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Contents

Aviation Forecast Assumptions and Discontinuities: Survey Results

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Results of a survey of air transportation forecasters, planners, and researchers from four global regions and six industry sectors are reported. The survey results cover four major areas: the overall business environment in aviation, markets and prices, competition and regulation, and operations and technology. Wide variations in assumptions among the 120 respondents are noted in several important factors such as price levels, price elasticity, and the effect of changing government regulations on airline routes and operations. The most important assumptions identified by the respondents include changes in real air fares and real economic growth, the availability and price of jet fuel, government regulation, airport and airway capacity constraints, and inflation. The most important modifiers—defined as discontinuities (or surprises)—include the disruptive impact of a prolonged oil embargo by the oil-producing nations, a major recession, further large cuts in air-fare discounts, and automobile gasoline rationing.

This paper discusses a survey of 120 aviation forecasters and planners concerning the assumptions that are critical to developing aviation forecasts and assessing the aviation outlook for the 1980s. The purpose of the 118-question survey was to foster discussion of aviation forecasts. In this area, assumptions are frequently considered without being stated or, in many cases, are ignored entirely. This study suggests that these hidden assumptions should be stated clearly, whether in quantitative or qualitative form.

The survey was also designed to aid forecasters and planners in assessing aviation forecasts, identifying new assumptions or modifiers that may be useful in developing future forecasts, and making comparisons and resolving differences among forecasts. It was also intended to provide the basis for further discussion and study.

The statements and trends discussed here are not the forecasts per se of any individual or group; rather, they are the collective expert views and expectations of more than 100 thoughtful executives and researchers from several regions of the world about the major factors and underlying forces that will shape aviation during the 1980s.

The paper covers four major areas:

1. The overall business environment—the major assumptions and modifiers that will influence air transportation in the 1980s;
2. Markets and prices—some baseline values for economic growth by geographic region, air fares, price elasticity, traffic, and regional expansion;
3. Competition and regulation—the major competitive forces and regulatory changes that will most affect aviation demand; and
4. Operations and technology—the changing level of operating costs, particularly fuel expenses; values for load factors; and an assessment of the shifting fleet mix.

The survey document was designed in July 1978, several months before the passage of the October 24, 1978, U.S. Airline Deregulation Act and the subsequent restructuring of the International Air Transport Association (IATA). However, the survey was sent out during October 1978, and replies were received during November and December.

Respondents to the survey come from a wide spectrum of aviation interests: 23 percent from commercial airlines, 23 percent from universities and research centers, 18 percent from manufacturers of engines, 17 percent from government agencies, 7 percent from airframe manufacturers, and 5 percent from airport executives. Eighty-five percent of the respondents resided in the United States, 10 percent in Western Europe, 2 percent in Asia, and 3 percent in Canada. It is obvious that the number of respondents is too small to provide statistical precision; the intent of the comparisons is rather to offer suggestions and points of divergence as a means of improving our understanding of aviation forecasts by focusing on their assumptions. Considerable additional effort will be required in the future to properly assess the values and impacts of the variables and factors discussed. However, some baseline values are presented for selected assumptions in order to facilitate and stimulate discussion.

MAJOR FINDINGS

Overall Business Environment

The aviation business environment of the 1980s will be complex, competitive, and full of challenge. A number of important factors will influence air transportation demand in the decade ahead, including changes in the economy, energy availability, prices, government regulation, and airport and airway capacity constraints. Each of the four major areas is discussed in relation to these assumptions.

Six major factors can be identified as crucial assumptions that any forecaster needs to specify when making a useful and sound forecast. Table 1 gives the ranking of these factors as specified by the consensus of respondents.

Two of the six major assumptions received a very high response from the executives who completed the survey: Changes in real air fares—prices of air travel excluding inflation effects—were specified by 98 percent of the respondents, and changes in real economic growth were specified by 94 percent. The other four major assumptions were also ranked high by at least 70 percent of the respondents: jet fuel prices and availability (75 percent), contraction and expansion of the business cycle (75 percent), government regulation (72 percent), and airport and airway capacity constraints (73 percent).

Three of the six modifiers were specified by more than 80 percent of the respondents (see Table 2): an Organization of Petroleum Exporting Countries (OPEC) oil embargo of at least three months (82 percent), a major recession such as the one in the 1973-1975 period (91 percent), and further large cuts in air-fare discounts (88 percent). Almost half of the survey participants said that an OPEC oil embargo would have a severe impact on their aviation activity. The other three modifiers considered important by more than two-thirds of the participating researchers were automobile gasoline rationing for at least one year (68 percent), complete airline deregulation (75 percent), and an aircraft fuel-allocation program (69 percent). About one-quarter of the respondents stated that complete global airline deregulation would have a severe effect on their activities.

There were differences among respondents by region. Those in the United States and Canada were more concerned about changes in air fares, real economic growth, and contractions of the business cycle than were the total group of respondents. European participants were much more emphatic about assumptions concerning terrorism and hijacking, the availability and price of jet fuel, and, particularly, the availability of adequate facilities for tourism. The greater weight given by aircraft manufacturers to assumptions concerning new aircraft and engine technology is not surprising. Airlines, for the most part, gave considerable attention to government regulations concerning noise, airport and airway capacity constraints, and changing consumer tastes and motivations. Government respondents emphasized assumptions concerning safety, terrorism, and airport and airway capacity.

In terms of modifiers, Western European respondents gave greater weight to the impact of airline deregulation, further large cuts in air-fare discounts, and the lifting of airport curfews. U.S. participants felt that an aircraft fuel-allocation program would have a more severe impact on their operations than did the consensus. Airport operators and engine suppliers felt that a major recession like the one in 1973 and 1974 would have a disruptive effect on their activities.

In spite of uncertainty and concern about these problems, most of the researchers were optimistic about the future of aviation. About 45 percent stated that mostly favorable conditions would prevail in the decade ahead, 50 percent believed that there would be a period of both favorable and unfavorable changes, and only 5 percent said that there would be a mostly troublesome economic environment.

Table 1. Survey response on importance of various factors in influencing air transportation demand.

	Percentage of Respondents		
Factor	Crucial	Very Important	Moderately Important or of Little Importance
Air-fare levels in real terms	39	59	2
Real economic growth	37	57	6
Business cycles	23	52	25
Inflation	10	56	34
Rates of population growth	4	35	61
Consumer tastes and motivation	14	54	32
Terrorism and hijacking	5	10	85
Unemployment	3	32	65
Capital shortages or weak investment	10	43	47
Availability and price of fuel	35	40	25
Government regulations and controls (noise, routes, fares)	24	48	28
Airport and airway capacity constraints	23	50	27
Availability of tourism facilities and accommodations	9	61	30
Environmental and ecological concerns	4	32	64
Aircraft utilization and mix	8	42	50
Rising economic nationalism or protectionism	7	32	61
Threats from competitive modes (rail, automobile, communications)	2	12	86
New aircraft and engine technology (new versus derivative aircraft)	5	29	66
Geographic shifts or population migration to new urban areas	3	35	62

Table 2. Survey response on effect various events or factors would have on respondents' aviation activity in the 1980s.

	Percentage of Respondents			
Factor	Severe Impact	Moderate Impact	Light Impact	No Impact
OPEC oil embargo lasting at least three months	48	34	13	5
Major recession such as that in 1973 and 1974	42	49	7	2
Merger of two or more major air carriers	2	13	47	38
Aircraft fuel-allocation program	21	48	24	7
Financial collapse of one or more major carriers that results in major route restructuring	14	35	36	15
Complete airline deregulation	25	50	18	7
Further large cuts in air-fare discounts	36	49	13	2
U.S. production of supersonic transport	7	13	37	43
Automobile gasoline rationing for at least one year	26	42	26	6
Lifting of airport curfews	2	28	50	20
Elimination of Civil Aeronautics Board regulation of air fares	17	48	27	8
Elimination of IATA agreements on air fares	19	32	37	12

Markets and Prices

According to the questionnaire responses, the period of the 1980s will be characterized by relatively buoyant economic growth, declining air fares in real terms, an increasing number of special air-fare offerings, an increasing sensitivity of air traffic to price changes, and important opportunities in three major regions: the United States, Western Europe, and the Middle East. The survey produced the following specific assumptions concerning economic growth rates.

During the 1980s, real economic growth in the United States will average 3.3 percent, which is close to the U.S. economic pace for the past 30 years. It will average 3.5 percent for Western Europe and 4.8 percent for Japan, both of which rates are lower than historical growth rates for those nations but relatively higher than the rates of economic expansion they realized during the 1970s. These assumptions are developed by statistically averaging all of the responses; considerable uncertainty accompanies the estimated means, particularly among respondents outside the United States. European respondents generally assumed lower U.S. growth rates than the consensus. European airlines believed that real economic growth in Europe and the United States will be much lower than is generally believed. Governmental and consulting participants generally specified higher rates of economic growth for their baseline assumptions, whereas airlines and engine suppliers used much lower rates.

Respondents were asked what the rate of change in air fares would be in the 1980s (as measured by yield) in comparison with consumer price increases (see Figure 1). Sixty-one percent indicated that fares for U.S. air carriers would decline, and 32 percent indicated that U.S. fares would rise at the same rate as inflation. For Western European carriers, 49 percent believed that fares would decline and 36 percent that fares would keep pace with inflation. Airlines, engine suppliers, and consulting groups believed that inflation rates would be lower than did the consensus of respondents; government participants in the survey assumed higher rates of growth. It was the consensus view that during the 1980s there would be 6.6 percent annual growth in the U.S. consumer price index.

Major peak discounts or peak-load pricing policies are

Figure 1. Survey response on anticipated rate of change in air fares (as measured by yield) in the 1980s in comparison with consumer price increases.

Table 3. Survey response on likely price elasticity of demand for air travel in the 1980s.

Type of Passenger Travel	Percentage of Respondents by Price Elasticity				
	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0
Overall	6	26	53	11	4
Distance <806 km	17	29	37	10	7
Domestic	4	30	51	12	3
International	6	13	37	33	11
Business	49	33	14	3	1
Personal	3	9	35	36	17

Note: 1 km = 0.62 mile.

foreseen as very likely or probable by 95 percent of the survey participants; "no-frill" fares that cover only the bare-bones cost of transportation and do not pay for meals or beverages are expected by 87 percent of the aviation forecasters and planners. Two other types of fares were foreseen by at least two-thirds of the participants: (a) fill-up fares that provide air transportation at reduced prices for passengers but only when space is available and (b) first-class fares that are at least 30 percent higher than coach-economy fares. Airframe manufacturers and airlines were more emphatic about the importance of these assumptions than others. On the other hand, planners in Western Europe gave certain types of fares—such as off-peak discounts, fill-up fares, and first-class fares—a much higher probability than did the consensus of respondents.

