reporting periods. Both the operations counts and fuel data should be collected periodically over a full year. Second, a follow-up study is needed to determine fueling practices at each airport surveyed. For instance, how much in fuel sales is not reported because of private tanks or unlicensed dealers and how much is consistently ferried into or out of the airport?

SAMPLING DESIGN FOR NONTOWERED AIRPORTS

Use of Systematic Cluster Samples

When there is no accurate independent indicator of seasonal variation at a particular nontowered airport, or in cases where the indicators themselves must be tested for reliability, it will be necessary to conduct samples of activity throughout the year. A cost-effective method of sampling activity using an acoustical counter is to sample clusters of 7 days systematically throughout the year. All departures occurring during each of the sampled 7-day periods would be counted.

Analysis of data obtained in the Aircraft Activity Counter Demonstration Project indicates that significant differences in airport activity are associated with day of the week and season of the year. In order to sample where the variation occurs, days should be stratified into weekdays, and weekends and holidays. Seasons should be stratified based on annual weather patterns. For most areas of the country two, three, or four seasons could be used. If four seasons are used, the sample would be stratified into eight separate cells.

If 7-day clusters are used, a stratified sample is automatically proportional with respect to the day of the week. A systematic sample of 7-day clusters, which provides for an equal number of evenly spaced clusters per season, will provide proportionality of seasons. If seasonal as well as annual estimates of operations are desired, it is necessary to sample at least two 7-day clusters in each season.

To ensure randomness in the sample, the first of the sample weeks is chosen randomly. Subsequent sample weeks occur at equal intervals throughout the year. The sample size may be chosen to reflect the desired trade-off between cost and accuracy. Preliminary estimates of sampling error for alternative sample sizes and expected numbers of annual operations are shown in Table 3 (3).

TABLE 3 Approximate Percentage of Sampling Error in Estimates of Annual Operations by Size of Airport and Size of Sample

Approximate Annual Operations at Airport Being Sampled	No. of Weeks Sampled per Year				
	4	6	8	10	12
	Approximate Sampling Error (%)				
900	54	44	37	32	29
900- 2,399	51	41	34	30	27
2,400- 4,399	47	38	32	28	25
4,400- 7,199	44	35	30	26	23
7,200-10,499	40	32	27	24	21
10,500-14,599	36	29	25	21	19
14,600-19,199	33	26	22	19	17
19,200-24,599	29	23	20	17	15
24,600-30,499	25	20	17	15	13
More than 30,500	22	17	15	13	12

Sample Cost

One of the most significant aspects of the acoustical aircraft activity counter is that it permits periodic sampling or continuous monitoring at nontowered airports at a reasonable cost. The cost of resampling the Oregon airports previously counted as part of the Aircraft Activity Counter Demonstration Project was calculated based on the sampling plan presented in this paper and cost factors relevant to Oregon. Assuming a sample size to keep the sampling error in the range of 20 percent, costs range from $1,000 to $2,000 per airport. Costs would be higher if a larger sample was desired to reduce the sampling error. Costs could be lowered by tolerating less accurate estimates.

Estimating Annual Operations from Sample Data

After the sampling of departures has been concluded, the sample data must be extrapolated to estimate a full year of operations. This section illustrates how annual operations and sampling error are estimated from data gathered according to the sampling plan discussed previously. Specifically this estimating procedure assumes that sample data consist of counts of departures taken during two or more 7-day periods in each season.

Total operations (landings and departures) during each season may be estimated by expanding the sum of the sampled departures in each season by 2(N/n); where N = number of weeks per season (e.g., 13 if quarters are used), and n = number of weeks sampled in each season. Total annual operations is estimated by summing the seasonal operations estimates.

Calculation of the variance of the estimate is not as straightforward because the sampling plan was based on weekly clusters instead of random days. The variance of the estimated seasonal operations is estimated by Equation 2:

$$\hat{V}(2\hat{D}_j) = (2^2)(N^2)[1-(n/N)] \left[n \sum_{i=1}^{n} d_{ij}^2 - \left(\sum_{i=1}^{n} d_{ij} \right)^2 \right] / n^2(n-1) \qquad (2)$$

where

$\hat{D}_j$ = estimated departures in the jth season,
$\hat{V}(2\hat{D}_j)$ = estimated variance of estimated total operations for the jth season, and
d_{ij} = departures counted during the ith week of the jth season.

The variance of the estimate of total annual operations then is given by Equation 3.

$$\hat{V}(2\hat{D}) = \sum_{i=1}^{J} \hat{V}(2\hat{D}_j) \qquad (3)$$

where J = total number of seasons.

The estimated variances of the estimates of seasonal and annual operations may then be used to calculate the percent sampling error of each estimate at the 95 percent confidence level by using Equations 4 and 5. The sampling error of seasonal estimates is

$$\hat{E}(2\hat{D}_j) = 100\, [\hat{V}(2\hat{D}_j)]^{1/2} / \hat{D}_j \qquad (4)$$

and the sampling error of annual estimates is

$$\hat{E}(2\hat{D}) = 100\, [\hat{V}(2\hat{D})]^{1/2} / \hat{D} \qquad (5)$$

It should be noted that the procedure for estimating sampling error can be used even if the seasons in the stratified sample are not proportional. However, if proportionality of the day of week stratification is lost, further adjustments are required.

Distribution of Operations

Often the distribution of operations, including seasonal distributions and monthly, daily, and hourly peaks, is as important to airport planning, funding, and management decisions as the estimate of total annual operations.

A representative sample of departures can provide information on the distribution of airport activity. The empirical or observed distribution of sample data can be considered the most probable distribution of the population in the absence of other information about the population distribution (4).

The seasonal distribution may be determined by dividing the seasonal estimates of operations by the annual estimate. Independent information, such as fuel sales data, also may be useful in making estimates of seasonal or monthly operations, especially when the sample is small.

Samples of departure data can also provide a frequency distribution of hourly and daily departures for planning purposes. Because daily operations are expected to be twice the number of daily departures (assuming an equal number of landings and departures), the distribution of daily operations should mirror the distribution of daily departures. However, the distribution of hourly operations cannot be inferred from the distribution of hourly departures because it cannot be assumed that an equal number of landings and departures will occur in any one hour.

The peak number of departures can be identified directly from the frequency distribution of departures per hour or day. Peak daily operations are used to plan for airport design capacity, airport improvement projects, and service demands. Peak hourly departures are useful to airport managers and fixed-base operators in planning for service demands and staffing requirements.

In some cases, the daily or hourly peak-to-mean ratio also may be a useful statistic. Sample data indicate that peak-to-mean ratios tend to be inversely related to the size of the airport. Peak departures tend to increase as mean departures increase, but at a slower rate.

IMPACT OF ECONOMIC DOWNTURN AND AIR TRAFFIC CONTROL WALKOUT ON FINDINGS

Before concluding, some attention should be given to two important factors that affected the level of operations during the sample period used in this analysis. The severe economic downturn in 1981 reduced all aviation activity. In August 1981 the air traffic controllers walkout resulted in an additional reduction in operations at many airports. Because of these events, 1981 may have been an atypical year for aviation, but it is improbable that they affected the major conclusions of the study.

Conclusions about the comparison of towered and nontowered operations are based on differences in the seasonal distribution of operations. Seasonal variations of operations would not have been changed substantially because of economic recovery or the elimination of the third quarter downturn resulting from the air traffic controllers walkout. The sampling procedures developed and the estimates of confidence intervals reflect the seasonal and daily variations in operations at nontowered airports. Sample size requirements might be reduced if these variations were reduced, but the procedure itself would not change substantially.

CONCLUSIONS

Aircraft operations data gathered during the Aircraft Activity Counter Demonstration Project have proved useful in analyzing and testing alternative sampling procedures for estimating aircraft activity at nontowered airports. The results of this analysis indicate that the most commonly used sampling procedures, which rely on comparisons of nontowered airports with towered airports, cannot be expected to provide reliable results. Other independent measures of aircraft activity, such as fuel sales data, may prove to be more useful than tower data for estimating activity at nontowered airports. However, further research is needed on the relationship between fuel sales data and aircraft operations at nontowered airports.

The most cost-effective procedure for making statistical estimates of aircraft activity at nontowered airports is to use an acoustical aircraft activity counter to obtain a series of cluster samples systematically drawn throughout the year. Such samples can provide valuable information on seasonal and peak use patterns as well as total annual operations.

Based on these findings it is recommended that the FAA devote more attention to techniques that do not rely on comparisons with tower data to estimate air activity at nontowered airports. Further research should be devoted to finding and evaluating alternative independent measures of variation in activity at nontowered airports. Further research is also needed on the use of acoustical aircraft activity counters or similar equipment to reduce the cost of periodic sampling.

The Oregon Aeronautics Division is currently conducting a counting program using the procedures recommended in this study as part of the federally sponsored Continuous Aviation System Planning Process. Activity counts are being used in system planning and to update Airport Master Records (5010 forms); and significantly improved data are being supplied to airport sponsors, managers, fixed-based operators, and planners.

ACKNOWLEDGMENT

This paper draws on the information and ideas presented in the Aircraft Activity Counter Demonstration Project Final Report, November 1982. The project final report was prepared by the Oregon Department of Transportation, Aeronautics Division, and by the Oregon State University Survey Research Center, in cooperation with the Washington State Aeronautics Division and Idaho Division of Aeronautics and Public Transportation. The Aircraft Activity Counter Demonstration Project was jointly funded by the Federal Aviation Administration, the Pacific Northwest Regional Commission, and the states of Oregon, Washington, and Idaho.

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Publication of this paper sponsored by Committee on State Role in Air Transport.

Mission-Oriented Maintenance for Military Aircraft and Implications for Public Transportation Fleet Maintenance

MAXIMILIAN M. ETSCHMAIER

ABSTRACT

Traditionally military and civilian fleet management organizations have been designed to separate the maintenance function from the operations function as much as possible. This minimizes the need for exchange of information between operations and maintenance. The limited control available through current information management resources has justified this separation. Because real time information systems have become more powerful and less expensive, different approaches to the design of fleet management organizations have become practical. A new approach, mission-oriented maintenance, looks at the entire fleet management organization as an integral system and optimizes this system toward the primary mission. To this end it redefines the interaction between operations and maintenance. It maximizes overall flexibility and develops a new set of objectives for maintenance. The result is a system that gives maintenance a clear understanding of its role within the overall mission and significantly improves fleet availability for operational purposes. The approach is applicable to the maintenance of any fleet, and it can also be used for stationary equipment operated in large numbers to accomplish one goal (e.g., power generating equipment in an electric utility). A mission-oriented maintenance program is developed for the air force of a small country. The procedures used in this development are outlined and some results are presented. An outline is also given for a mission-oriented maintenance approach to public transportation fleets.

Over the past 30 years or so significant insights have been gained into the nature of aircraft maintenance. This was brought about by a systems approach to the processes that are responsible for the safe operation of an aircraft. One of the principal findings was that any possibility of a component failure is unacceptable if the component is vital for the safety of operations and that component failure can be virtually eliminated by proper design or by monitoring the deterioration of the component. Preventive reconditioning (overhauls) or discard of a critical component based on age or operating time was found to be an unsatisfactory protection. Instead maintenance programs have been developed that call for ongoing monitoring or periodic inspection of the condition of components. Replacement or reconditioning is performed when the observed conditions demand it. Thus the practice of time-determined overhauls has now been eliminated for critical components and is only used for noncritical components when economic conditions permit.

The practice of time-determined overhauls can be viewed as a static approach in which the times between overhauls or replacement can be optimized based on failure data and other quantitative information. The current approach, by contrast, treats maintenance as a dynamic process in which continuous actions are taken to assure most economically the continued safety of the aircraft. It amounts to the conscious management of safety of operations and avoidance of any situation where it is jeopardized. In the current approach many of the monitoring tasks are performed by operating crews during preflight checks or during normal flight operations; thus, the operating crews become part of the maintenance team.

The methods by which modern aircraft maintenance programs are being developed are well documented by the Air Transport Association (1) and Nowlan and Heap (2). The latter also include an extensive literature review and bibliography. The most important features of these aircraft maintenance programs are described in the following paragraphs.