Air traffic demand was seen as sensitive to changes in air fares: Overall passenger traffic will rise by 11.5 percent for every 10 percent cut in real air fares in the 1980s. Certain types of air travel markets, however, differ from this overall average: Air passenger travel for distances less than 806 km (500 miles) and air business travel in general are considered to be much less sensitive to price changes. International travel and air travel for personal reasons are much more sensitive to price changes. There was uncertainty in the survey about each of the values of price elasticity (stated here as the statistical mean of all respondents), but the greatest differences among participants were among the values for price elasticity for air travel markets where trips are shorter than 806 km. There was somewhat greater confidence in price elasticity for personal trips—e.g., a 10 percent cut in real air fares would result in a 15.5 percent increase in air travel demand.

There is considerable controversy about price elasticity. It is therefore no surprise that assumptions about price elasticity differ widely among aviation forecasters (see Table 3). For example, airframe manufacturers, airlines, and consultants believed that the overall passenger travel market was much more price sensitive than the consensus of respondents believed it to be. But, on domestic routes, airlines felt that prices were less elastic, whereas airframe manufacturers perceived them to be more elastic then the statistical average. There was an even greater difference in the responses concerning business travel markets: Airlines and consultants tended to see higher price elasticity here, whereas university researchers and engine suppliers saw much lower elasticity. Western European forecasters saw domestic markets as less price elastic than Americans did, probably because of the shorter stage lengths and other factors, but they believed that business travel may be more price sensitive than did other respondents.

Respondents were asked to which of eight major world regions they would direct their efforts in aviation in the 1980s if they had sole responsibility for their organization's flight operations, facilities planning, or marketing. The results are summarized below:

Region	Percentage of Respondents			
	Greatest Effort	Large Effort	Some Effort	Little or No Effort
United States	59	29	12	0
Western Europe	10	57	22	11
Middle East	11	50	24	15
Japan	10	49	26	15
South America	3	39	41	17
Canada	2	29	52	17
Africa	2	22	43	33
Eastern Europe	1	13	40	46

According to the consensus view, the greatest amount of effort in terms of new aviation facilities, increased flight operations, and marketing activities will be directed toward the United States, Western Europe, and the Middle East. Almost 60 percent of the survey par-

Table 4. Survey response on anticipated rate of change in operating costs of major U.S. trunk air carriers in the 1980s.

Cost	Percentage of Respondents		
	Costs Will Rise Faster than Inflation	Costs Will Rise at Same Rate as Inflation	Costs Will Decline Relative to Inflation
Direct operating costs	47	46	15
Fuel	77	18	5
Flight crew and insurance	48	50	2
Maintenance, flight equipment	18	58	24
Depreciation and rentals	19	55	26
Indirect operating costs, such as food, reservations, ground handling	19	66	15

ticipants identified the United States as the region most likely to be the focus of the greatest effort in aviation in the 1980s. In terms of traffic growth, however, the regions with the highest gains were seen to be Japan, South America (in domestic and international markets), and Western Europe (in international markets).

Competition and Regulation

The aviation environment will be strongly affected during the 1980s by sharply rising competition and changing government regulation. More than 90 percent of the respondents foresaw major new low-fare pricing strategies, governmental regulatory changes, new route awards, and new approaches to obtaining better financial terms and credit availability as major forces or important competitive factors in the aviation industry.

About 69 percent stated that acquisitions and mergers would be a major factor or an important force during the decade ahead. U.S. respondents and small aircraft manufacturers particularly expected acquisition and merger activity to be intense during the 1980s. More than 80 percent stated that other competitive factors would be the purchase of new-technology aircraft to lower operating costs and the ability to attract and retain good personnel and managers.

It was considered quite probable that airlines that operate within U.S. markets and airports would meet current U.S. noise regulations by 1990. Respondents indicated that the U.S. aviation industry would be most affected by the declining role of government regulation over prices and routes but that airline operating economics would become more important and increasing the freedom of route entry would increase the intensity of competition on routes. Government and engine suppliers felt that reduced regulation would be a major stimulant in the growth of regional airlines and that this in turn would stimulate the growth of demand in short-to-intermediate markets. On the other hand, airlines and university researchers were more emphatic about the likelihood that airline operating economics would become more important as a result of aviation deregulation.

Operations and Technology

Table 4 gives the survey response to a question on how fast various elements of airline operating costs will rise during the 1980s, in comparison with U.S. inflation rates, for total operations of major U.S. trunk carriers. The response indicates that virtually all costs directly related to aircraft operations (direct operating costs) will rise relative to consumer price increases but fuel costs will increase most rapidly.

To a question on how fuel expenses are likely to change as a proportion of total direct operating costs for major U.S. trunk airlines by 1990, the respondents indicated the following (fuel costs were 38 percent of direct operating costs in 1977):

Change	Percentage of Respondents
Increase (%)	
> 50	9
46-50	19
40-45	49
Remain the same as in 1977	16
Decline	7

Engine suppliers and airframe manufacturers were the most pessimistic about rising energy costs; government respondents generally felt that energy costs might remain at approximately the current level.

In response to questions on load factors and changes in aircraft mix, most respondents believed that load factors would reach the 61-65 percent range by 1990 and that two-engine wide-body and new-technology aircraft would be the fastest-growing sectors in aircraft utilization in the 1980s. About 63 percent of the respondents expected a major increase in production of two-engine wide-body aircraft; 73 percent stated that there would be major growth in the use of new-technology aircraft and their derivatives. Europeans saw greater growth in the use of two-engine wide-body aircraft, and a number of airlines and most university researchers agreed with this view. "Some increase" was seen in the use of three-engine wide-body aircraft by the consensus of respondents; airlines, however, gave growth in the use of this type of aircraft a higher rating.

Near-Term Sales and Earnings Prospects

In view of the concern about economic problems, fuel price increases, and the changing environment of government regulation, respondents to the survey were surprisingly optimistic in rating their own prospects for growth until 1985. Most of the participants appeared to feel that their own organizations would do better than their competitors. Eighty-one percent stated that their own sales outlook would be quite favorable or generally good and 67 percent that their own growth in earnings would be quite favorable or generally good.

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Demand Analysis for International Air Travel

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Time-series models for 10 international air travel markets are calibrated. These models are used to analyze traffic developments and to investigate whether conventional models of traffic demand can be used to forecast international air traffic. The models use simple specifications in which demand is represented by per capita income and intercountry trade flows and supply is represented by prevailing fares. Because of data limitations, no attempt is made to model demand and supply simultaneously. The results of the analysis are encouraging and indicate that, although the use of traffic demand modeling in analyzing international air traffic has many limitations, there is a good potential for developing this methodology into a useful forecasting aid.

The use of econometric models of air travel demand has been common practice for many years. Such models are typically applied in setting pricing policy on the basis of estimated elasticities and in traffic forecasting on the basis of exogenous forecasts of the demand and supply variables of the models. Most applications of this type have, however, been confined to domestic air travel, and indeed most of this work has been limited to U.S. domestic air travel. Apart from some applications in the North Atlantic and the local European markets, few if any applications of econometric models can be found for any of the almost 20 major international air travel markets, as defined by the International Air Transport Association.

There are many reasons for this disparity in methodological development and application. Apart from the simple historic lag in the development of aviation between the United States and many other regions of the world, the most important reason probably has to do with the difficulty involved in assembling the information necessary for the development of econometric models.

Many countries in the world do not have the advanced data-management systems required to keep track of the development of aviation and related socioeconomic activities. It is very difficult, if at all possible, to find the parity between data systems that is required to establish a "market" data base. A market in this regard is defined as a pair of regions, each of which contains one or more countries and between which there is air travel activity of interest. Possibly the most important difficulty, however, is that the efficacy of modeling air travel between region pairs in the world can be questioned on the ground that little of the regularity that permits meaningful modeling exists between regions in patterns of development, travel behavior, supply characteristics, and determinants of demand.

In the face of these deterrents, an attempt has been made to investigate the feasibility of developing a set of econometric models for air travel in world markets. The purpose of this study is to calibrate such models and evaluate their efficacy for traffic forecasting. This paper reports on some of the findings of the study and focuses on the results of the analysis for the following 12 international markets, which cover a range of geographic areas and traffic densities: North Atlantic, Mid-Atlantic, South Atlantic, North America-South America, North America-Central America, Europe-Northern Africa, Europe-Southern Africa, local Europe, Europe-Far East/Australasia, North Pacific and Mid-Pacific, South Pacific, and local Far East/Australasia.

METHODOLOGY

Theoretically, it can be said that all variables used in traffic forecasting are dependent and should actually be combined into a single model system. This model system would be estimated simultaneously by using multivariate statistical techniques. Although this is true of demand analysis in general, no attempt was made in this study to undertake a simultaneous modeling effort. The main reason for this is that the data base used is rather fragmented and inadequate for complete multivariate analysis. Because of the limited data base, the models are calibrated individually and are thus short-term models that do not take into account long-term feedback effects between demand and supply. Any such effects would have to be inputted as scenarios in a repeated application of the forecasting process.

Another limitation in modeling traffic demand is that, since it cannot be assumed that the different markets have the same demand function, each market is analyzed separately. This means that the data base for each market has to come from historic data and that some sort of time-series analysis is appropriate. The model would have the following general form:

$$T_t = T(\underline{D}_t, \underline{S}_t, \underline{E}_t) \qquad (1)$$

where

- T_t = total market traffic in year t (revenue passenger kilometers),
- $\underline{D}_t$ = values in year t of a vector of socioeconomic demand variables,
- $\underline{S}_t$ = values in year t of a vector of supply variables, and
- $\underline{E}_t$ = independent error terms for each year.

Because it is anticipated that data problems will preclude any thorough time-series analysis or multivariate modeling of demand and supply, the specification of the models is kept to the simplest possible level. Indeed, it was with great difficulty that data for only seven years (1970 through 1976) were compiled for the study markets. Model specification is limited to a linear form and a multiplicative form with an exponential price function. By assuming that all annual errors are independent and identically distributed and avoiding to the extent possible the simultaneous specification of correlated variables of $\underline{D}$ or $\underline{S}$, the estimation is performed with multiple-regression analysis by using ordinary least squares. This choice of an estimation technique is again based on the limited number of observations available for the analysis.