The aircraft is divided into significant components. An analysis is performed to determine how critical each component is to the safety and completion of the mission and the characteristics of its systematic deterioration during use. Systematic deterioration may be inherent wear (fatigue or friction); or it may be caused by environmental conditions, either lasting in nature (e.g., corrosion) or instantaneous (e.g., accidents). If the rate of deterioration of a component can reasonably be reduced by lubrication, adjustment, and so forth, that activity is included in the maintenance program.

For each component critical to safety, an inspection type and inspection interval are selected that permit the identification of a deteriorating condition before it causes the component to fail. If there are alternatives, the selection is made on the basis of economic considerations and on how the maintenance task can be fitted into the usage pattern of the aircraft. If no suitable inspection can be identified, other measures are mandated. These measures may be the redesign of the component or the aircraft either to permit a suitable inspection or to make the component noncritical. In some instances, a change in the operating procedures, including changes in operating limits, may also be indicated.

For components that are not critical to safety, inspections are prescribed to prevent negative effects on, or in conjunction with, other components. If the condition of a component cannot be determined and its deterioration is related to use or age, then a periodic discard or reconditioning may be prescribed if economically justified. For components that are known to deteriorate, remedial actions are specified that have to be performed when certain levels of deterioration are detected. For other components, such as structural components that are not expected to deteriorate, remedial actions are only developed if and when deterioration is actually detected.

After all components are reviewed, the maintenance actions are assembled into a comprehensive maintenance program for the aircraft. Such a program identifies a hierarchy of checks and defines times before which these checks have to be performed. Before the maintenance program for civilian aircraft can be implemented in the United States, it has to be approved by a supervisory agency such as the Federal Aviation Administration. Once approved, the maintenance program becomes mandatory and deviations require special permission.

MAINTENANCE AND OPERATIONS

With few exceptions, airlines exist to satisfy some demand for transportation. Similarly a military fleet of aircraft exists to perform sorties to meet the requirements of the military situation. The role of maintenance is to keep aircraft in a safe and operational condition, ready to perform the missions demanded of them. Maintenance also has to have the capability to meet unforeseen circumstances that demand deviation from the prescribed course of events and to do this with a minimal disturbance of operations at a minimal cost.

The following elements can be used to minimize the cost of maintenance:

- Define the maintenance program.
- Develop an adequate set of repair procedures.
- Establish resource levels and deployment patterns for personnel, material, equipment, and standby aircraft.
- Schedule maintenance tasks.
- Schedule personnel.
- Define and establish a capability for information processing and analysis and record keeping.

To have an economically viable capability to handle unforeseen events, the maintenance function has to be as flexible as is practical. This requires a general appreciation of the need for flexibility by all maintenance personnel and one or more of the following capabilities:

- Redeployment of resources on short notice,
- Ability to defer or alter scheduled work, and
- Fast information processing and decision making.

An example of an unforeseen event is damage to an aircraft, caused either by an accident or by some unforeseen deterioration, that may require considerable work capacity to repair or that may remove the aircraft from the operational fleet for some time. Another example is disturbance in the operational pattern that might change the utilization rate of individual aircraft or that might cause aircraft not to be available for scheduled maintenance tasks. To minimize the effect of either of these events on flight operations, maintenance can keep spare aircraft and extra manpower. However, both of these measures are expensive and the need for them can be greatly reduced by structuring maintenance work and the maintenance organization in a flexible manner.

The operations department of an airline is charged with developing the best program of scheduled and charter flights that permits the most profitable use of the aircraft and with executing this program as closely as possible to the plan. In a military context the situation is not much different except that the demand often arises from a threat and is identifiable only a short time in advance.

Maintenance requirements limit the ability of operations to meet the demand and to respond to unforeseen events or disturbances. Operations has to know and understand the limitations that maintenance imposes on the use of aircraft to be able to develop the best possible operational plan. In the same way, of course, maintenance has to understand the demands from operations to be able to develop a maintenance program that best meets the operational requirements.

Traditionally maintenance and operations departments have communicated their needs to each other in the form of constraints and negotiated a mutually acceptable set of provisions. Essentially time periods are set aside during which specified numbers of aircraft have to be available for maintenance. Both maintenance and operations develop their best plans around these constraints. Any desirable deviations are negotiated in developing the airline schedule and evaluation process. In a military organization a fixed number of aircraft are often set aside for maintenance, and the military command does not plan on their availability. Of course, in a battle situation the commander may decide to use the maintenance aircraft for operations as well.

Undoubtedly the existence of constraints, which separate the spheres of maintenance and operations from each other, can simplify the management problem. Each department manages its affairs as independently as possible. However, this independence has its price and it is believed that if the boundaries between operations and maintenance could be relaxed, the organization would be able to meet the demand more economically. Modern means of communication and information processing should make it possible to increase the flexibility between operations and maintenance; however, developing a mission-oriented maintenance system is a technical prerequisite. Organizational changes are also necessary to realize the benefits fully.

MISSION-ORIENTED MAINTENANCE

The Air Transport Association has specified a set of maintenance tasks for each component. Tasks were selected on the basis of economic analysis and how well they would fit into the work flow of maintenance shops and operational patterns. However, maintenance frequently has to be performed under circumstances that are quite different from the planned conditions. The constellation of parameters assumed in the economic analysis does not apply in these situations. The use of resources that were previously acquired, possibly at great expense, may make little or no difference in total cost. Other resources that could have previously been acquired at little cost, but were not, may not be available at any price on short notice. In addition, alternative courses of action, such as standby aircraft or schedule changes, are not possible without a long lead time.

It follows, therefore, that it would be more desirable to select the optimal maintenance task when the actual situation under which the task has to be performed is known. Of course, an economic optimization cannot be undertaken every time maintenance is required. Instead, a well structured program can be developed, which offers specific choices and precise instructions on how to make the selection.

The situation is similar at the level of checks. Individual tasks are packaged into checks based mostly on ease of administration and, to some degree, economics. Maintenance tasks are neatly packaged into checks so that total maintenance progress is easier to track and work is easier to schedule. If, for unforeseen reasons, the workload on a given day is excessive, it would be advantageous to perform only the work that is absolutely necessary instead of the whole package. The deferred items can be handled whenever capacity becomes available again or whenever their time limit expires. As with individual maintenance tasks, such a system would become unmanageable unless a system were introduced and a capability for information processing were available.

Making a maintenance program more flexible means that the aircraft can be used more effectively for the mission of the organization. A flexible maintenance program is commonly referred to as mission-oriented maintenance. Mission-oriented maintenance does not minimize maintenance cost or aircraft downtime nor can it be used to defer maintenance indefinitely. The temptation to do so, however, clearly exists. Therefore, a mission-oriented maintenance program can only be implemented if genuine cooperation exists between maintenance and operations. This cooperation requires an effective and reliable means of communication.

Many elements of a mission-oriented maintenance program are standard in many airlines today, although none is known to have a formal program in place. In the following section mission-oriented maintenance programs for a military organization are briefly described. Then an outline is given for the development of a mission-oriented maintenance program for an airline or other civilian operators of fleets of vehicles in scheduled transportation.

MISSION-ORIENTED MAINTENANCE PROGRAMS FOR A MILITARY ORGANIZATION

The mission-oriented maintenance programs described here were developed within the context of a project to restructure the maintenance and logistics section of the air force of a small, nonaligned country. The project included the development of new organizational structures and procedures for operations, planning, decision making, and information processing. The project was motivated by the expected acquisition of the latest technology combat aircraft.

The military objective is strictly limited to territorial defense. It is expected that almost any hostile engagement will take place within the boundaries of the country. Because the country is small it is expected that when a hostile engagement starts, no part of the country may be assumed to be safe. Consequently it is not possible to plan a staging area, and all personnel, material, equipment, and facilities are expected to be affected by combat.

Without going into details, a wartime scenario may be characterized by a prolonged period of tension, interrupted by episodes of combat. The duration of each combat episode is expected to be on the order of several days. During these episodes, flying activity will be at a high level and all aircraft will be on alert. During the intervening periods of tension flying activity will be less but the requirements for readiness will still be high. During wartime all aircraft will be operated in small groups from makeshift bases scattered throughout the country. In times of combat it is expected that frequent relocations will occur.

The point of departure for the development of the mission-oriented maintenance programs was conventional maintenance programs based on manufacturers' recommendations and approved by an independent authority. This authority operates much as the Federal Aviation Administration does in the United States for civilian aircraft. All maintenance programs that were in effect at the beginning of the project had been in place for years; therefore, the military organizations and the work force were accustomed to them. It was widely recognized, however, that aircraft ground times were excessive.

The first step in developing the mission-oriented maintenance programs was to assemble a comprehensive data base encompassing the following information:

- Existing maintenance programs,
- Existing maintenance practices,
- Wartime mission scenarios for aircraft and maintenance personnel,
- Estimates of qualitative and quantitative requirements for damage repair during periods of military conflict, and
- Maintenance requirements of aircraft components.

In addition to permitting a more systematic development of the new maintenance programs, the data base was intended to provide

- A basis for comparing the effectiveness of the existing maintenance programs with that of the new programs.
- An assurance that the existing programs and practices would be used as a basis for the new programs. Much thought that had gone into developing the existing practices could be transferred to developing the new programs and practices. Thorough analysis of the existing situation could help assure that the new programs and practices called for a minimum amount of change and disruption.
- An educational experience for the members of the project team, most of whom had little experience in designing a maintenance program. Analysis of the current situation sharpened their perception and awareness of factors that determine the effectiveness of a maintenance program design.
- Some immediate improvements in the practice of maintenance.

Objectives for the Wartime Maintenance Programs

After the data base had been assembled, it was possible to state what form maintenance programs for wartime could take and what objectives could be met. A wartime maintenance program is the best expression of what is possible. Holding off the specification of objectives for the wartime maintenance programs until completion of the basic information made it possible to make the objectives realistic.

The most important objectives are described briefly below.

1. Safety must be assured at all times. It is tempting to think that during combat safety will be of little importance. Certainly many situations will occur when adherence to restrictions imposed by safety considerations will probably mean death. However, the purpose is to limit these situations to unforeseeable events and to assure safety in all other cases.
2. It has to be possible to sustain wartime operations indefinitely according to the given operations profiles. This means keeping up with all maintenance work and expected repairs in the mode of operation planned for wartime.
3. The sum total of resources required for peace and wartime operations of the maintenance program has to be minimized. This is different from minimizing peacetime and wartime maintenance programs separately. It is also different from minimizing the

manpower or equipment required for some particular maintenance task. Minimizing the sum total of resources required implies that there is no penalty for using resources that are already available. Thus minimizing workload is only important when it would exceed the capacity of available personnel. Minimization of aircraft downtime is not important as long as it does not interfere with the requirements of the military command (i.e., as long as it can be accommodated in the operational windows made available by the military command). In fact a general principle has been adapted to aircraft maintenance: All resources, once acquired, are free unless they can be gainfully disposed of.

4. During wartime all aircraft have to be operational or at least be operational within a short time specified by the military command.

5. The transition from peacetime operations to wartime operations has to be accomplished within a short time.

The objectives just stated imply that all maintenance work has to be arranged in small packages, each one of which can be done in a few hours. Furthermore, from any point within any package, it should be possible to reach a flyable condition within a short period of time. No absolute limits were specified for either of these times; instead the personnel developing the maintenance programs were instructed to make them as small as reasonably practical. The requirement for quick transition from peacetime to wartime maintenance means that the wartime maintenance programs must be essentially part of the peacetime maintenance programs.

New Maintenance Programs

The new maintenance programs are based on a definition of states of maintenance of an aircraft. The following states were defined.

I--Aircraft meets all peacetime maintenance requirements.
II--Aircraft meets all wartime maintenance requirements but violates some peacetime requirements.
III--Aircraft has exceeded the due date for a maintenance event. To define this state completely it is necessary to know which maintenance event is past due and which parts of the work included in that maintenance event have already been completed.
IV--A component has exceeded a time limit.
V--Aircraft is not airworthy.

Figure 1 shows a typical profile along which an aircraft might progress from peacetime through wartime. Naturally the aircraft starts out in state I (i.e., it meets all peacetime requirements). The target state for wartime is state II, when all wartime maintenance requirements are met. The time the aircraft spends in state II is interrupted by times in states III and IV, when due dates for aircraft or component maintenance work have been exceeded. During these times special inspections may have to be performed. The flying hours spent in these two states at any one time are limited. If they are exceeded, the aircraft enters state V. Because this event should not occur if the programs are followed, it is not shown in the diagram.

The new maintenance programs were developed by proceeding through the following steps:

1. Assume a time by which the due date for each aircraft maintenance event can be exceeded.

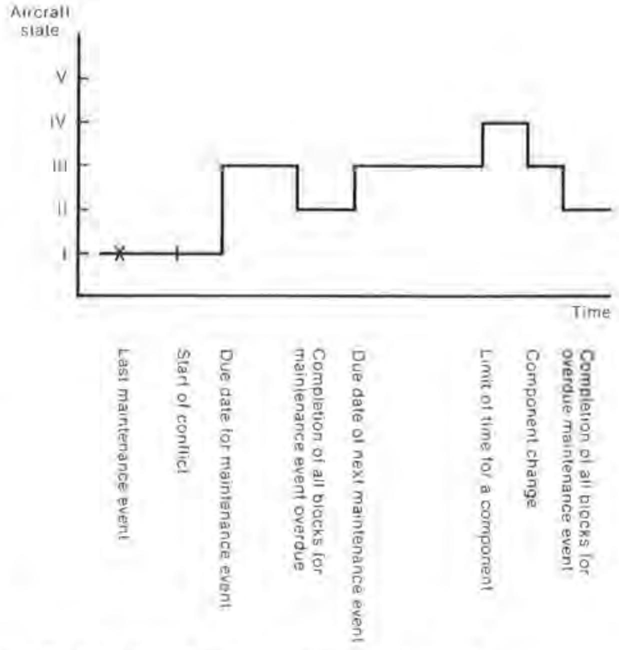

FIGURE 1 Typical profile of states for an aircraft.

2. Analyze each task in the maintenance event by asking the following two questions:

- How can this task be simplified in peacetime as well as in wartime?
- Which inspections will have to be performed during the time this maintenance task is past due (state III)? Specify the type and frequency of inspection.

Most of this information was collected in the analysis of the maintenance requirements of components. This step therefore consists mostly of gathering and reviewing this past information.

3. Analyze all time-limited, individually tracked components and for each one of these components

- Determine by how much the time limit can be exceeded (the length of time the component may remain in state IV) and
- Determine which, if any, inspections will have to be performed during state IV.

Again this step consists mostly of collecting information previously developed.

4. Arrange all maintenance events into packages that can meaningfully be done together and that meet the specified objectives. Draw network diagrams, if necessary.

5. Arrange all the packages developed above for each check, together with the additional tasks included in the peacetime maintenance program, in a project network and find the optimal duration for the check.

Results

Mission-oriented maintenance programs were developed for all helicopter fleets and combat aircraft. Wartime versions were developed for all but the highest level check, the airframe overhaul. It was determined that the airframe overhaul could be postponed safely for any realistically anticipated duration of a war.

The results by far exceeded the most optimistic expectations. The wartime maintenance programs easily met all of the objectives. The time limits on states III and IV were considerably longer than expected. A surprising number of tasks from the original programs were found to serve no purpose and could be eliminated for the new peacetime maintenance programs. For the new wartime programs a large number of additional tasks could be eliminated. Tables 1 and 2 give the results for the wartime program for one of the helicopters. The time limit for state III from all levels of checks was 200 flight hours. As can be seen, the additional inspections that have to be performed during state III are minimal and can be easily accommodated in the anticipated mission scenarios.

TABLE 1 Results for a Helicopter, States I and II

Maintenance Event	Number of Tasks	
	State I	State II
100 hr	106	43
300 hr	123	54
1,200 hr	121	31

TABLE 2 Results for a Helicopter, State III

State III Inspections					
As Necessary		Daily		Every 25 hr	
Number	Time (min)	Number	Time (min)	Number	Time (min)
4	180	3	15	2	15
5	210	5	25	3	25
1	30	5	45	10	205

The wartime maintenance programs were tested during maneuvers. The results of these confirmed that it is possible to perform all maintenance tasks under battlefield conditions and within time windows specified by the military command. No aircraft scheduled for operations was unavailable because of maintenance. Also, it was possible to keep up with all maintenance work that became due, so there was no backlog of deferred maintenance work at the end of maneuvers.

The backlog of maintenance work is difficult to measure. In this case the measure was the total number of hours that could be flown before different levels of checks would become due on all aircraft. This number actually decreased during the maneuvers for all checks except the highest one. Another measure was the discounted expected future work load (DEFL). This measure calculates all expected future work discounted to the present over the hours that can be flown before the work is due. It compresses into one number all information about the future work. An increase in this number indicates an increase in the backlog. For a description of this measure refer to Etschmaier (3). The DEFL calculated over the duration of the maneuvers for the fighter aircraft increased slightly. The reason, however, was that progress made on overhauls during that period was not included in the calculation.

When the work packages of the wartime maintenance programs, together with the additional peacetime tasks, were assembled into peacetime checks, significant reductions in ground time compared with the old peacetime checks were realized. For example, for the fighter aircraft the total amount of ground time over all checks, including the airframe overhaul, was reduced by 46 percent. This resulted in several additional aircraft being made available to operations. Essentially the operational fleet was increased without any capital expenditure, because the additional expenses consisted of the cost of the development work and the investment in spare parts, tools, and equipment. This was negligible compared to the capital value of the added operational aircraft.

MISSION-ORIENTED MAINTENANCE FOR PUBLIC TRANSPORTATION FLEETS

Compared with the military situation, public transportation fleets may be regarded as being in a continuous state of war. There is no equivalent of a peacetime that allows preparation and practice. Instead, the fleet is always engaged in the performance of its primary missions. Therefore it is not meaningful to make a distinction between equivalent peacetime and wartime maintenance programs. However, few fleets can be considered as being in the same state all the time. There are peak periods when most vehicles are needed, off-peak periods when only some of them are needed, and periods when all vehicles are idle. Apart from times of normal operations there are also times when special needs for vehicles arise, for example, charter or emergency services. Another example would be times when the operational pattern is disturbed and more vehicles are needed to satisfy the normal demand (inclement weather is a frequent cause). Finally technical problems may arise that may reduce either the available fleet or the manpower available to perform the normal maintenance program. In all of these cases maintenance programs with a mission orientation can be of considerable benefit.

The most important aspect of a mission-oriented maintenance program is that it could provide flexibility to cope with each one of these situations. It could provide flexibility in the work to be performed as well as in when to perform the work. As in the military situation described, it could provide alternative ways of assuring the same level of safety. For example, some deterioration can be detected before it becomes critical either by a rather superficial, simple inspection or by a thorough one requiring considerable downtime and possibly special tools and equipment.

The superficial inspection will provide a relatively short warning time (i.e., the time from when the deterioration is first recognizable until it becomes critical). This inspection has to be performed rather frequently. On the other hand, the thorough inspection would provide a long warning time and thus would be performed infrequently. In the long run, the total time in man-hours as well as in vehicle downtime required for the simple inspection may exceed that required for the thorough inspection. However, if the simple inspection can be accommodated in operational windows and the more thorough one cannot, the simple inspection might still be preferable.

What is preferable might depend on the specific situation at a given time, and the situation may change from time to time. It would be beneficial if the maintenance program would allow for either method. The same is true for breaking larger maintenance checks into smaller packages that would be performed one at a time.

Although a mission-oriented maintenance program can provide considerable benefits to most fleets of public transportation, it would be naive to expect that such a program could be implemented without supporting action. Considerable changes in organizational structure and mode of operation would be necessary in most cases. Even though changes would not be expensive, they would require the understanding and cooperation of the entire organization to be permanently successful. The changes would affect the way operational decisions are made and how information is processed and transmitted within the organization.

A considerable information processing capability would be necessary to monitor the maintenance status of each vehicle at any time and to identify those vehicles that are nearing some limit. Also, it is necessary to have measures that indicate the status of the maintenance workload for the entire fleet. In the current system it can be detected quickly whether the maintenance workload is being kept up, especially for the lower level checks. If flexibility were introduced, it would be possible to accumulate a large backlog of work that would have to be performed at the same time. It might not be obvious, however, particularly if the maintenance department were occupied with some problem that required urgent attention. The measure of the discounted expected future workload (DEFL) was developed to protect against uncontrolled increase of the work backlog. By choosing the proper discount rate, different DEFLs could be used to highlight long-range and short-range problems.

The task of scheduling work, given the increased flexibility, would be much easier with a mission-oriented maintenance program. There might be many more tasks to keep track of, however, and a much more complicated description of the maintenance status of each vehicle. This may well be beyond the capabilities of most conventional scheduling practices, either manual or computerized. Innovative methods of scheduling would have to be developed that would be capable of handling a large amount of information for a problem with many equally good solutions. For more details on possible solutions see Etschmaier (3,4).

Airlines

Airlines occupy a special place among operators of public transportation fleets because their vehicles are the most expensive, the most technologically advanced, and the most vulnerable. Also, the airline industry is the youngest of all transportation industries. For all these reasons, airlines have the most advanced maintenance programs. Most maintenance work for airlines is done when the aircraft are not needed for operations. For short haul operations this is usually during the night. Standby ratios of 1 or 2 percent are quite common.

The practice of systematically establishing minimum equipment lists (i.e., lists of equipment that has to operate if the aircraft is to be used in flight service) provides considerable flexibility for using aircraft with defects in components not on the list. Or, viewed another way, it provides flexibility in when repairs of defective components have to be performed. The trend in engine maintenance points in the same direction. More and more engines are removed from aircraft not because they are malfunctioning but because their rate of fuel consumption exceeds some limits. In the absence of safety considerations, considerable flexibility exists as to when to remove an engine.

There can be little doubt that the maintenance programs in effect at most airlines are at least near optimal for systems where all aircraft of a fleet, or possibly a subfleet, are used in the same way. This is the way most airlines plan to operate; however, there may be air services that do not fit this pattern. Examples are isolated routes, charter service, and networks with pronounced radial structures, where all aircraft fly from one point on the periphery through the central hub to another point on the periphery. In this time of deregulation it would be desirable to experiment with many different service alternatives. For such experiments existing maintenance programs could prove to be less than optimal.

In summary, it appears that although airlines already have excellent maintenance programs, benefits could still be gained by incorporating a mission-oriented program. For fleets that have not shared the recent developments in airline maintenance the potential benefits are much more significant.

Urban Bus Transit

Urban bus transit is an example of public transportation that is probably at the other end of the spectrum from airlines when it comes to maintenance. Transit bus maintenance has not progressed in the same way as that for airlines. In transit many people still believe that the best maintenance policy is preventive rework or discard of components on the basis of age. They expect that if life limits are properly chosen, in-service failures can be eliminated and the entire operation will be optimal. Others are looking for technological improvements that are expected to help accomplish this.

A recent study by Etschmaier (5) put these efforts into perspective. The study also showed that the record of transit bus maintenance is not good. Indications are that although the money spent has increased considerably, performance has not improved. The study advocates a completely new look at all aspects of maintenance in a transit system. Within such an effort, mission-oriented maintenance programs could be developed in a way similar to that described in the military project. Significant improvements can be expected, and there would be no need for big investments or for additional manpower. It must be recognized, however, that mission orientation requires a new look at the entire system. Without this, improvements are not likely to occur.

ACKNOWLEDGMENT

This paper was written while the author was a Faculty Fellow at the U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts. The work was sponsored by the Urban Mass Transportation Administration, Office of Technical Assistance, Office of Methods and Support. The author is indebted to Donald E. Ward, Granville Paules, and George Anagnostopoules for their support and contributions.

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Publication of this paper sponsored by Committee on Air Transport Operations and Maintenance.

A Model for Determining the Width of Airport Pedestrian Corridors

ALBERT T. STODDARD III

ABSTRACT

A mathematical model for designing pedestrian corridors in airport terminals is presented. The model is based on a concept of minimizing the sum of construction costs, operating costs, and passenger walking time. The development of the model is explained. The model has been written for use with a hand-held programmable calculator and tested to check the validity of the model results against other design procedures. A sensitivity analysis was performed to determine the effects of different values for independent variables. Finally, the model results are compared with an actual terminal building design. The design procedure selected a width very close to the actual design. The results indicate that the model may be a useful tool in selecting the width of passenger corridors.