Another choice severely limited by data availability is the choice of the explanatory variables. Demand variables are selected from among the following: (a) per capita disposable income representing nonbusiness traffic demand and (b) export-import trade representing business traffic demand. These variables are defined for each market by taking a weighted average of their values for selected countries that are representative of the regions that make up the market. The averages are weighted by the airline traffic of each of these countries. In some cases, the variable values for a single representative country are used when complete data on the demand variables are not available. Supply variables are selected from three: air fare, by using either lowest excursion fare or economy fare; market yield per passenger kilometer; and capacity in available seat kilometers. The fare variables are selected for a city pair that is considered representative in the market. All monetary variables are specified in current terms and in real terms deflated by consumer price indices constructed by using weighted averages for countries in either region of the market in question. In some cases in which there are insufficient data to permit the construction of a weighted average, a single-country consumer price index is used instead.

Different model forms were calibrated for each market. The form most commonly used and consistently most significant statistically is the multiplicative form. However, to permit the possibility of variations in price elasticities over time or to detect whether such variations exist, a model form in which the price variable is entered exponentially was calibrated. A model that has two demand variables (income and trade) and one supply variable (yield) would be expressed as follows:

$$T = a_1 \cdot (\text{income})^{a_2} \cdot (\text{trade})^{a_3} \cdot \exp[a_4 \cdot (\text{yield})] \qquad (2)$$

where the t subscript for year has been dropped from all variables for simplicity and where $a_1, \ldots a_4$, are the model parameters. In this model, the income and trade elasticities of demand are, respectively, a_2 and a_3. The yield elasticity, however, is not constant and is given by $[a_4 \cdot (\text{yield})]$. This model form consistently proved more significant than the one in which price elasticity is constant. The advantage of this form is that it recognizes a factor that has been found repeatedly in earlier demand studies—that elasticity is very low when the price is low and increases with the value of price itself.

Since there are anywhere from two to four variables in the traffic demand model and only six years of data on which to calibrate it, it should be recognized that considerable variation can be expected in the parameter values. Although all calibration results appear to be statistically significant at least at the 90 percent level and most at the 95 percent level, it is still very important to recognize the limitations of this type of model for forecasting. Recalibration with additional data is imperative if the model is to be used for forecasting beyond, say, three years.

Another cause for skepticism and extreme care in using traffic demand models for forecasting is that, for many markets that include developing countries, the efficacy of econometric modeling can be questioned on basic principles. Little regularity exists in these markets in patterns of development, travel behavior, and supply characteristics. In the Europe-Northern Africa market, for example—which is defined as including Western Europe and the countries of Africa south of Algeria, Morocco, and Tunisia and north of Angola, Zambia, and Mozámbique—it is hard to imagine that the same determinants of travel demand exist in both regions. A variable such as per capita disposable income is likely to mean much less in terms of travel demand in, say, Upper Volta than in France. Ideally, one would wish to seek other determinants of travel demand that might be suitable for the developing countries of the world, but here one encounters the problem of data availability and must limit the analysis to assumption and conjecture. The few data available on developing economies are typically compiled by international organizations such as the United Nations and cover "conventional" measures of economic activity such as gross national product and per capita income. Another reason for doubting the ability of econometric models to forecast over longer periods of time is the fantastic growth rates that are occurring in many of the developing parts of the world. Technological and economic developments are occurring at such a rate that what happens during a seven-year period for which one has data to construct a model may not be happening during the subsequent period over which one wishes to forecast. On the basis of all this, it is reiterated that the models should be used for short-term forecasting and their validity should be continuously rechecked against additional data. To facilitate a comparative analysis that might be interesting, no attempt was made to integrate elaborate models in markets where such are possible, such as the North Atlantic. Similar models were calibrated for all markets under study. Selected countries in the regions and markets for which demand models are calibrated are given in Table 1.

RESULTS OF TRAFFIC DEMAND MODELS

The results of the calibration of traffic demand models for 12 study markets are given in Table 2. The only market for which a model calibration was not successful was the Europe-Middle East market. There are two probable reasons for this:

1. The market has experienced significant increases in traffic during the 1970-1976 period and appears to be continually in a state of flux, which makes econometric modeling rather difficult.
2. Socioeconomic data for Middle Eastern countries were not available, and to base the traffic solely on demand variables for the European countries was unacceptable both theoretically and statistically.

The results for all of the other study markets appear to be significant statistically, the F-values being significant at at least the 90 percent level and the R^2-values above 85 percent and in most cases above 95 percent. These study markets represent quite a range in terms of market characteristics and traffic volumes and trends. The volumes vary between an average of 71 billion revenue passenger-km for the study period in the North Atlantic and slightly more than 7 billion revenue passenger-km in the Europe-Northern Africa market. Steady growth is seen in some markets such as the Europe-Middle East market, in which traffic nearly tripled during the study period, whereas relatively low rates of growth—approximately 4-5 percent/year—are observed in markets such as the North Atlantic and the North America-Central America markets. Some markets appear to be dominated by nonbusiness traffic, and the income variable appears as the one variable in the demand model; others exhibit a balance between business and nonbusiness traffic, and both the income and trade demand variables appear in the models. Yield elasticities of demand vary from a low of about -0.20 in the Europe-Northern Africa market to a high of about -0.3 in the North America-South America market (see Table 3). The first of these two markets is one in which recent increases in capacity appear to have induced additional traffic

Table 1. Selected countries within markets and regions.

Market	Region A	Region B
North Atlantic	United States, Canada	United Kingdom, France, Germany, Italy, Switzerland, Holland, Sweden
Mid-Atlantic	United States	United Kingdom, France, Germany, Holland, Spain
South Atlantic	France, Germany, Italy, Portugal, Spain, Switzerland	
North America-Central America	United States, Canada	Mexico, Jamaica, Bahamas, Netherlands Antilles
North America-South America	United States, Canada	Venezuela
Europe-Northern Africa	United Kingdom, France, Germany, Holland, Italy, Switzerland	
Europe-Southern Africa	United Kingdom	
Europe-Far East/Australasia	United Kingdom, France, Germany, Italy, Holland, Sweden, Switzerland	Australia, Japan
Europe-Middle East		
South Pacific	United States, Canada	Australia, New Zealand
North Pacific and Mid-Pacific	United States, Canada	Japan, Philippines
Local Far East/Australasia	Australia, New Zealand, Philippines, Japan	
Local Europe	United Kingdom, France, Germany, Italy, Spain, Sweden, Switzerland	

Table 2. Summary of demand model calibration.

Term	North America-South America	North America-Central America	North Atlantic	Mid-Atlantic	South Atlantic
Constant					
Value	-12.140	-16.698	3.452	-20.509	-6.466
Standard error	6.663	16.182	1.990	4.630	2.803
Trade					
Value	0.353			0.763	
Standard error	0.143			0.247	
Composite disposable income per capita					
Value	2.379	3.575	1.010	3.015	2.146
Standard error	0.842	1.907	0.232	0.612	0.363
Yield					
Value			-0.170	-0.197	
Standard error			0.097	0.082	
Fare					
Value	-0.0052	-0.012			-0.0017
Standard error	0.0029	0.005			0.0007
Capacity					
Value					
Standard error					
Average revenue passenger kilometers (000 000s)	7151	12 189	71 417	5804	5693
R^2	0.962	0.856	0.944	0.985	0.972
F	17.14	8.97	15.77	46.79	19.13

Table 2 (continued).

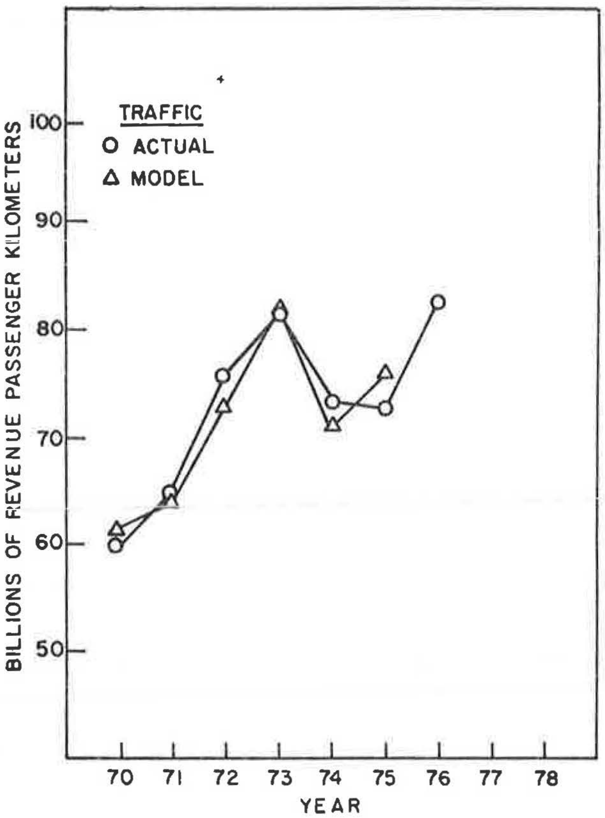
Term	Europe-Northern Africa	Europe-Southern Africa	Europe-Far East/Australasia	North Pacific and Mid-Pacific	South Pacific	Local Europe	Local Far East/Australasia
Constant							
Value	-3.383	-0.866	-8.633	-26.709	5.570	-8.878	-3.333
Standard error	1.398	4.380	6.664	16.540	1.055	4.052	0.593
Trade							
Value		0.561			0.550	1.666	
Standard error		0.172			0.122	0.374	
Composite disposable income per capita							
Value	0.399	0.979	2.431	4.850		0.839	0.616
Standard error	0.209	0.449	0.794	7.089		0.832	0.103
Yield							
Value	-0.047		-0.083		-0.505		
Standard error	0.026		0.164		0.064		
Fare							
Value		-0.003		-0.0032		-0.0049	-0.0006
Standard error		0.0004		0.001		0.0014	0.003
Capacity							
Value	0.996						0.825
Standard error	0.079						0.042
Average revenue passenger kilometers (000 000s)	4057	8593	26 981	12 375	4883	59 468	6641
R^2	0.997	0.975	0.973	0.884	0.967	0.951	0.999
F	239.27	26.22	55.54	8.14	58.78	12.99	1127.96

Notes: 1 km = 0.62 mile.
Constant and fare and yield variables are in exponential form.

Table 3. Elasticities of supply variable.