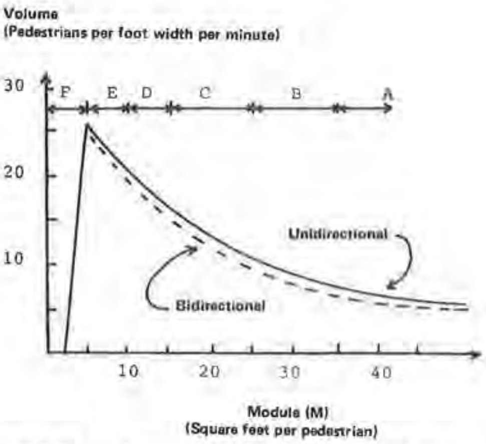

FIGURE 1 Volume of pedestrian flow and area occupied on walkways *(4)*.

Many models have been developed for designing airport passenger terminals. Service facilities such as ticket counters, security checkpoints, and gate check-in lend themselves to modeling as queuing processes. The overall design philosophy has been modeled by both de Neufville (1) and Braaksma (2). The size of waiting areas at boarding gates is based on queue size for passengers arriving at the gate (3). The size of walking areas is based primarily on the work of Fruin (4). Design is based on the desired level of service and the facility size is chosen to meet that level of service for the pedestrian flow. This concept is illustrated in Figure 1.

The levels of service normally associated with terminal design are B and C. At level B the pedestrian is free to select a walking speed, but may experience crossing and reverse direction conflicts. This level would be an appropriate design for terminals without severe peaking. At level C the pedestrian's freedom of speed becomes restricted and is appropriate for terminals that have severe peaking. Levels of service D, E, and F are not considered to be appropriate for design, although D and E might be acceptable during very short peak flow periods.

As can be seen, this design procedure relies heavily on the judgment of the designer for determining an appropriate level of service and then selecting a point within the range of the level of service. No specific consideration is given to the trade-off between costs of congestion and costs to construct, operate, and maintain wider corridors. de Neufville and Grillot (5) note that the selection of level of service represents a compromise between construction costs and inconvenience. Economic efficiency requires that a system operate at the point of minimum cost. In this case that point is the minimum of the sum of delay, construction, and operating costs. A rational design procedure would be to minimize some function of costs. This model formulation develops such a design procedure.

MODEL FORMULATION

To minimize the sum of pedestrian delay, construction costs, and operating costs, it is necessary to select measures of each that are compatible. The measure selected is monetary cost. Construction cost is initially a monetary cost and, for comparability, the capital cost need only be discounted to an appropriate time period. Similarly, operating cost may be estimated in monetary terms. Measurement of pedestrian delay in terms of money is more difficult. Instead of measuring delay, it is equivalent to measure walking time over a set distance and use this walking time multiplied by the value of that time to the traveler. The time to traverse a corridor is a cost to the pedestrian and any change above the minimum is the actual delay.

To determine walking time, it is necessary to know the walking speed. The best study of walking speeds with congestion effects is that done by Fruin (4). Relying on Fruin's work, it is possible to develop several relationships that lead to the formulation of an unconstrained minimization problem. For the purpose of developing a design tool, the analysis has been limited to corridors such as those found in pier finger type terminals. A further simplifying assumption is that no gates are located in the area to be designed. These assumptions restrict pedestrian flow to be along the corridor without interference from crossing flow or queues. The design procedure may then be modified to consider more complex situations. The case where a gate area is adjacent to the corridor will be analyzed specifically in a later section.

The first relationship defines P, the volume per unit width, to be equal to the total volume divided by the width of the corridor. The relationship used is then $P = D/x$, where P = flow in pedestrians per foot width per minute (PFM), D = flow in pedestrians per minute, and x = corridor width in feet.

The next relationship in determining walking speed is based on observations made by Fruin. Figure 1 shows the relationship between volume and the inverse of density, or module. Observe that the effects of bidirectional versus unidirectional flow are very small. Because terminals that experience peaking (typical of airport terminals) are normally designed for level of service C, it is possible to assume a linear relationship in the range of level C through level E or values of the module from 5 to 25. The approximation of the inverse relationship in Figure 1 is $M = -1.2P + 35$ for $10 \le P \le 25$, where M = module in square feet per pedestrian.

The final relationship results in walking speed as a function of the module. Values observed by Fruin are shown in Figure 2. The curve shown in Figure 2 may be approximated by the function $S = 50 + 60 \ln(M - 2)$, where S = walking speed in feet per minute. Walking time is simply the distance traversed divided by the speed. By selecting the distance to be 1 ft, the total length of the corridor need not be known. Construction cost per square foot is approximately equal to the cost per foot of width over the range being considered. If the cost increases dramatically by widening the corridor, the designer must consider that in determining a design width after using this procedure to establish the desired effective width. Operating costs are treated similarly. If the time period is selected as one year, the problem becomes

$$\min TC = T\theta D/[50 + 60 \ln(-1.2\, D/x + 33)] + cx + Ox$$

where

TC = total annual cost,
T = total time of peak flow in hours per year,
θ = value of time in dollars per hour,
D = peak flow in pedestrians per minute,
x = corridor width in feet,
c = annualized capital cost per square foot, and
O = annual operation and maintenance cost per square foot.

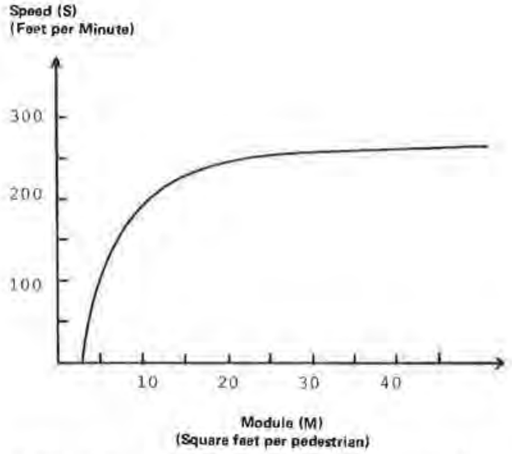

FIGURE 2 Pedestrian speed on walkways: traffic impeded, one-way flow *(4)*.

Because the problem is nonlinear, the solution technique chosen was a Golden Section Search over the range of x for $10 \le P \le 25$ (6). Termination was set for a solution within a range of 0.5 ft of the minimum. This range is satisfactory for design because other factors in construction influence the optimal width and a value to the nearest foot for pedestrian flow is acceptable. A program to solve the problem was written for a hand-held programmable calculator. The program required approximately 300 steps and goes through eight iterations of the search to reach the closure criterion. The time required for solution is approximately 1 min. The program could be written for other hand-held calculators with sufficient program memory.

MODEL RESULTS

The model was tested (a) to analyze the sensitivity of the solution to different input values and (b) to determine the validity of results of this procedure compared with results from other design procedures. The average value of time for air travelers was based on Yu and Kerr who found that in 1971 the values ranged from $5.78 to $14 per hour with a most likely value just under $10 (7). These values were increased at a rate of 5 percent per year so that a range of $10 to $20 per hour with a most likely value of $16 was used in the model. The designer should be aware of the problems associated with both estimating and using an average value of time. An in-depth discussion of the question of value of time is beyond the scope of this paper; however, a sensitivity analysis was performed to show the effects of using different values of time.

The passenger flow volume used for testing was obtained from Horonjeff (8). The peak flow occurs for 10 min at a rate of 260 pedestrians per minute with other flows less than 120 pedestrians per minute. The value of T is based on the 10 min peak flow and is obtained by converting minutes to hours, assuming the peak occurs 5 days per week, each week of the year. Construction cost was estimated at $50 per square foot. This cost is much lower than commercial airport terminals but is useful in analyzing the sensitivity of the model. Three discount factors were used: 10 percent based on the standard used by the government, 14 percent based on the rate of government bonds, and 18 percent based on the prime rate. The different discount factors also give an indication of what happens to the solution for changes in the estimate of construction cost. The economic life of terminal facilities was selected as 15 years based on the findings of Ashford (9). Operating costs were estimated at $4 per square foot.

Figure 3 shows the results for different values of time and annual capital construction costs. As expected, the corridor is wider for increased values of time and for lower construction costs. Also, the sensitivity to the value of time decreases as construction costs increase. Figure 4 shows the effect of increasing pedestrian flow from 260 to 350 pedestrians per minute. Note that as the flow increases, the solution becomes more sensitive to the value of time as indicated by the slope of a line drawn through the solutions.

The next step in testing the design model was to compare model results with results from other design procedures. Fruin gave two examples that are useful for this test (4). The first is for the design of a pier finger in an airline terminal. The problem statement is: "A Boeing 747 is expected to discharge up to 362 passengers in a 5-minute period. Determine the approximate finger width... Evaluate the impact of the simultaneous arrival of a second such aircraft." Assuming level of service A for the first aircraft, Fruin determined the appropriate width to be 10.2 ft. He then checked the simultaneous arrival of a second aircraft and found that this is level of service C, which is acceptable.

Using the model the approach to the problem is different. The simultaneous arrival is assumed to be a 5-min peak flow of 145 passengers per minute. Using $16 as the value of time, $9.82 as the annual capital cost, and $4 as the annual operating cost, the solution is 8.6 ft. This width is at the upper end of level of service D, which may be acceptable for a 5-min period. Thus, there is only a small difference between the model result and the result using Fruin's procedure.

The second example is a design for a terminal concourse. The problem reads: "Based on forecasts of future passenger demand and traffic patterns, a commuter transportation terminal is estimated to have a 15 minute design peak of 5,000 passengers. During the peak 15 minutes, a short, 5 minute micropeak, or peak-within-the-peak, is expected to occur, which is estimated to be 50 percent higher than the average for the design period. Based on the estimated demand, determine...the dimensions of the main access corridor...." Although the problem is for a commuter terminal, the results provide additional comparison for the model. Fruin designs for level of service C and determines the width to be 22.2 ft. Checking the micropeak he finds level E, which "could be tolerated for short periods." The model result, using $10 as the value of time, $9.82 as the annualized capital cost, and $4 as the annual operating cost, is a width of 22.9 ft. This is very close to Fruin's solution.

Evaluation of the micropeak results in level of service E, which is acceptable. Designing for the micropeak using the model yields a width of 26.8 ft, which is level of service D. As the peak period is lengthened, the level of service increases toward level B. This also is in accord with design practice

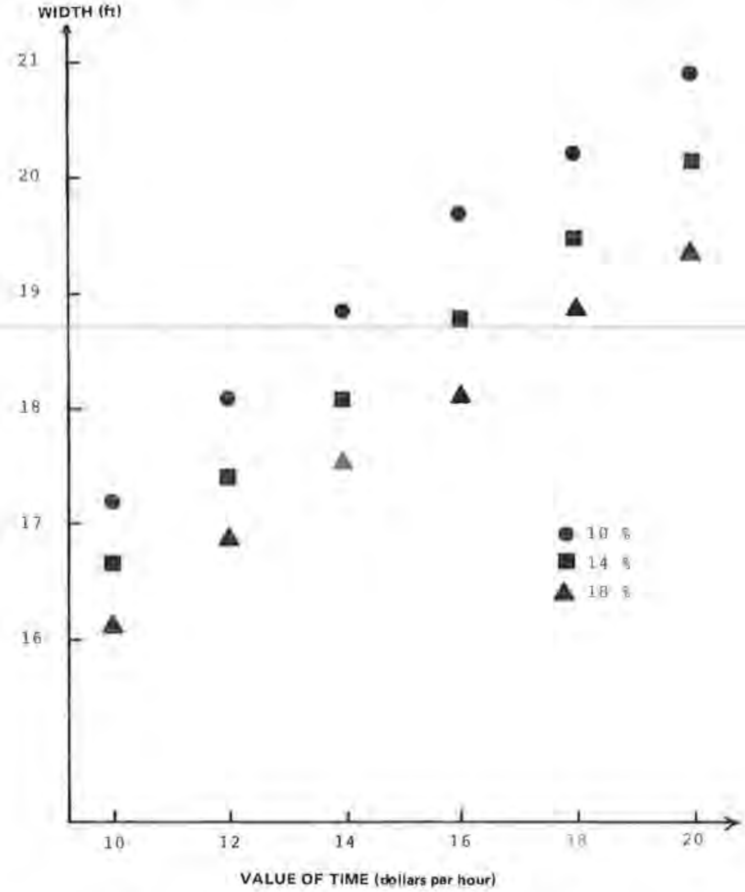

FIGURE 3 Results for different values of time and annual capital construction costs.

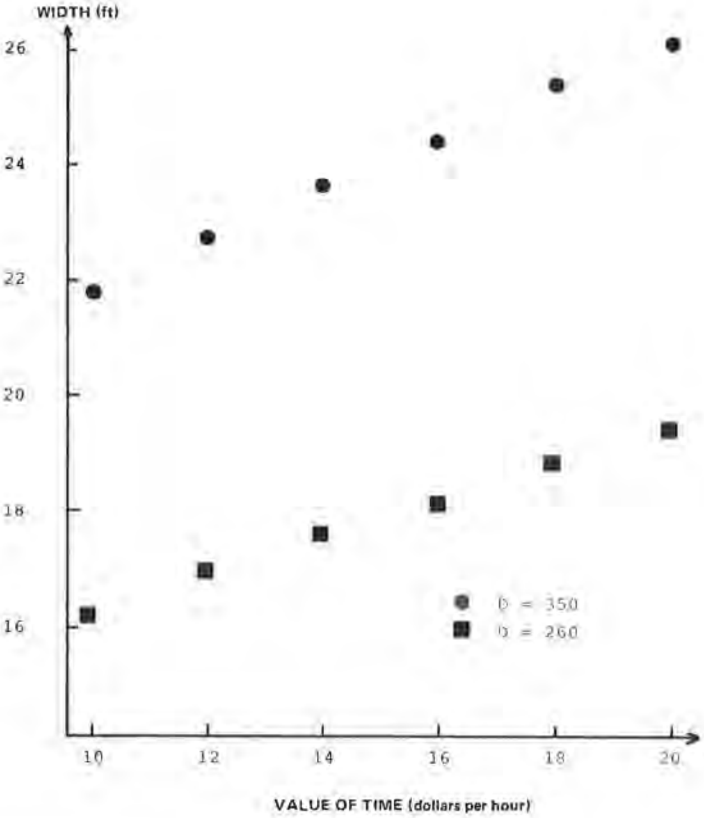

FIGURE 4 Effect of increasing the pedestrian flow.

for terminals that do not have severe peaks. Shorter peak periods move the design width toward level D, which can be tolerated for very short periods. The model results compare favorably in both cases with results using other design procedures.

These two design examples are clearly simplifications and do not consider all possible pedestrian flows. In the case of the arrival of two 747 aircraft, it is likely that additional aircraft would be arriving or departing and that nontraveling pedestrians would add to the flow. An accurate design would require a full analysis to determine the peak pedestrian flow.

APPLICATION

The model results are now compared to an actual terminal building. The D concourse at Stapleton International Airport in Denver, Colorado, was designed for a capacity of 16 PFM. The effective width of the corridor as it leaves the main terminal is 53 ft. The flow is 850 pedestrians per minute. The estimated cost of construction for terminal concourses in Denver is $110 per square foot. Assuming that the peak is a 10-min period, Figure 5 shows the model results for different values of time and discount factors. The implication is that the value of time is at the middle of the range used for analysis. The most likely values for model parameters yield an effective width of 53 ft for the peak flow period. The results are in the appropriate range and provide service near the transition from level C to level D.

Two more comparisons were made using the model. Looking at the pedestrian flow in the first example and the widths computed in Figure 3, the level of service is C for the peak flow period and level A for all the other flows. This is clearly an acceptable design. Figure 6 shows the results of a queuing model for passengers arriving at a departure lounge. Making several assumptions about the characteristics of the queue, an estimate can be made of the effects on pedestrian flow. Assuming for purposes of illustration that the aircraft seats 200 passengers, the maximum queue length is estimated to be 75 passengers and the flow to the gate to be five passengers per minute. Assuming further that passengers in the queue require 7 ft^2 each, that the queue is entirely in the corridor, and that the queue extends along the corridor for 75 ft, the queue occupies 7 ft of the corridor width. Taking a width of 20 ft and the flow passing the gate of 255 pedestrians per minute, the level of service lies between levels D and E. The assumptions used are conservative because many people choose to wait in the lounge area before checking in rather than standing in a queue. The level of service may be acceptable for the period during which it might occur. If the queue is not orderly, the effective corridor width may be further degraded to the point that the corridor itself becomes a queuing situation. The importance of providing space for formation of the queue within the departure lounge is evident in order to reduce the deterioration of level of pedestrian service.

All of the tests of the model have shown the results to be valid for the design of pedestrian corridors in terminals that have peak flow periods. When the length of the peak flow period exceeds 30 min, the model results should be checked closely. If the level of service approaches level B, the designer should consider alternate design procedures as the model is constrained to operate at level C and below. The model results provide for an effective width, and the design must provide added width for any items that may impede flow. In addition,

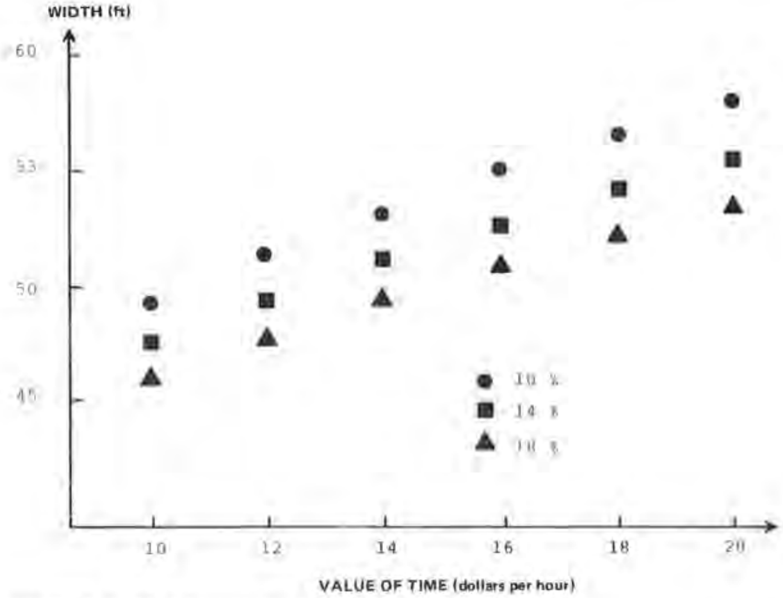

FIGURE 5 Model results for Stapleton D concourse.

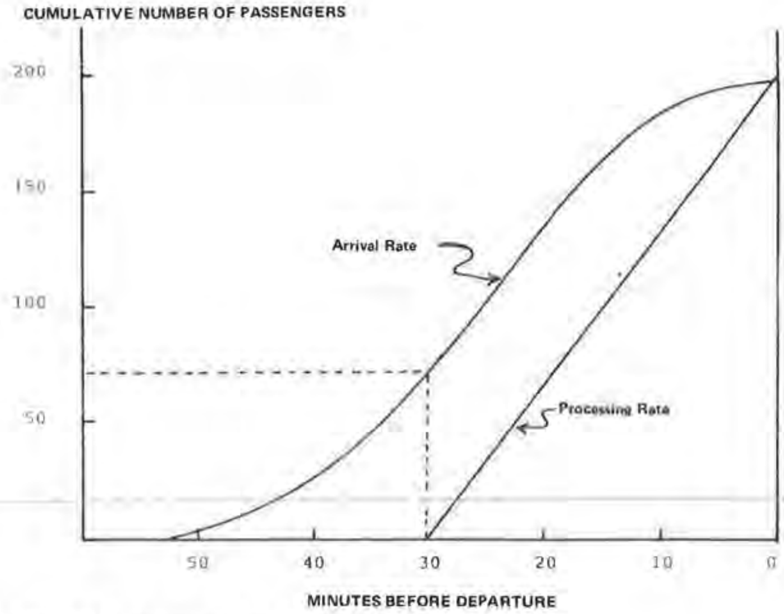

FIGURE 6 Passenger flow to departure lounge.

there is a boundary effect and the designer should allow 1.5 ft additional width along each side of the corridor. The width determined by using this procedure should be used as an input to the total design procedure. The designer must also consider construction costs, procedures, and materials.

CONCLUSION

The model presented provides a rational procedure for selecting the appropriate width of pedestrian corridors. The method is an improvement over selection of width based entirely on the design level of service. For example, consider the Denver concourse. Designing for level of service C would indicate a width from 53 to 85 ft. At $110 per square foot, the construction cost for a corridor 100 ft long would range from $583,000 to $935,000. The designer must select the appropriate point within this range. The model gives the designer a procedure for selecting an initial point which may be modified in consideration of other design requirements. The time to program the calculator and perform the analysis should take less than 1 hour of the designer's time and would be well worth that cost. The alternative is a design that may be too wide and hence too costly or one that may operate at an unacceptable level of service for extended periods.

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Publication of this paper sponsored by Committee on Airport Landside Operations.

Aviation Legislation and Infrastructure: Policy Implications for the 1980s

YUPO CHAN

ABSTRACT

Airport and airway legislation together with technological advances facilitate developments in aviation. Currently aviation is repeating one of its several historical bifurcations as the transition is made from the 1970s to the 1980s. The recently passed airport and airway improvement legislation, for example, authorizes substantially increased expenditures from the Airport and Airway Trust Fund through 1987, the main bulk of which is for modernization of air traffic control facilities and equipment. A collateral legislation, the Airline Deregulation Act of 1978, in addition to rearranging the traffic patterns of the country, may stimulate the growth of the regionals (commuters) and air taxis, thus placing stringent requirements on existing terminal and airway capacity. Exacerbating the terminal capacity problem are certain implications of the Aviation Safety and Noise Abatement Act of 1979, which may result in reducing the time window for flight operations in major hubs, thus further decreasing airport capacity. Fortunately FAA's recent National Airspace System (NAS) plan, together with expanded funding authorized by the Airport and Airway Act of 1982, will address much of the capacity, safety, and productivity issues in the long run--particularly with respect to the enroute environment. In the meantime, however, traffic growth will place serious limitations on terminal capacity--both air and ground operations, with the latter being more intractable. A feasible way to provide both capacity and level of safety in the short run is to redistribute the traffic (particularly connecting traffic) from bottlenecks to the less congested parts of the system; this is clearly allowed by the deregulation act.

In the United States, airport and airway legislation--together with the evolution of the terminal and air traffic control systems--is instrumental in facilitating the development of aviation. The first legislation devoted exclusively to airports, for example, was the Federal Airport Act of 1946, which established a federal-aid program to provide a system of public airports to meet the needs of the rapidly growing civil aeronautics industry. This program was subsidized through the 1950s by the federal government through general revenue appropriations. During this period, the first generation of the Air Traffic Control (ATC) system was put in place.

Traffic growth in the 1960s created a demand for still more airport and airway development, including second generation ATC systems. There was also a requirement for additional financial aid to accommodate growth. By 1968 this, along with the excessive delays at major airports, led to a concerted effort by the federal government and industry that resulted in the enactment of the Airport and Airway Development Act of 1970. Instead of using the General Fund to finance the airport and airway system, a program was developed whereby users of the system would pay for it. This act created new user taxes to be placed in the Airport and Airway Trust Fund.

Between the end of World War II and the end of the 1960s, federal grants-in-aid for airport development totaled a little more than a billion dollars. The 1970 legislation (PL 91-258) called for a budget twice that amount for the 1970s alone. The act provided for two grant-in-aid programs: the Airport Development Aid Program (ADAP) and the Planning Grant Program (PGP). Both are matching-fund assistance programs in which the federal government pays a predetermined share of approved airport planning and development project costs; and the airport owners at the various state and local levels, who are eligible to participate in the program, pay the rest. The act also provided for acquiring, establishing, and improving air navigation facilities and equipment and provided for research and development and operation and maintenance of the air traffic control and navigation system. This allowed the third generation ATC system to be phased in.