Market	Type of Elasticity	1970	1971	1972	1973	1974	1975	1976
North America-South America	Fare	-1.609	-1.711	-1.529	-1.472	-1.576	-1.565	-1.544
North America-Central America	Fare	-3.240	-3.156	-3.036	-3.000	-3.000	-2.832	-2.976
North Atlantic	Yield	-0.476	-0.471	-0.413	-0.411	-0.456	-0.449	-0.415
Mid-Atlantic	Yield	-0.686	-0.583	-0.544	-0.473	-0.376	-0.491	-0.481
South Atlantic	Fare	-1.404	-1.294	-1.309	-1.380	-1.176	-1.384	-1.241
Europe-Northern Africa	Yield	-0.209	-0.194	-0.218	-0.168	-0.144	-0.151	-0.155
Europe-Southern Africa	Fare	-2.289	-2.163	-2.184	-2.259	-2.112	-1.926	-1.740
Europe-Far East/Australasia	Yield	-0.313	-0.270	-0.242	-0.217	-0.207	-0.193	-0.194
North Pacific and Mid-Pacific	Fare	-2.470	-2.134	-2.262	-2.160	-1.978	-1.878	-1.709
South Pacific	Yield	-1.692	-1.601	-1.520	-1.505	-1.480	-1.252	-1.182
Local Europe	Fare	-0.891	-0.636	-0.624	-0.893	0.021	-0.891	-0.858
Local Far East/Australasia	Fare	-0.294	-0.279	-0.297	-0.260	-0.255	-0.267	-0.268

Figure 1. Comparison of actual and model traffic for North Atlantic market.



growth, and capacity appears as a variable in the demand model.

It is probably more profitable at this stage to look at the results of each market separately than to attempt a complete comparative analysis between markets. A complete comparative analysis would require an in-depth study of the various demand and supply factors as they differ from market to market.

Detailed results of the calibration for each market are shown in Figures 1-12. Each of the markets is discussed briefly below.

North Atlantic

The North Atlantic market is by far the largest of all the markets in the study in terms of traffic and capacity. The average over the study period is 71 billion revenue passenger-km; traffic in 1976 totaled more than 80 billion revenue passenger-km. The model used in this study represents a rather crude and aggregate one compared with the type that might be developed for this market. The North Atlantic is perhaps the only market in which traffic data would allow a detailed analysis of demand stratified by trip purpose. Indeed, a more detailed demand model of this market has been produced in an earlier study (1). However, for the sake of consistency in modeling and to provide for some comparative analysis with other markets, it was decided to include a model for the North Atlantic market that is similar in structure to the ones used elsewhere. In the computerized integrated forecasting process, it is possible to incorporate any model.

The model shown in Figure 1 includes income as a demand variable but not trade. This is not to say that business traffic is unimportant in this market. But, since more than 60 percent of traffic in the North Atlantic market is nonbusiness traffic, income remained as the only significant demand variable. Real yield elasticity is low at about -0.4 and appears stable over time.

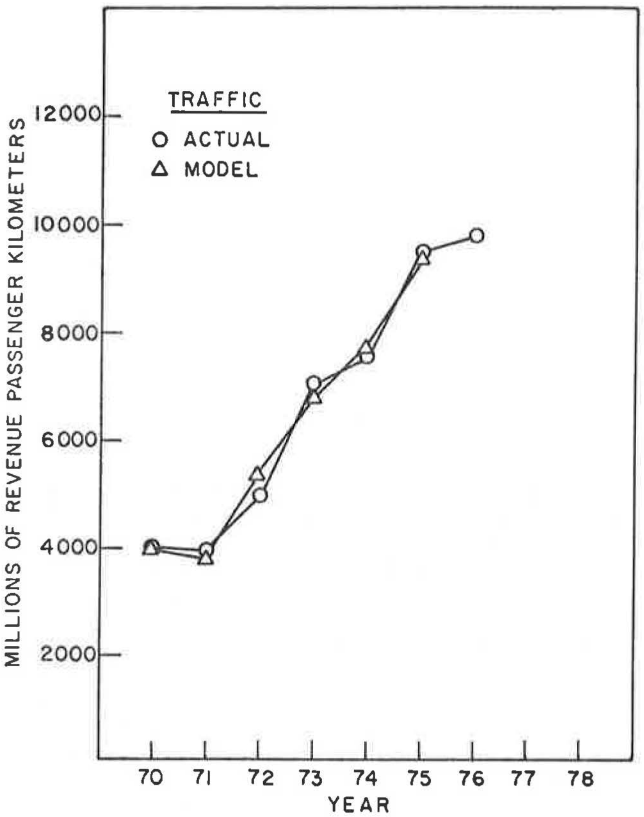
Mid-Atlantic

The interesting thing about the Mid-Atlantic market is that, although it is thought of as a market that connects Europe and the central and northern parts of South America, a considerable proportion of its traffic is in fact between Europe and the United States via Miami. For this reason we find that the variables in the model are composite for European countries and the United States. Thus, the variable of per capita income is a weighted average for Europe and the United States only because of the absence of a complete data set of income measures for the South American countries of the Mid-Atlantic market.

The Mid-Atlantic market is a low-volume market that in 1976 had only about 10 billion revenue passenger-km (the large stage length indicates a low passenger traffic volume). Except for two periods of depression in traffic—one in 1971 and the other in 1974—it has undergone relatively steady growth during the 1970-1976 period (see Figure 2). Trends in trade and per capita income together seem to reflect similar depressions: Trade declined significantly in 1971, and disposable income did not increase in real terms in 1974. Yield in the Mid-Atlantic market declined steadily until 1974, when it rose by about 25 percent. This does not, however, seem to have had a significant effect on traffic development, and one would expect that yield elasticity would be low in this market. Indeed, as the model shows, the elasticity has declined from -0.7 to -0.5 during the study period.

Charter traffic is insignificant in the Mid-Atlantic market, and the traffic demand model was constructed to include only scheduled traffic. The calibration re-

Figure 2. Comparison of actual and model traffic for Mid-Atlantic market.



sult shows both trade and income to be significant variables; income elasticity is a high +3.0 and trade elasticity a low +0.76. It would seem, then, that both business and nonbusiness traffic occur in this market and that, as expected, nonbusiness demand is more elastic than business demand.

South Atlantic

The South Atlantic market is another low-volume, long-haul market; traffic in 1976 was less than 7 billion passenger-km. Traffic growth has not been as fast as that in other markets, and it seems to have declined since 1976 (see Figure 3). Because data were not available for most of the South American countries of this market, it was not possible to represent the changes in economic development in these countries, such as important phenomena of growth in some (e.g., Brazil) and high inflation rates in others (e.g., Argentina). The market demand model is based solely on European economic indicators, a deficiency that ought to be remedied if additional data become available.

Charter traffic appears insignificant in this market as a percentage of the total traffic, and therefore the model is calibrated for scheduled traffic only. The calibration results show two interesting phenomena for this market. One is that income is the only demand variable found to be significant, which indicates that nonbusiness traffic predominates. The other is that fare rather than yield appears to be the significant price variable. One reason for this could be the fact that yield did not decline much in real terms, and this results in a positive correlation with traffic and precludes yield as a significant price variable. Besides, there is not a wide choice of fares in the South

Figure 3. Comparison of actual and model traffic for South Atlantic market.

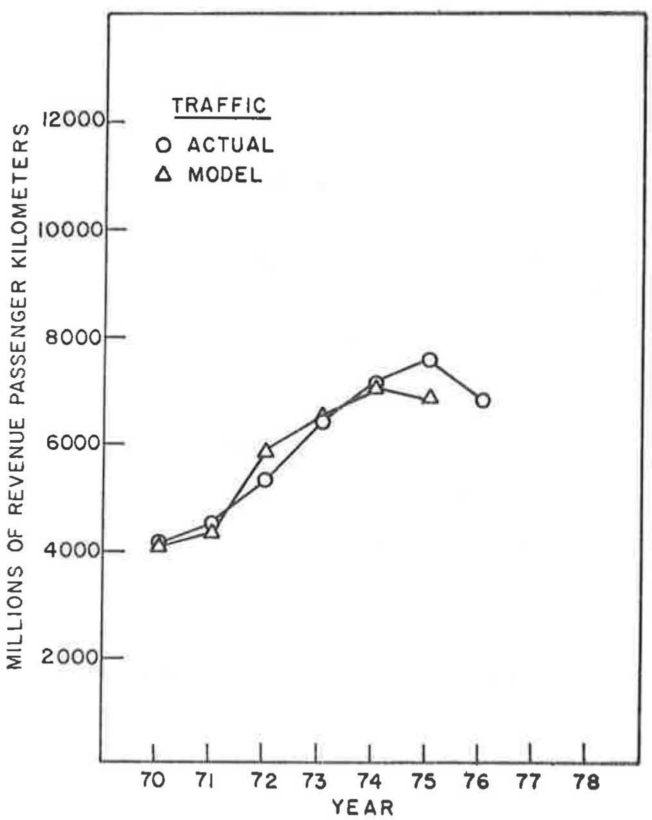
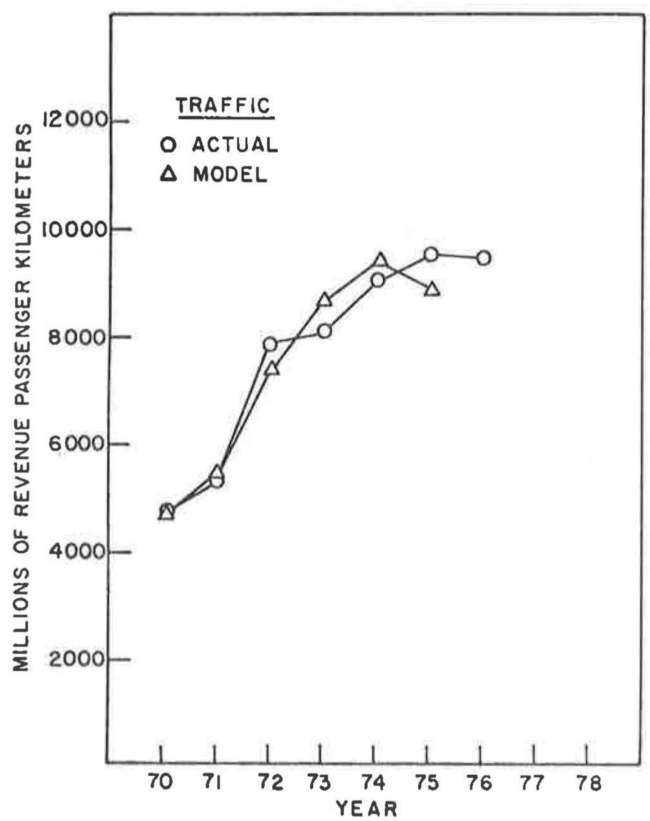


Figure 4. Comparison of actual and model traffic for North America-South America market.