MAJOR ISSUES

The legislative authority for certain provisions of the Airport and Airway Act of 1970 expired on September 30, 1980. In spite of a generally favorable opinion of the implementation of the Airport and Airway Development Act over the past 10 years, some changes in the 1970 act have been suggested (1).

Federal Aviation Administration (FAA) forecasts (2,3) indicate a need for an increased number of services and for increasing national aviation system and airport capacity. To a lesser degree, other forecasts indicate growth of air traffic over the next decade as well (4,5). This occurs in an era when major portions of the ATC systems are now outdated after 20 or more years of use (6). Replacement of this equipment, particularly computers, must be given consideration.

A major concern for the airport and airway system over the next few years is congestion. Privately owned airports, included in the National Airport System Plan (NASP), often serve transportation needs by relieving congestion at large air-carrier airports or by providing a link to scheduled airline services. Indications are that unless federal funding is forthcoming, a substantial number of these airports may have to be closed in the 1980s, mainly because of financial problems (7).

At the same time, reliever airports are becoming increasingly more important as congestion at major airports grows. Reliever airports are most suitable to handle general aviation traffic, diverting it from the high-density, air-carrier airports. It has been suggested that more reliever airports be designated. These reliever airports, however, must offer services and convenience comparable to major air-carrier airports and constitute a suitable alternative to attract general aviation traffic. Possibilities for the increased funding of reliever airports, or inclusion of these airports under the obligational authority of air-carrier airports, are being considered. It has been suggested, for instance, that regional carrier (commuter), reliever, and general aviation airports should receive a greater percentage of Trust Fund money (instead of 17 percent) in order to provide safer alternatives to the growing use of the already busy air-carrier airports.

Another suggested idea is the renewal of an old practice for some of the larger airports--that of allowing these individual airports to collect their own head taxes. This would be in lieu of the ADAP ticket tax. These airports would drop out of the ADAP under this plan and finance projects with the taxes they collect. As a result of this change, the federal-aid program could be focused more on the needs of smaller airports.

The existing airport and airway system relies heavily on the federal government for both the actual provision of services and the administration of an airport development program. Increased state and local involvement in administering and providing various airport and airway services is considered desirable; this might, however, lead to a lack of standardization of the airport and airway systems.

Air-carrier airports received 86 percent of ADAP funds, but according to the NASP (8) these airports needed only 62.6 percent of the ADAP apportionments. On the other hand, general aviation airports need 37.4 percent but receive only 14 percent. It has been suggested that the current proportions be changed. This priority apportionment is based on the population of a state or region. It is possible that an activity factor could be included in the apportionment formula, and this might result in a restructuring of priorities.

There is an opposite school of thought, namely, that air-carrier activity has generated about 93.5 percent of trust fund revenue and received only about 86 percent of ADAP funds. In contrast, general aviation has generated a mere 6.5 percent of trust fund revenue but received a disproportionately large share of 14 percent of ADAP funds. This line of reasoning argues for an increase of air-carrier share of the expenditures from the trust fund. This equity issue is more controversial and the debate is likely to continue for a long time.

As of September 1980 the Trust Fund had an uncommitted balance of about $2.9 billion, or the equivalent of 2 years' expenditure at the prevailing rate. By 1982 the balance was $3.9 billion. The 1983 and 1984 balances are projected to be $4.6 and $5.1 billion, respectively.

AIRPORT AND AIRWAY IMPROVEMENT ACT OF 1982

This long-awaited legislation, passed in September 1982 as PL 97-248 (9), extends--with certain modifications--program authorizations contained in the Airport and Airway Development Act of 1970 and continues the funding mechanism. Space limitation prevents a comprehensive coverage of the general reauthorizations, such as the reauthorization of the passenger ticket tax. Instead features of this legislation are cited that indicate how it is different from the previous legislation:

1. A significant increase in the authorized level of funding for the facilities-and-equipment appropriation, which finances the capital costs of modernizing the airway system;
2. An increase in the proposed program level for research, engineering, and development, which paves the way for timely development of advanced airway systems and technology in future years;
3. Increased program levels for airport development and planning grants, which will be consolidated into a single airport grant program;
4. Broadening of the eligible users of airport grants to include certain noise-compatibility items and planning of noise-abatement actions;
5. A 6-year extension of the Airport and Airway Trust Fund;

6. A 6-year extension of existing aviation user taxes in general, with the 7-cent per gallon nongasoline fuel tax replaced by a tax of 14 cents for noncommercial aviation, and the 3-cent gasoline tax by 8 cents or 10.5 cents per gallon (depending on the grade);

7. A large increase in the amount of the ongoing costs of operating and maintaining the airway system that will be coming from the Airport and Airway Trust Fund rather than the General Fund;

8. Emphasis on improved system planning and development of reliever airports in the large metropolitan areas where traffic is congested;

9. Provision for studying the involvement of the states and local authorities in their larger airports' ability for self-financing without federal assistance; and

10. A provision to assure that airport owners and operators make their facilities available for use by air carriers and other users on fair and reasonable terms without unjust discrimination.

The total FAA projected expenditures for the next 5 years, mainly for system modernization, substantially exceed the expenditures for the 1970s. The overall estimated FAA budget of $22.8 billion for the next 5 years (including the $5 billion from the General Fund) calls for major efforts to accommodate the projected growth in air traffic.

The authorized levels for facilities and equipment are comparable substantively with the FAA budget estimate; perhaps this reflects the congressional endorsement of the need for improving air-navigation facilities (see Table 1). Another area of agreement between the authorization and the proposed FAA budget is expenditure for research and development, where both appear to recognize the need for the application of new technology to ATC systems.

In reexamining the figures, however, the funding levels for the authorizations and FAA budget estimate are different in several areas. First, the administration's budget estimate for airport monies is substantially lower for the period during which the larger airports are expected to be defederalized. More precisely, the administration's estimate is $2.54 billion lower than the legislative authorization.

A departure from the 1970 legislation is allowed for the operations and maintenance budget (even though the use of trust funds for the administrative function of FAA is limited) in that the trust fund may be used to cover the operation of air-navigation facilities.

Overall the total authorization from the trust fund shows substantial increases through 1985, mainly because of the increased investment in airway system improvement. From then on the authorizations taper off and even decrease in 1987 (see Table 1).

There are controversial items in the airport and aviation authorizations. Studies to set priorities--such as the congressionally mandated studies on self-financing of large airports and airport access--are needed to clarify these issues. The use of priorities, instead of allocation formulas based on enplanements alone, is an issue pending before the administration and Congress before the reauthorization debate in 1987.

COLLATERAL LEGISLATION

In addition to the Airport and Airway Improvement Act, several recent acts have direct relationship to the evolution of the airport and ATC system.

Airline Deregulation Act

The enactment of the Airline Deregulation Act (PL 95-504) has permitted a readjustment of the market served by the majors (trunks), nationals (locals), and regionals (commuters). The majors, which receive no subsidy for low-density service, are abandoning what remains of their short-distance routes, except where these short trips supply enough passengers to their high-density routes to make it economically feasible to maintain them as feeders. Although less rapidly, the nationals, which are still subsidized, are also moving away from short-distance and low-ridership service. At the same time, the regionals are expanding to fill these gaps. This expansion of commuter airline services, which use smaller aircraft, appears to be a dominant factor in the growth of traffic at many airports.

The effects of the deregulation act (as amended) for the remainder of the 1980s include the following:

1. The net result of the termination of domestic route programs in 1981 was a readjustment of the route patterns that had evolved over the decades because of route regulation by the Civil Aeronautics Board (CAB). Such redistribution of traffic among the airports may result from efforts by air carriers to divert through and connecting passengers to hubs that are less busy.

2. Between 1983 and 1985, a subsidized carrier may be replaced on a route by a regional or other carrier if such replacement will result in (a) a reduction in or elimination of a subsidy and (b) improved service. During this replacement process, the number of takeoffs and landings is likely to increase because the same amount of traffic normally carried by larger airplanes will be handled by smaller planes. Therefore, an increase in traffic may occur during the 1983 to 1985 period.

3. Under the deregulation act, service to small communities is encouraged and continued; 555 small communities are designated for essential air ser-

TABLE 1 Aviation Authorizations ($ millions) *(9,20)*

	FY 1982	FY 1983	FY 1984	FY 1985	FY 1986	FY 1987	Total 1982-1987
Grant-in-aid	450	600	793.5	912	1,017	1,017.2	4,789.7
Facilities and equipment	261	725	1,393	1,407	1,377	1,164	6,327
Research engineering and development	72	134	286	269	215	193	169
Operations and maintenance	800	826.7	828.6	830.6	832.7	835.0	4,953.6
Trust Fund Total	1,583	2,285.7 (3,120)	3,301.1 (3,920)	3,418.6 (3,930)	3,441.7 (3,930)	3,209.2 (3,740)	17,239.3
Percentage increase over previous year	–	44.4	44.4 (25.6)	3.56 (.26)	.68 (-.51)	-6.76 (-4.35)	–

Note: The figures in parentheses include amounts authorized under the Airport and Airway Improvements Act of 1982 and the Surface Transportation Assistance Act of 1982.

vice. Thus, by law, these 555 communities are guaranteed minimum service at least until 1988. This establishes the lower bound on traffic forecasts for the next 5 years.

International Air Transportation Competition Act

With several major exceptions, the philosophy of the International Air Transportation Competition Act of 1979 (PL 96-192) is an extension of the Airline Deregulation Act. It amends the Federal Aviation Act of 1958 to place "maximum reliance on competitive market forces" in international air transportation. Under bilateral agreements, there may be a larger number of gateway cities for international air transportation. Also, there would probably be more competition between domestic and foreign carriers in providing low-cost transportation overseas. Depending on the economy and size of aircraft, the total number of flights spread between these gateway cities may be increasing in the decade ahead.

Aviation Safety and Noise Abatement Act

A number of laws for controlling aviation noise have been enacted. These include the Noise Control Act, the Quiet Communities Act, and, most recently, the Aviation Safety and Noise Abatement Act of 1979 (PL 96-193). These culminate in increasingly stringent noise control measures prescribed for a number of urbanized areas.

In spite of these requirements on aircraft, there appears to be an increased intolerance by the public toward noise, particularly at the airport communities. The Aviation Safety and Noise Abatement Act establishes a single system for measuring noise in coordination with land use planning. Local governments and airport owners play a large part in determining what constitutes acceptable noise exposure.

The act also specifies noise standards for aircraft types at certain airports. The standard is considerably more relaxed for two-engined aircraft that serve most small communities where an exemption is granted for noncomplying aircraft. Because the expected growth of air traffic will come principally from regional carriers, a significant portion of the aircraft may not comply with the latest stringent noise requirements until 1988. If noise exposure is to be defined both as noise from the aircraft engine and the frequency and time of occurrence (exposure), this may imply either fewer aircraft operations or a narrower operating window at most major airports unless breakthroughs occur in the use of noise abatement flight procedures.

Another provision of the act allows the use of funds from the unexpended balance of the Airport and Airway Trust Fund to finance expenditures incurred under this act (as previously alluded to). In addition all foreign carriers engaging in transportation to the United States are expected to meet specified noise standards. Thus it is virtually certain that these noise standards will be implemented.

TECHNOLOGICAL TRENDS

Technological trends also have a definite bearing on future aviation developments. If timely implementation is no problem, technological solutions can address the capacity, safety, and productivity issues for both the airport and airway components of the aviation system. These technological solutions are reviewed below in two parts: the enroute portion of a flight (airway) and the terminal capacity (airport).

Airway Systems

Perhaps the most obsolete part of the present ATC system is the computer, which has been frozen to 1960 technologies (such as the IBM 9020s). The present National Airspace System (NAS) plan and other studies (10-12) call for replacement of this computer system by the early 1990s. The key is to make this transition in an evolutionary manner to avoid risks to safety.

When the computers are in place, the second milestone of the airway system will be an Automated Enroute Air Traffic Control System (AERA). Such a computer-based system will undoubtedly relieve the work load of the air traffic controllers at enroute control centers and flight service stations, because much of the work formerly performed manually by controllers will be handled by the computer. Aside from increasing the productivity of controllers, it is conceivable that airlines could save fuel by following a more meticulous and responsive flight path designed by the AERA. The system is scheduled for implementation starting in the early 1990s.