Atlantic market. The Paris-Rio de Janeiro economy fare is the price variable for the model.

Income in the South Atlantic market exhibits an elasticity of +2.1, and the fare elasticity varies between -1.4 and -1.2. None of these values are unexpected for traffic that may be predominantly nonbusiness.

Although the model fit appears statistically acceptable, it is important to restate the reservation concerning the absence of demand variables for the South American countries and the need to update the data base for that region.

North America-South America

The North America-South America market has lower traffic volumes than the North America-Central America market. It experienced moderate growth throughout the study period and had traffic volumes of about 5 billion and 9 billion revenue passenger-km in 1970 and 1976, respectively (see Figure 4). It is a market that serves both business and nonbusiness travel. Both trade and income appear in the traffic model as variables of demand, although income elasticity (+2.38) is significantly larger than trade elasticity (+0.35). This can be expected, since trade experienced sharp growth during the study period whereas income barely increased.

The North America-South America market has no significant charter traffic, and no such traffic was included in the demand model. Fare rather than yield is used as the price variable, as it was in the North America-Central America market, and the excursion fare between Miami and Lima is used as a representative market fare. The fare elasticity, -1.50, is lower (in absolute terms) than that for the North America-Central America market, possibly because of the presence of business traffic. Perhaps for the same reason, income elasticity is also lower.

North America-Central America

The North America-Central America market is a medium-sized, short-haul market that had a traffic volume of approximately 11 billion revenue passenger-km in 1976. The market experienced strong growth prior to 1972, after which traffic appears to have stabilized (see Figure 5). Since it is a market of predominantly vacation traffic, only income appears in the models as a demand variable. Real income in the market, which is a weighted average for the United States, Canada, and Mexico, appears to have declined after 1973. This is probably caused by high inflation rates, which increased the composite consumer price index from 100 in 1970 to approximately 150 in 1976.

Charter traffic, which constitutes a major proportion of total traffic (more than 20 percent), is included in the traffic model for this market. The strong dependence of traffic demand on income in this market can be seen from the rather low constant-term value (exponent -16.7) and the rather high income elasticity (+3.57). Fare elasticity is also rather high, oscillating very close to -3.00 during the years of analysis.

A comparison of actual traffic trends with those produced by the traffic demand model seems to suggest that perhaps a time lag of one year is appropriate in the relation between income and traffic. This refinement is to be the subject of further study of this model.

The absence of wide choices in fare structure allowed the use of a specific fare rather than market yield as the price variable for this market. Unlike many other markets, the real yield did not decline during the 1970-1976 period. Many model calibrations in which yield was used as the price variable resulted in positive elasticities, and consequently a fare variable was used instead. The regular economy fare between New York and Mexico City was used as the representative fare in this market in order to analyze the historic trend of the price of travel. A price elasticity of approximately -3.00 was obtained for this market.

Europe-Northern Africa

In spite of what the name implies, the Europe-Northern Africa market does not include the countries of "North Africa" but covers traffic between Europe and countries south of Algeria, Morocco, and Tunisia and north of Angola, Mozambique, Zambia, and Tanzania. The two markets in this study that include Africa—this one and the Europe-Southern Africa market—suffer from lack of data on the African countries involved, with the exception of South Africa.

The income variable for this market is the weighted average for European countries only, as is the composite consumer price index. This is a deficiency caused by lack of data; if additional data on the African countries were obtained, it would be highly desirable to recalibrate the model. The fact that the model shows an exceptionally good statistical fit should not distract attention from the need to remedy the data situation (see Figure 6).

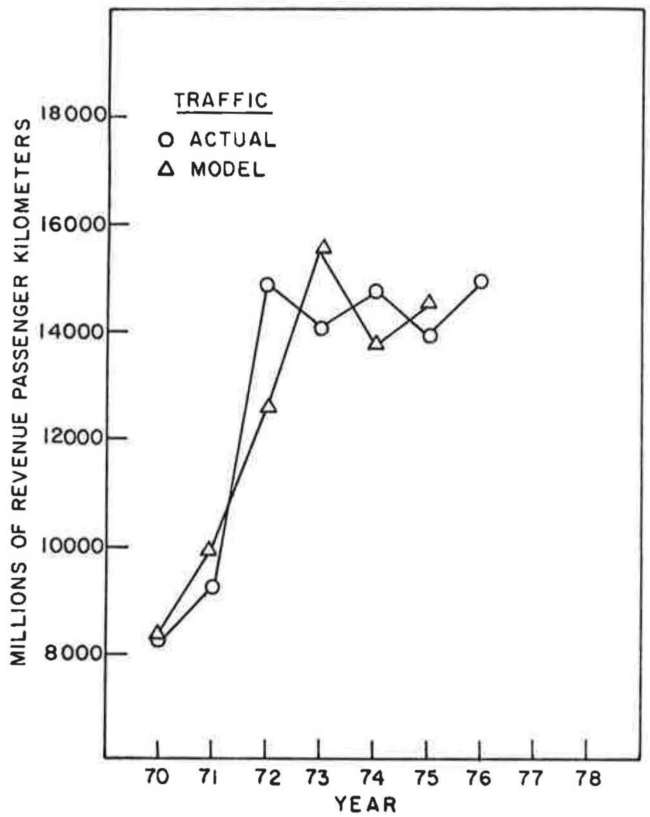
The Europe-Northern Africa market has experienced capacity growth, especially during the period after 1974. Between 1974 and 1976, total available capacity in seat kilometers increased from 6.8 billion to slightly more than 12.3 billion. During the same period, the traffic increased from 3.5 billion to about 7.5 billion revenue passenger-km, which indicates a consistently high market load factor. This leads to the suspicion that capacity may have been constraining traffic development and that it should be included as a demand variable in the model. Indeed, capacity turns out to be a significant demand variable in relation to which the demand appears to have an elasticity in the neighborhood of +1.0. If continued fleet and airline expansion in the market results in a faster increase in capacity than in traffic, it is likely that capacity will no longer be a determinant of traffic demand in that market. The development of this market should therefore be monitored to assess the need to modify the model for future application.

Ideally, one would wish to estimate a simultaneous demand and supply model in which demand is affected by capacity and capacity by demand. Such an estimation would require a more elaborate technique, such as indirect least squares. Further research into this question is in order, especially in light of the limited data available for model estimation. Simultaneous model estimation should ideally be used for all markets in which capacity appears to influence traffic development.

Income appears to be the only significant demand variable in the model for this market. This indicates that nonbusiness traffic may be predominant in this market or that the trend in per capita income is sufficiently strongly correlated with traffic that trade does not add any explanatory power to the model in a significant way.

A result of the introduction of capacity as a traffic-influencing factor is that income and yield explain less of the variations in traffic and this results in both of their elasticities being rather low. Income elasticity is constant at +0.4, and yield elasticity varies between -0.2 and -0.15—unexpectedly low values if the market is truly predominantly a nonbusiness travel market.

Figure 5. Comparison of actual and model traffic for North America-Central America market.



Europe-Southern Africa

The Europe-Southern Africa market is dominated by traffic between Europe and the country of South Africa. However, data availability limits the specification of variables to European countries. The model includes both trade and income as demand variables. This would be expected because the market includes almost equally important proportions of business and nonbusiness traffic.

The Europe-Southern Africa market is a medium-density market with an average traffic volume of 8.5 billion revenue passenger-km during the study period. It experienced strong growth between 1973 and 1976, during which time the volume increased from about 8.4 billion to 13 billion revenue passenger-km. The trends indicate that this strong growth in traffic is related to two factors: a decline in air fares (here represented by the London-Johannesburg economy fare) and a slowing of the growth of the inflation rate, which resulted in an increase in U.K. disposable income per capita. It is interesting that the increase in traffic occurred despite the decline in trade flows after 1974 (see Figure 7). It appears that nonbusiness traffic is taking a more important role in this market.

The absence of complex fare packages in the market prompted the use of a single representative fare rather than yield in the model. In addition to its simplicity, this appears to have advantages in relation to statistical significance. Another indication of the dominance of nonbusiness traffic could be the relative price elasticity of the traffic, which varies between -2.3 and -1.74 during the study period.

Figure 6. Comparison of actual and model traffic for Europe-Northern Africa market.

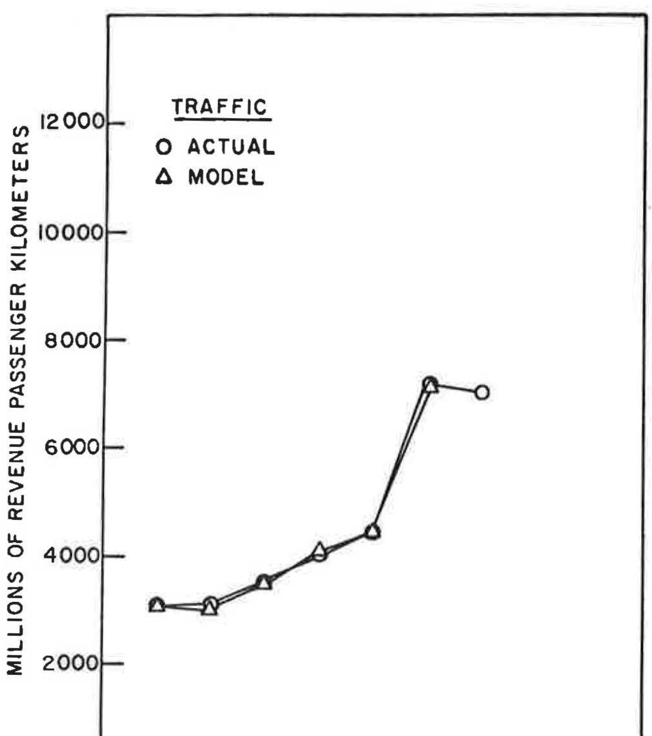


Figure 7. Comparison of actual and model traffic for Europe-Southern Africa market.

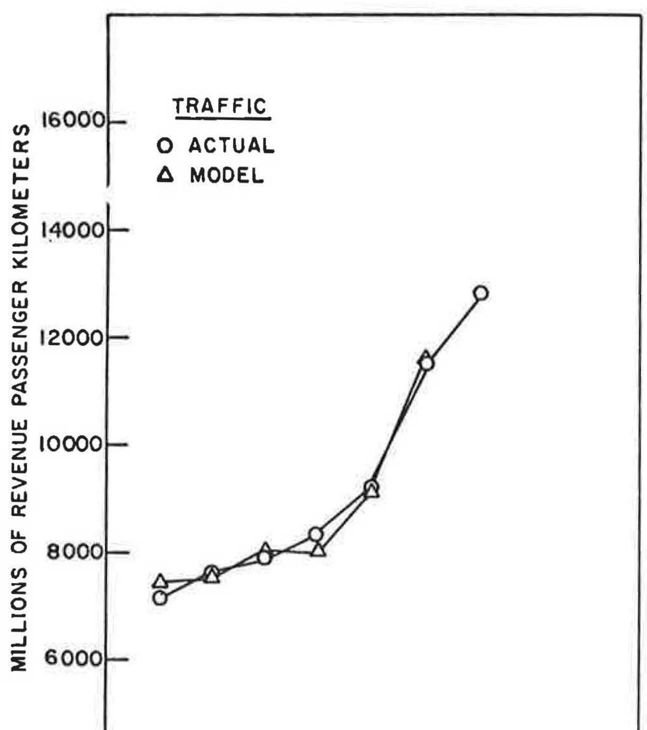
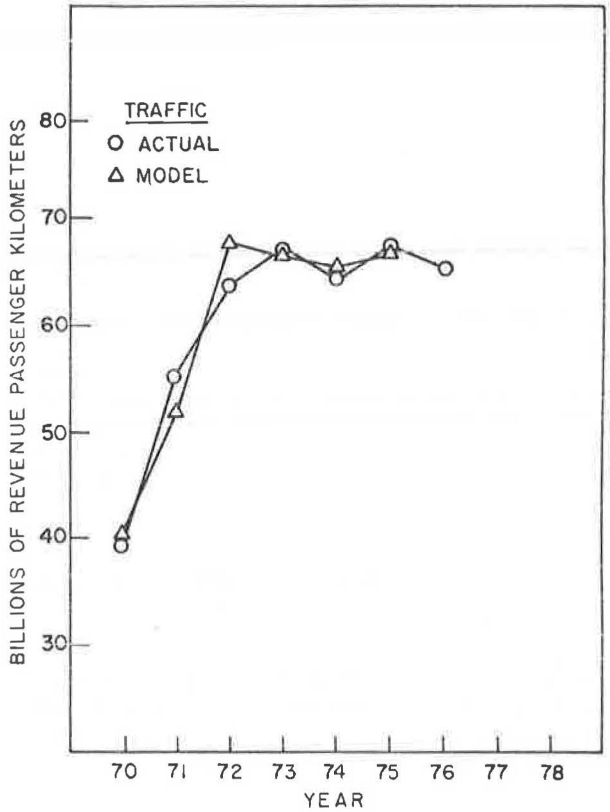


Figure 8. Comparison of actual and model traffic for local Europe market.



Local Europe

The local Europe market is unlike the other markets included in this study. It is a high-density, short-haul market in which traffic grew from 39 billion to 65 billion revenue passenger-km during the study period (see Figure 8). The market exhibits a relatively high load factor of about 60 percent, but capacity does not appear to be a constraint on traffic development and this variable is not included in the model. Local Europe is also a market of relatively high yield (about 9 cents/revenue passenger-km in 1976) and relatively high cost (about 5.2 cents/revenue passenger-km in 1976).

Charter traffic constitutes about 47 percent of the total traffic in the market. This percentage did not change appreciably during the study period. Consequently, the model does include charter traffic. It is implicitly assumed that the relative fares of scheduled and charter operations have not changed much during the study period (or else the charter share would have changed), and based on this assumption the model is constructed with a representative fare as the price variable. In the analysis, the fare variable always appeared more statistically significant than the yield variable. The representative fare used is the London-Rome economy fare.

The local Europe market serves both business and nonbusiness traffic. Both trade and income appear in the model as demand variables; traffic shows a higher elasticity for trade (+1.67) than for income (+0.84). Fare elasticity is about -0.8, which indicates a relatively inelastic demand. An interesting phenomenon in the market is the strong growth before 1972 and the relative stagnation after that. This trend appears to be the re-

Figure 9. Comparison of actual and model traffic for Europe-Far East/Australasia market.

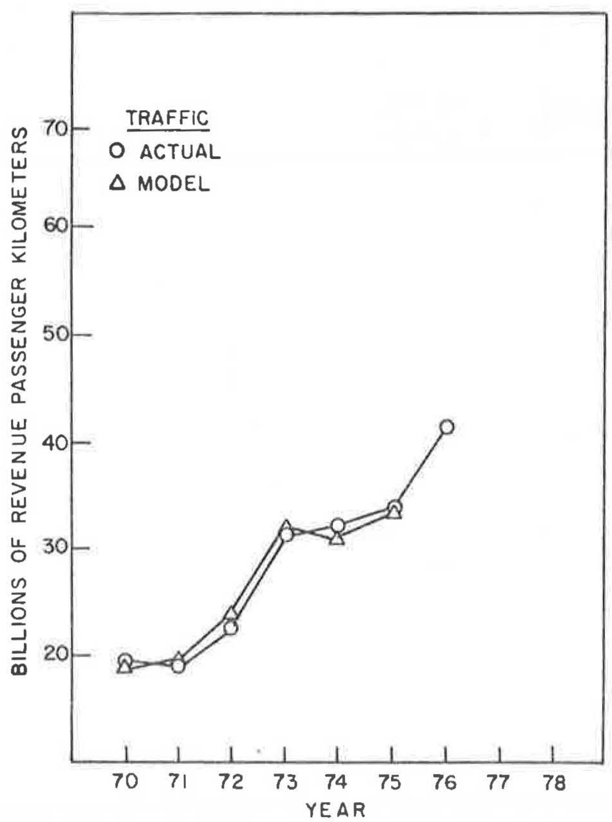


Figure 10. Comparison of actual and model traffic for South Pacific market.

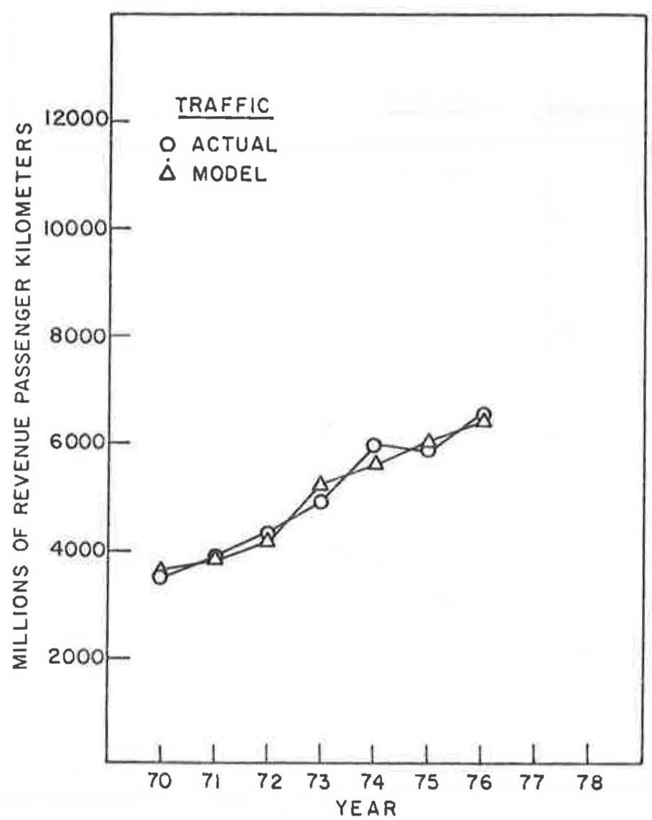


Figure 11. Comparison of actual and model traffic for North Pacific and Mid-Pacific market.

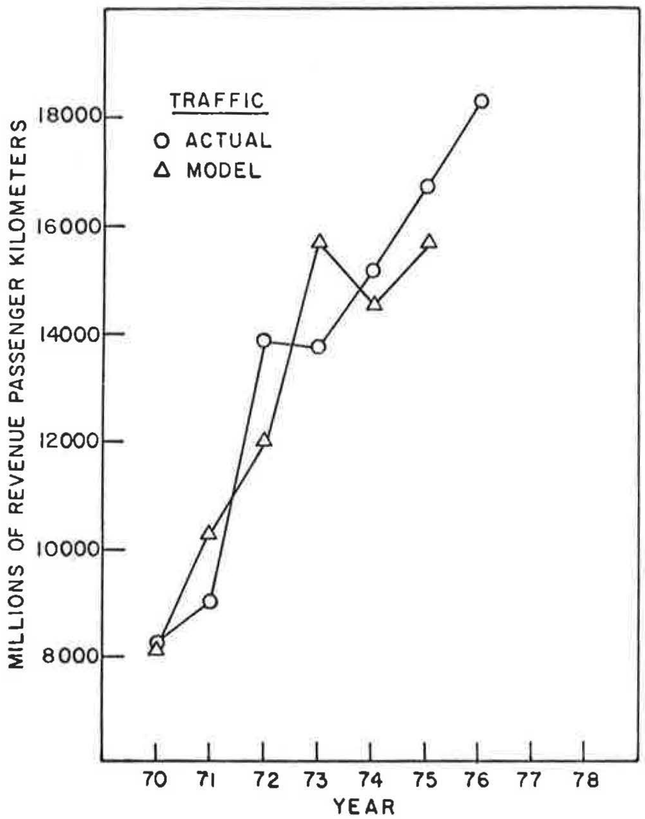
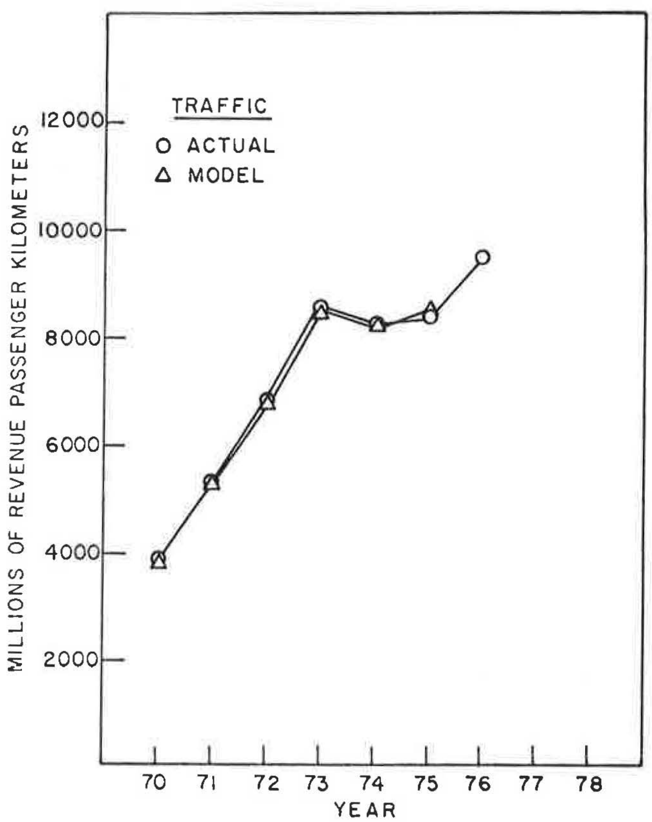


Figure 12. Comparison of actual and model traffic for local Far East/ Australasia market.



sult of a similar trend in trade combined with an increase in real price (as measured by fare) between 1971 and 1973. Weighted disposable income also shows a stagnation in real terms after 1973.