A third component of the airway system is communications. A new data link mode-S (formerly the Discrete Address Beacon) system will allow communication between aircraft, as well as between aircraft and ground. This will replace the existing (less precise) Air Traffic Control Radar Beacon System (ATCRBS). Scheduled implementation date is the late 1980s. User aircraft will have to be equipped with a transponder, which is estimated to cost $10,000. This cost can be absorbed by commercial aircraft, but it may put a strain on general aviation aircraft even though the decision to acquire such equipment is optional.

After Mode-S communications are in place (by the year 2000), the Traffic Alert Collision and Avoidance System (TCAS) can be implemented in aircraft cockpits. The system is designed to alert pilots of intruding aircraft and give optional information on the location of intruders and on possible collision avoidance maneuvers. Obviously the implementation will add to the cost of producing aircraft.

As a summary, the implementation dates of the above technologies are shown in Figure 1.

Airport Systems

Capacity at terminal areas can be most dramatically increased by new airport or runway construction. Environmental, ease-of-access, and financial constraints, however, will preclude constructing new airports in most large metropolitan areas at least during the 1980s. The addition of runways, particularly short runways for separate, small aircraft operations, is more feasible, although land availability can often become a problem.

The benefit of additional runways can be more fully realized if they are accompanied by the appropriate ATC improvements. Microwave Landing Systems (MLS), for instance, can guide aircraft on more flexible approach paths. Thus, a small aircraft can be brought in on a short runway by a different flight path than a large aircraft and thus avoid wake vortex problems, resulting in a more efficient use of the terminal airspace. This strategy requires aircraft to be equipped with MLS avionics instead of the existing Instrument Landing System (ILS). The required MLS technology exists and a phased implementation is anticipated between 1985 and 2000.

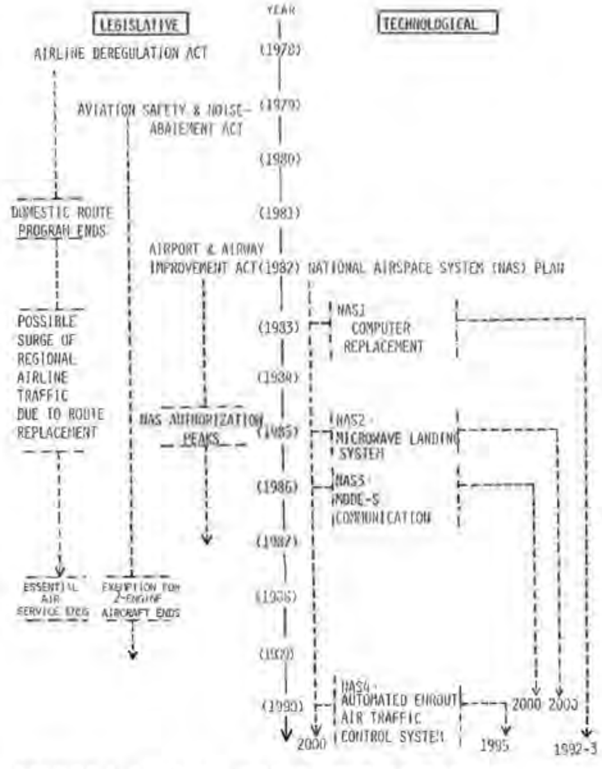

FIGURE 1 Legislative and technological milestones.

Aircraft need to be equipped with the appropriate avionics to use MLS; this represents an added cost to aircraft.

As another example, improved navigation (such as through the use of MLS) can make it possible to reduce minimum-spacing standards between parallel runways. This means that eventually triple parallel runways can be used in all-weather conditions thus reducing the land requirement for new runway construction.

Accurate monitoring of the wake vortex pattern and better understanding of the physics of wake vortex along the approach paths and at the aircraft wings can lead to reduced aircraft separation thus increasing terminal capacity. An allied concept is automated metering and spacing of aircraft after the communication, surveillance, and navigation capabilities of the ATC system are in place. Once the new ATC systems (particularly replacement of the computer system by mid-1990s) are in place, they would significantly reduce the uncertainty of aircraft arrival time at an airport, resulting in more efficient use of its runways.

Depending on the weather, traffic mix, and airspace use at neighboring airports, the capacity achievable in an airport is quite different. Substantial gains in capacity can be realized by a timely and carefully constructed management scheme for a given configuration of airfield and airspace. The computer can play a key role in making strategic decisions about runway use and approach directions under real-time constraints. Such systems offer realistic and practical solutions to the current terminal capacity problems. Regrettably, the implementation schedule for such systems (if any) is uncertain.

All of the above system innovations are geared toward improvement of the safety, capacity, and efficiency of airways. They have little to do with the ground access to airports, which also has a serious set of problems. It is clear that access and linkages between multiple airports in an urban area will significantly increase the traffic-handling capability of the aviation system. Because most of the ground transportation infrastructure has been in place for some time, however, the improvement in airport access is often a political and financial problem that falls largely outside the realm of technological solutions.

IMPLICATIONS FOR THE 1980s

Under the framework set forth by the legislation and technology discussed previously, what are the most likely configurations and developments for the airport infrastructure in the 1980s? With the concerns for safety, system productivity, cost recovery, and the need to provide additional capacity and minimize delays, what are the most logical system alternatives and what are the logical public policy options for the remainder of the 1980s?

Noise Abatement

First the possible effects of noise-control requirements on the infrastructure are addressed. There are two parts to the mandate on noise control: one on the aircraft itself and the other on the noise exposure of the community surrounding the airport. The former concerns aircraft engineering, particularly the engine. The latter deals with land use compatibility at the airport, adapting suitable flight paths for noise abatement, and the community's tolerance for airplane noise.

According to the Environmental Protection Agency (13), the application of noise technology certification rules to subsonic aircraft in 1980 and 1985 will show a substantial decrease in noise exposure in future years, but the full effect will not be felt until well beyond 2000. The noise exposure of the basic Concorde supersonic fleet will tend to dominate completely the noise exposure of possible supersonic operations in the United States, which will include existing Concorde-type aircraft and could include any reasonable number of other supersonic aircraft that comply with existing or proposed noise rules.

Before the year 2000, a more immediate achievement in airport noise reduction is possible by using improved takeoff and flight procedures. The optimal procedure will be a function of a particular airport's demographic environment. Maximum power cutback procedures during landing, however, offer additional noise reduction for the nation's airports. With the advent of MLS and other navigational aids, the optimal takeoff and landing procedure will tend to improve.

Noise control around airports is a local issue. The imposition of community noise standards often places a limit on aircraft activity in major hubs. The proposed noise levels in Illinois, for example, would require O'Hare to reduce its traffic to 40 percent of the current level, if the current mix of aircraft types is to be maintained. Another analysis was carried out on the noise abatement procedure for major airports in the United States and around the world. Of the 138 airports studied, 83 or 60 percent have operating restrictions for noise abatement. Of particular interest is the average curfew of 8 hours 21 minutes that is in effect for 28 airports and the corresponding reduction in capacity at these airports. If community concern over noise heightens and substantial relief from noise (due to improved aircraft design) is not forthcoming until the turn of the century, the total number of operating hours available at all airports will decrease, resulting in more congestion at major hubs.

The noise problem tends to be insidious. As airports attract more surrounding developments the perceived level of airport noise by the neighborhood residents tends to grow. This can only be prevented by judicious land use regulations around airports. Land banking by airport authorities is one way to ameliorate the noise problem and the problem of availability of land for airport expansion.

Safety Assurance

Safety is intimately related to capacity and productivity because a crowded sky and overloaded controllers invite accidents. Aviation safety can be viewed in two parts: accidents that occur in the vicinity of airports and accidents that occur enroute. Statistics show that the two flight phases--landing and takeoff--account for the majority of all accidents, but the majority of fatal accidents and fatalities occur during the in-flight phase.

Serious concerns are expressed about the safety of commuter operations. More than 50 percent of the 300 or so airports served only by regional carriers do not have a Visual Approach Slope Indicator, ILS, tower, radar, or lights (8). If the expected growth in regional airline operations materializes as a result of deregulation (Figure 1), these safety concerns will become increasingly critical.

At the major hubs and the large airports, the instrumentation for safe takeoffs and landings exists, but the increasing regional airline traffic and general aviation may tax their capacity to the extreme. In an environment where there is a mixed fleet consisting of small commuter or general aviation aircraft and the large major and national aircraft, the wake vortex problem becomes acute. Another allied problem is the definition of positively controlled airspace at a terminal; this becomes critical in congested hubs served by large and small planes.

Microwave Landing Systems (MLS) and short runway construction appear to be an effective means of assuring safety by separating approach paths and expanding terminal capacity, although full implementation will not be completed until the late 1990s (see Figure 1). Automated management schemes--if implemented widely among airports in a timely fashion--are another strategy to assure safety and expand capacity.

In the enroute environment the ATC system, comprised of regional ATC centers and flight service stations, is definitely being improved. For example, increased automation and better communication links (including an upgraded computer network) are underway. Improved data links between the aircraft and controllers pave the way for a better separation advisory service which has the potential to reduce the risk of midair collisions and decrease the burden on air traffic controllers.

Congestion Relief

The Airport and Airway Development Act of 1970 states clearly that "the airport...will be available for public use on fair and reasonable terms...." This policy has resulted in the historic first-come-first-serve entry into the ATC system around the airports. Growth in traffic, however, has resulted in average delays of 8 minutes in 1978, and this is projected to increase to 25 minutes in 1987, assuming a modest 2 percent annual traffic growth. Most of the airports that experience serious delay problems rank among the top 15 airports in both enplaned passengers and air-carrier operations (2).

One feasible way to overcome the terminal capacity problem is through ATC procedures. In a 1979 User Conference, the following short-term operational solutions were identified: central flow control, flight advisory procedures, profile descents, and manual enroute metering.

In addition to MLSs, short runways, and airfield and airspace management, the wake vortex avoidance system and automated metering and spacing are among the major engineering programs designed to address this problem. Implementation plans for these engineering programs, however, are uncertain and far in the future. Automated metering and spacing, for example, cannot be implemented until most of the ATC improvements are in place in the late 1990s.

Short-Term Solutions

Of more immediate value (in the 1980s) are solutions that modify the demand for service at terminals. The economic concept of pricing (14), for example, can be implemented by local airport authorities. This will set the landing fee at congested airports (usually large hubs) at the marginal cost imposed on all the delay and inconvenience caused to others who wish to land at the same time. Although such a pricing scheme can be efficient and even cost recoverable, there are problems in implementation. Aside from the technical problem of accurately determining such a fee, the practice tends to discriminate against general aviation aircraft and regional carriers, which cannot pay as much as nationals and majors.

On the other hand at uncongested airports (usually in smaller communities) marginal-cost pricing can result in financial loss to the airport authority. "Ramsey pricing" has been proposed (15) in these airports to maximize net social benefit and recover costs. To implement this, a departure from the current weight-based fee is necessary. In its place, the fee is assessed on the basis of a fixed fee per landing plus a charge per available seat mile, thus taking into account both the aircraft size and distance covered.

Thus, by means of pricing or other incentives, the local authority can achieve a more balanced use of airport facilities in a large metropolitan area. Underutilized airports, including reliever airports, can supplement the terminal capacity--for both air and ground operations--at many large cities. General aviation use of reliever airports, for example, is quite feasible as long as comparable navigational and terminal facilities are available. The use of underutilized airports by commercial aircraft, however, requires that extensive connectivity be provided between the multiple airports in a metropolitan area; this is an issue that defies simple solutions.

The airline route network may be adjusted in a postderegulation era to shift some of the hubbing activities to less busy airports around the country. This applies particularly to connecting traffic--both domestic and international--that can be redistributed among uncongested airports. Aside from using disincentives such as congestion and concern about safety, more positive incentives need to be introduced to expedite the implementation of such a solution.

A simple experiment performed by Chan et al. (16) shows the feasibility of traffic distribution from the point of view of excess capacity that exists in the airport system as a whole. Examining only the top 24 hub airports, a redistribution of traffic after the complete removal of route authority and addition of more international gateways tends to place loads on some relatively less busy airports such as Cleveland and Kansas City. In other words, cities like Cleveland and Kansas City--under a totally deregulated and institutionally free environment--are logical stops for both domestic and international connecting traffic. They are geographically located to gain the largest share of the possible traffic growth between major cities--ignoring for the time being the precise magnitude of traffic growth projection between major hubs.