This is probably a market in which the data could permit a more detailed analysis of traffic demand. Country pair modeling is a possibility here. However, for the sake of consistency with the other analysis and with the integrated forecasting process, such an analysis was not attempted.

Europe-Far East/Australasia

The Europe-Far East/Australasia market is a long-haul market that connects two regions that are rather extensive in size and in number of countries. Traffic growth has been rather strong: from 14 billion to 39 billion revenue passenger-km during the 1970-1976 period (see Figure 9). The percentage share of charter traffic has consistently declined, from 22 to 7 percent, during the same period. Since the total traffic trend appears to be rather close to the trend for weighted per capita income, income is used as the demand variable in the model.

This market appears to be dominated by traffic between the United Kingdom and India and Australia and vacation traffic generated in Japan. Trade does not appear to be statistically significant and is not included in the model.

Despite the rather low charter share in recent years, the traffic model includes charter traffic. In using this model for forecasting, assumptions have to be made about charter share in computing passenger revenues and other related performance measures. Inflation is high in this market, and as a result real income growth is low and real yield declines considerably during the study period. This is perhaps another indication that, in order to successfully forecast traffic, a good prediction of the inflation rate is essential.

South Pacific

The South Pacific market is a relatively low-density market that had an average traffic volume of only about 5 billion revenue passenger-km during the study period. Growth has, however, been steady: Traffic increased from 3.5 billion revenue passenger-km in 1970 to about 6.6 billion revenue passenger-km in 1976 (see Figure 10). Although this market includes the South Pacific islands, which are typically tourist attractions, business traffic appears to dominate the market. It can be seen from the historic trends for this market that traffic volumes follow a pattern very similar to that followed by total trade between the countries of the market (here taken as the United States, Canada, the western hemisphere, and Australia and New Zealand). Attempts to include a nonbusiness demand variable such as income in the model did not prove successful. However, the model, with trade and yield as the only variables, is highly significant statistically and appears to be adequate for short-term forecasting. It would be desirable to recalibrate the model by using additional traffic data to see whether income would enter significantly as a nonbusiness traffic demand variable.

The South Pacific market exhibits relatively high inflation, as indicated by the large composite consumer price index. Consequently, real yield declines appreciably during the study period, and real trade does not show much growth. The decline in real yield results in a decline in yield elasticity, as would be expected from the form of the model. But the magnitude of elasticity is rather high, around -1.50, for a market with a good proportion of business traffic. This is probably attributable to the fact that the decline in real yield is taken as a reason for the strong growth in traffic, since real trade does not grow appreciably in real terms. Another reason is that this is a market with a very large stage length. Fare levels are rather high, and one would expect demand to be relatively elastic.

Charter traffic in the South Pacific market makes up an insignificant proportion of the total traffic—5 percent during the 1970-1976 period. For this reason, charter traffic is not included in the model.

North Pacific and Mid-Pacific

The traffic demand model for the North Pacific and Mid-Pacific market (see Figure 11) has been rather difficult to calibrate. The traffic level is generally rather low but underwent strong growth between 1970 and 1976, rising from 8 billion to more than 18 billion revenue passenger-km. Traffic in 1972 appears to be unexpectedly high, equaling the value in 1973. This cannot be explained by the trends of any of the socioeconomic variables used in the analysis. Indeed, what appears as a decline in traffic in 1973 is associated with a growth in real income. Real yield increased in 1972, as did traffic. All of this leads one to suspect a data problem, but there is no means of checking such a suspicion.

The share of charter traffic in the market steadily increased during the study period, rising from 4.5 percent in 1970 to 22 percent in 1974 and then dropping back to 14 percent in 1976. Charter traffic is therefore included in the demand model, and an assumption must be made in the forecasting process about the future charter share.

With traffic in this market dominated by the United States, Canada, and Japan, the variables for these three countries were used to derive the composite values for the model. Income appears to be the only significant demand variable and fare rather than yield to be significant as the price variable. Income elasticity is +4.8, and fare elasticity varies between -2.5 and -1.7 during the 1970-1976 period. Both of these values are considered too large. The absence of trade in a market believed to contain a significant proportion of business traffic is another source of concern about the model for this market. All in all, it would appear that some additional work on this market may be in order.

Local Far East/Australasia

The local Far East/Australasia market covers a larger area than its name might imply: all the area from India eastward to Japan and southeastward, including Australia and New Zealand. Any analysis of this market is then, by necessity, very aggregate. It is a relatively low-density market: Passenger traffic amounts to approximately 8.5 billion revenue passenger-km which, considering the medium stage lengths, is rather low (see Figure 12).

The market has relatively high load factors; load factors varied from 57 percent in 1970 to 60 percent in 1976. This indicates that capacity may be a constraint on traffic development. Indeed, the analysis indicates capacity to be a significant variable in the demand model, with an elasticity of +0.8. The other demand variable in the model is weighted per capita disposable income, which indicates that nonbusiness traffic may predominate. Income elasticity is low at +0.62, which probably results from the fact that capacity has explained a good part of traffic development. The traffic trend, which shows a period of stagnation between 1974 and 1976, is very similar to the trend for income. Inflation rates in the market are rather high: The composite consumer price index rises from 100 to 200 during the study period.

Note that the income variable in this case is not a weighted composite but that of Japan alone. Since a sizable proportion of the traffic is vacation traffic generated in Japan, this is not too restrictive.

Price is represented by the Tokyo-Bangkok economy fare. This was found to be appropriate because this market does not have any significant choices in terms of fares or any charter operations to speak of. Again, capacity increases seem to explain a significant proportion of the traffic development, and fare elasticity appears to be low—in the -0.29 to -0.27 range. Fares have almost doubled during the study period, but the high inflation rates result in a decline in real fares.

SUMMARY

The results of the calibration of traffic demand models for 12 of the 13 study markets appear to be generally good. In fact, given the nature of the data base and the vastly varied conditions that exist in the various world travel markets, the results are surprisingly good. With the exception of the North Pacific and Mid-Pacific market and the North America-Central America market, all models appear to be statistically significant and to exhibit good fits with historic trends. It is interesting that model structures and, to a certain extent, parameter values are quite similar. For example, most yield elasticities fall within less than 1.0 of one another; fare elasticities vary by slightly more.

It would seem that, although further work on traffic demand modeling in these international travel markets is certainly warranted, use of the current models in short-term forecasting is feasible. The good statistical results obtained by using these models show rather low standard error values and permit forecasting with confidence.

More work should be done on the Europe-Middle East market, but such work is feasible only if additional data are obtained. Both socioeconomic variables and carrier data appear to be lacking for this market, and it is a market that must be modeled with particular care because of the significant changes in traffic that have occurred in recent years. Two other markets need further work: the North Pacific and Mid-Pacific and the North America-Central America markets. With additional socioeconomic data, particularly for the North Pacific and Mid-Pacific markets, it might be possible to successfully calibrate a traffic demand model. These two markets have been integrated in the forecasting process, but their results should be looked at with more skepticism than those for the other markets.

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Cost Forecasting for International Airline Operations

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Cost models are constructed and calibrated to describe airline operating costs in selected international markets. These models are then used to demonstrate how operating costs can be forecast for relatively short time horizons, such as three years. The models confirm the concept that operating costs in different markets of the world air transportation system are significantly different. The reasons for this include the geographic characteristics of the different markets in terms of stage lengths and network structure and the differences in input prices for items such as fuel and labor. Fleet mix is also an important determinant of operating costs. The use of wide-body aircraft is seen to have a significant impact on reducing airline operating costs. Recently, operating costs have tended to decline in real terms but to increase in current terms. The forecasts made for a three-year period indicate that these trends might continue. These forecasts, however, are strongly dependent on assumptions regarding fuel prices.

In an era of technological and economic change in air transportation, it has become even more important than before to assess current operating costs and to forecast future costs. Analysis of air transportation policy has become more dependent than ever on a sound understanding of the factors that affect costs. Air fares have to be justified on the basis of airline costs and, in view of the novel pricing approaches that are evident in many air transportation markets, cost analyses have become indispensable.

Other policy analyses in which cost forecasts constitute an important input include the planning of airline capacity, the planning of fleet renewal and aircraft acquisition, agreements between carriers or governments on capacities and fares, and financial planning for airline operations. Cost forecasts provide a basis for pricing and for financial planning for the year of the forecast. In other aspects of airline policy analysis, the comparison of cost and revenue forecasts provides the basis for evaluating the potential performance of a carrier or a market.

In this paper, a system of cost models is presented that is used to forecast airline operating costs in 13 markets that cover the majority of world air transportation activities. Forecasts made by using these models are presented as illustrations. These forecasts depend on specific assumptions, or scenarios, concerning the economic factors that affect costs and that are exogenous to the policy framework in question.

HISTORIC TRENDS OF AIRLINE COSTS

The evolution of airline operating costs in the past decade is characterized by two features. The first is the continuous decline in real operating costs until 1973 and 1974, when the sharp increase in fuel price reversed the trend. Thereafter, the tendency of costs is again toward stabilization and a decline similar to, albeit not as rapid as, that preceding the 1973-1974 period. The second feature is the sharp quantum jump in operating costs brought about in the 1973-1974 period by increases in fuel prices. The rise in costs is significant even when measured in real terms. In many markets, 1974 operating costs in real terms were brought back up to their 1964 levels, and the results of 10 years of technological advances and productivity increases were lost. The 1973-1974 increases in fuel prices were responsible, however, for bringing about some changes in operating technologies that resulted in a decrease in operating costs. The most important of these is the common practice of speed reduction, which resulted in significant savings in fuel consumption per unit of output. Another interesting result of the fuel price change is that, in many markets of the world and for the first time, direct operating costs exceeded indirect costs, which would indicate that improving the efficiency of flight operations became relatively more important for reducing costs than improving managerial and support-activity productivity.