All these near-term solutions are quite attractive in their implementation potential, and some of them were put into place at selective terminals during the air traffic controller strike in 1981 through 1983. However, the fundamental policy of equal access to airports appears to be interpreted differently from first-come-first-serve. It is not surprising, therefore, that except for National and John Wayne Airports, allocation mechanisms are supposed to be removed by December 1983. A task force called for by the 1982 legislation to study the problem of allocating the use of airport facilities and airspace among users (17) reached many conclusions that are consonant with the findings in this paper.

It is clear that although highly valuable increases in capacity can be realized from changes in operational philosophy (in the short term) and ATC improvements at the terminal (in the long term), the major gains in terminal capacity are achieved only by adding new runways and building new major airports. Existing public policy, however, does not favor gaining additional airport real estate in the foreseeable future.

The real bottleneck--ground access to airports and connectivity between airports--is still the greatest unresolved problem in the entire aviation system. There are, however, some insights to be gained from past studies of this problem. First, the traffic volume to an airport is only a fraction of total urban travel. It is often too scant to justify an exclusive high-cost access mode. Second, air travelers in general are more sensitive to cost than time in traveling to airports (18), as contrasted with the reverse for the average urban commuter. The air travelers' relative sensitivity to cost means they are unwilling to finance high-cost access modes. Access facilities to airports can be justified, however, if they are part of an integrated urban commuting system.

The proposed use of aviation funds for ground access projects appears to be an innovative departure from the conventional wisdom and would allow an airport to be defined broadly to include ground access and multiple airport linkages in a city. But such a solution is fraught with flaws in equity and political obstacles in spite of its technical merits. Perhaps the proposed amendment to the 1982 act on ground access, the Surface Transportation Act of 1982 (PL9-424), and Emergency Jobs Bill (PL98-8) will help by providing financing for improving the transportation infrastructure in an urban area.

Future Public Policies

Some projections of the issues in the upcoming 1987 reauthorization legislation are discussed in the following paragraphs.

Projected Trust Fund revenues and FAA expenditures through the year 2000 were estimated based on aviation activity forecasts in the National Transportation Policy Study Commission (NTPSC) 1979 study (19), the NASP distribution of capital expenditures for 1978 to 1987, and the then mandated federal shares for various airport development projects. Accounting for inflation, the gross amount of annual expenditure required, as forecast by NTPSC, is about half the amount of that in the authorization of the 1982 act. It is interesting to note, for instance, that the NTPSC did not foresee the need for substantial improvement in the airway ATC system in the 1980s. This is shown by a comparison of the facility and equipment and research and development budgets. Neither did the NTPSC foresee FAA's use of Trust Funds in operations and maintenance. Traffic forecast by NTPSC, however, was higher than that which materialized. These discrepancies point out the fragility of econometric forecasts, particularly long-term projections.

Accrued revenues to the Trust Fund and funding requirements for 1982-1987 were also forecast and compared by the Office of Management and Budget in April 1982. Using the excise tax proposed by the administration, it was estimated that 85 percent of the FAA expenditures from the trust fund could be recovered by the proposed taxes if coupled with a drawdown of about $2.2 billion from the Trust Fund surplus, which corresponds to the amount that existed in 1978. The 1982 act subsequently allows for a slightly lower general aviation gasoline tax (8 cents or 10.5 cents instead of 12 cents a gallon). In spite of this, subsequent analysis by the Congressional Budget Office (20) still substantiates the findings of the cost-recovery calculations.

Learning from the experience of NTPSC, the thesis of this paper is that projections are only meaningful in a time frame within which there are solid reference points anchored by legislation and technological developments (see Figure 1, for example). Furthermore, a projection should consider all the factors and impacts on all parties--both qualitative and quantitative. The impact of the proposed improvements to airports and airways can be summarized in an impact-incidence matrix such as the one shown in Figure 2. In such a matrix, the objectives of improvements to the aviation system are identified and the effect of implementing the system on the parties concerned is documented.

The chief objectives of airport and airway improvement are

- Increase safety: avoid aircraft conflicts,
- Increase capacity: expand the traffic handling capabilities of airways and terminals,
- Increase productivity: achieve savings in the operations and maintenance budget through automation,
- Reduce noise: enhance the environment near airports and in the community in general through noise abatement, and
- Cost-recovery financing: devise an efficient means to pay for the cost of the system.

The affected parties can be identified also. Among the users of the aviation system are commercial airlines, general aviation, and the military. Where the military shares the same airspace with the civilian sector their domestic flights often have to observe FAA regulations. Included in the user category are passengers and shippers who are concerned with both air and ground operations.

A second group affected by improvements is the operators, which include the FAA for the national airspace and the airport authorities, who typically run the air terminals in the local communities. Private airports that make their facilities available for public use can also be listed, but it is assumed that such operators will be lumped under

	OBJECTIVES:				
IMPACTED PARTIES	SAFETY	CAPACITY	PRODUCTIVITY	NOISE	FINANCE
USERS:					
Commercial Aircraft	++ (enroute) + (terminal)	++ (enroute) + (terminal)			+
General Aviation		+			-
Military Aircraft		+			-
Passengers	+(air)	+(air)			+
Shippers	+(air)	+(air)			+
OPERATORS:					
FAA	++	++	+	+	+
Local Authorities					
Airport Authority	+(air)	+(air)	+	+	?
Local Governments				+	?
COMMUNITY:					
Airport Residents	+			+	
Nonusers	+			+	?
CONGRESS:	+	+	+	+	?
ADMINISTRATION:	+	+	+	+	?

KEY:				
	+	positive impact	+(air)	postive on air side only
	-	negative impact	+(enroute)	positive on enroute airways only
	?	uncertain impact		
	empty	"not applicable"	+(terminal)	positive on terminal airspace

FIGURE 2 Impact-incidence matrix of airport and airway system improvement.

local authorities. The inclusion of local governments under local authorities is necessary because the airport authority is primarily concerned with the airport real estate, whereas the local government has a broader concern with such items as ground access and other responsibilities to the community at large.

Under the community group are listed both those who are most critically exposed to aircraft noise around airports and the nonusers of the aviation system who bear part of the cost of the system (through contribution to the General Fund) without a direct benefit of riding as an air passenger or shipping freight directly on an aircraft.

Finally, the Congress and the administration are included in Figure 2 as interested parties. Although one can theoretically think of these agencies as representative of the interest of all the users, operators, and communities, this is not often the case in practice.

An examination of Figure 2 shows that most of the entries are rated as a "+", which stands for positive impacts on the identified parties as far as the specific objective is concerned. Overall, one may say that the general airway and airport improvements discussed in this paper receive support for their long-term potential (21). These are long-awaited improvements in an aging and oversubscribed ATC system. Inasmuch as the improvement thus far is primarily on airways, however, passengers and shippers still have to face the pervasive problem of ground access (and secondarily terminal capacity). In the short run, terminal and ground congestion can be alleviated through redistribution of traffic, and the legislation does begin to address this, although more indirectly than would be desired.

The place where negative impacts appear in general is under the issue of cost-recovery finance. The general aviation community and the military see little benefit from such systems as Mode-S and the Traffic Alert Collision and Avoidance System (TCAS). The cost is deemed too high for both parties when many of them are likely to fly in uncontrolled airspace. The military has a further reservation about the negative aerodynamic effects of such equipment on tactical aircraft.

Among the operators, local matching-fund financing for system improvements is uncertain for some of the smaller airports, particularly regional airline and privately owned airports. The uncertainty is even greater for local governments, which often are responsible for ground access to the airports. On the other hand, the concern shown by nonusers is obvious considering their tax support for a system they do not use and the yet unproven savings from operations and maintenance due to automation.

The stance of the Congress and the administration on the financial arrangement of the 1982 act and the NAS plan can be difficult to understand. The 1984 appropriations for the act, for instance, reduce expenditures from the Trust Fund by $2 billion, or 49 percent below the authorized level. FAA's operating expenditures from the Trust Fund are eliminated entirely--somewhat of a divergence from the intent of the 1982 act. The question could be asked: Why are expenditures cut and a large surplus allowed in the Trust Fund? There appears to be no logical explanation other than perhaps a maneuver to obscure the national deficit. What is really perplexing is the contradiction--which appears to be espoused by both the administration and the majority of Congress--with the intended use of the Trust Fund.

A major controversy also exists in the issue of self-financing of large airports. Studies (20) point to the ability of large airports to support themselves through head tax and tax-exempt bond financing, as they have done in the past. This would save the bulk of the average $800 million yearly expenditure projected for grants-in-aid through 1987 (see Table 1)--although the revenue going into the Trust

Fund would also be less when these large-contributor airports are uncoupled from the federal-aid system.

The self-financing ability of large airports is evident from the discussion on marginal-cost pricing for congested (large) airports and Ramsey pricing for uncongested (smaller) airports, where both the efficiency of such pricing schemes and the cost-recovery potential for large airports have been shown. However, many major airports, including the Port Authority of New York and New Jersey, are opposed to the self-financing proposal (16). The issue of self-financing is not whether the large airport can do it, but rather: Is it desirable?

SUMMARY AND FINDINGS

Aviation developments in the United States seem to bifurcate every decade or two, perhaps because of the rapid pace of technological change and the American life style. In the last three decades, for example, there have been two major pieces of aviation legislation and three generations of air traffic control systems. It now appears that as the United States emerges from the 1970s to 1980s, another major change is taking place, as characterized by deregulation, the 1982 act, and the FAA's modernization plan.

Partly because of the economy, the national airlines (and the majors) are still struggling to adjust to deregulation, and it appears that the open-sky policy will prevail for the next several years. During the period 1983 to 1985, for example, the expected replacement of national carriers by regionals--due to deregulation--at many communities around the country may result in a significant increase in the number of takeoffs and landings. Forecasters also have suggested traffic growth in the general aviation sector. This places additional requirements on capacity and safety both at terminals and on the airways.

More stringent noise requirements are about to be imposed around many of the airports. In spite of the mandated noise reduction in engines, the most effective noise-abatement procedure before the year 2000 continues to be in the area of land use planning, operational procedures for takeoff and landing, and, most critically, reducing the operating window of the airport. Imposition of curfew hours will definitely reduce the capacity at many of our major airports. Thus, on the one hand, air traffic grows as a result of deregulation; while on the other noise requirements tend to work against accommodating such growth in traffic. One short-term solution is to divert traffic to underutilized, reliever airports. This, together with the poor safety records of the regionals in the past, prompted a need to upgrade the smaller, reliever facilities.

The airport and airway authorizations of the 1982 act begin to address these issues, but much remains to be done. Meanwhile, the Surface Transportation Assistance Act of 1982 also theoretically helped by providing additional funding that potentially can be used to improve connectivity between and access to reliever and multiple airports around urban areas. Perhaps most importantly, airline deregulation allows for a much more flexible route structure for scheduled airlines. This may result in a shifting of through traffic from the existing connecting hubs and gateway cities to others where capacity is less taxed. It may mean, for instance, that much of the capacity problem and, for that matter, the safety problem can be addressed by encouraging a redistribution of traffic from the bottlenecks to the less congested areas. This may mean also the accelerated use of reliever or multiple airports in metropolitan areas.

The National Airspace System plan is generally received well by the users, operators, communities, the Congress, and the administration. There is particularly favorable reaction to its long-run contribution to the enroute part of the aviation system. Much less agreement exists about its short-run (before 1990) benefits, particularly at the terminal portion of the system. Even less agreement exists about an equitable way of paying for the funding authorized by the 1982 act, because a $4.6 billion surplus exists in the Trust Fund. In spite of the healthy tone set by the 1982 act, much room exists for innovation and improvement in future public policies.

ACKNOWLEDGMENT

Elements of this paper were originally drafted when the author was serving as a Congressional Fellow at the Office of Technology Assessment (OTA), U.S. Congress. The paper was extended and further refined at the State University of New York at Stony Brook and Washington State University.

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Publication of this paper sponsored by Task Force on Economics of Air Transport.