These features of operating-cost trends are clearly visible in the charts shown in Figures 1 and 2. Figure 1 shows trends in operating costs for the South Pacific (North America-Australasia) market for the period 1969 to 1976. It is interesting to note that by 1976 complete recovery from the effects of the fuel price increases of 1973 and 1974 was achieved, and a level of operating cost was achieved that could have been a continuation of the decline from 1969 to 1973. It is possible, of course, that all of the technological possibilities for cost reduction were used to achieve this recovery, such as speed reduction, increased use of wide-body equipment, and higher-density seating. If this were the case, further decreases in costs would become more difficult to achieve. Figure 2 (1) shows a similar operating-cost history for the U.S. domestic trunks for the period 1964 to 1975. Although domestic trunk operating costs are generally lower than those for the South Pacific market, the same general trends are observed.

The reasons for the decline in operating costs can be found in two factors, both of which are related to improvements in aircraft technology and airline operating efficiency. The first is the increase in fuel efficiency brought about by the introduction into the fleet of wide-body aircraft. This results from both the economy of scale of aircraft size and the more efficient engines that equip such aircraft. Figure 3 (1) shows trends in fuel efficiency for the domestic trunks of the United States. Similar fleet-changing trends in international operations are resulting in similar improvements in fuel efficiency for these operations. The two noticeable downward jumps in the curve shown in Figure 3 are caused by the introduction of wide-body aircraft in 1970 and the reduction in speeds that occurred in 1974.

The second factor that contributes to the reduction in operating costs is the increased labor productivity of airlines. Aided by such innovations as computer ticketing and reservation systems, airlines have been able to increase output faster than labor inputs. This is also caused by the introduction of larger aircraft, which have definite economies of scale. Figure 4 (1) shows a trend in airline labor productivity for U.S. domestic trunks. Jumps similar to those observed in the fuel-consumption trends are evident here as well.

It may be evident that technological advances have contributed to the reduction or at least the stabilization of airline operating costs and that with current technology the airlines can be said to have managed to absorb the effects of fuel price increases. But the crucial question for cost forecasting is whether such technological improvements have been exhausted, so that costs will start rising again, or whether there remain further opportunities to cope with current inflationary trends and maintain stability in those costs. This question is addressed here by analyzing costs in selected international air transportation markets and by constructing explanatory models of their evolution. These models are then used to forecast costs on the basis of plausible scenarios of the technical and economic environment of international air transportation.

ANALYSIS FRAMEWORK

Operating costs can be analyzed either by carrier or by market and can be based on time-series or cross-sectional information. In this study, the analysis of costs is based on time-series information for two reasons:

1. Different world markets are likely to differ significantly in their technical and economic operating environments. Even the same airline is likely to have different operating economics in different world markets. To pool all markets together in a cross-sectional analysis would mask many potentially very important determinants of operating costs.
2. This study is aimed at forecasting trends, and time-series analysis is more suitable for investigating cost trends and future potentials. What cross-sectional analysis does is to reveal any scale characteristics and permit the quantification of scale economies. In this case, however, no significant scale economies are expected, as many previous studies seem to indicate (2, 3).

The only cross-sectional analysis done here is in the comparison of costs by carrier and by market to determine which classification is more suitable for cost modeling.

Clearly, most policy analysis is done at the carrier level. Thus, cost forecasting needs to be performed at that level in order to be useful in such analysis. But, since there is strong suspicion that there are important intermarket differences that cannot be ignored, it fol-

Figure 1. Trend of average operating cost per available seat kilometer for the South Pacific market.

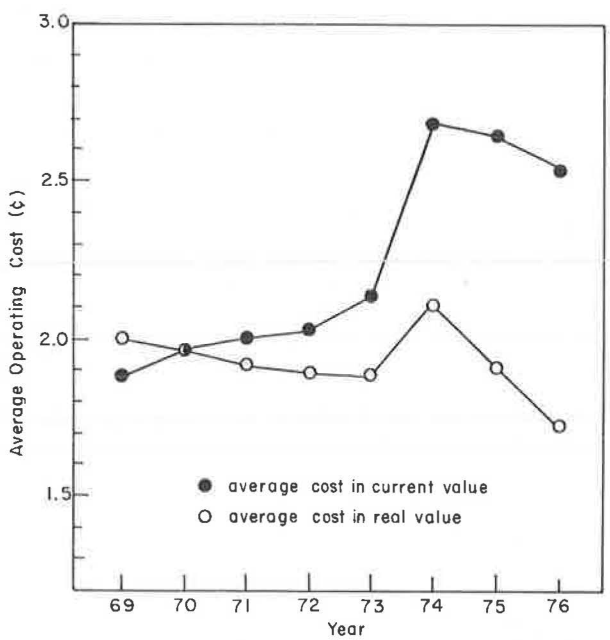


Figure 2. Trend in total real operating costs per unit of distance.

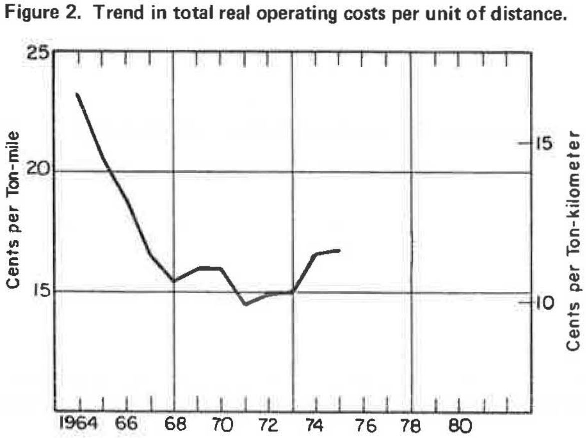


Figure 3. Trends in fuel consumption.

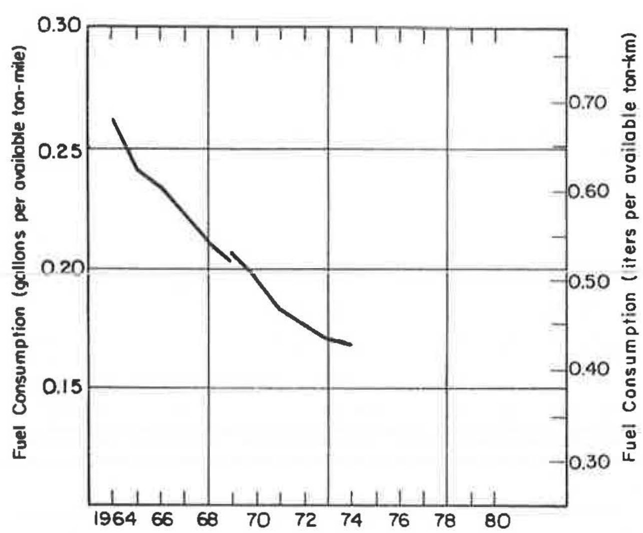
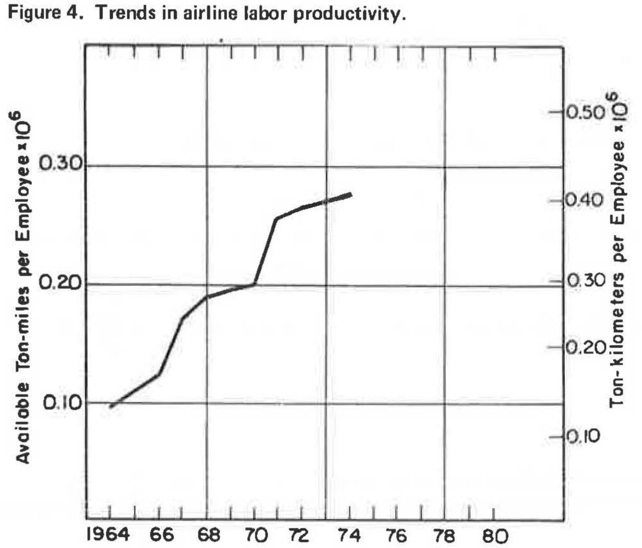


Figure 4. Trends in airline labor productivity.



lows that the analysis should be performed by carrier and separately for each market. Such analysis would require excessive information regarding the economic factors that affect each carrier's cost function in each market. For this reason, it was necessary to limit the scope of the analysis to only one dimension—that is, either market or carrier. After an investigation into the historic evolution of costs in 13 international air travel markets, it became clear that the variations in costs between markets were significantly larger than the variations in costs between carriers within each market. Since two of the major inputs—fuel and labor—are secured locally and their costs vary from place to place, this is the expected result. The models are therefore constructed to estimate total operating costs per available seat kilometer or available ton kilometer on a market-by-market basis.

Market Definition

A market is usually defined on the basis of a region pair; each region might include a number of countries of geographic proximity. In this study, 13 world markets are defined to cover more than 90 percent of total world revenue passenger kilometers of traffic. For the sake of brevity, the results for five markets are presented:

1. North Atlantic—traffic between North America and Western Europe and points beyond,
2. North America-South America—including for South America only countries south of Panama,
3. South Atlantic—traffic between Europe and Africa on one end and points in America south of Rio de Janeiro on the other end,
4. Europe-Middle East—traffic between Western Europe and points in the Middle East no further east than Tehran and including Egypt, and
5. South Pacific—traffic between America and points in the Pacific south of Hawaii, including Australia and New Zealand.

Data Base

The data used in the study were compiled as part of a larger data-management system for the analysis of international air transportation policy that has been developed at the Institute of Transportation Studies of the University of California, Berkeley. Included in the data base are total operating costs for the period 1969 to 1976, data on total capacity in each market, and fleet mix, fuel price, seating configurations, and inflation rates in selected countries that represent each market. For some markets, data were available on a carrier basis. These were used to compare the variations between carriers with those between markets to determine the feasibility of analysis by market (4).

ANALYSIS

The cost trends for the markets are shown in Figure 5. A remarkable similarity is observed in these trends. For all five markets, costs in 1969 appear to have been in the neighborhood of 2 cents/available seat kilometer (3.2 cents/available seat mile) and to have experienced a major upward jump in the 1973-1974 period, presumably because of the increase in fuel costs (throughout this paper, seat kilometers and seat miles indicate available capacity). By 1976, costs in these markets appear to be closer to 3 cents/seat-km (5 cents/seat mile), except in the Europe-Middle East market, where they are 4 cents/seat-km (6.4 cents/seat mile), and the

Figure 5. Comparison of average operating costs per available seat kilometer in different markets.

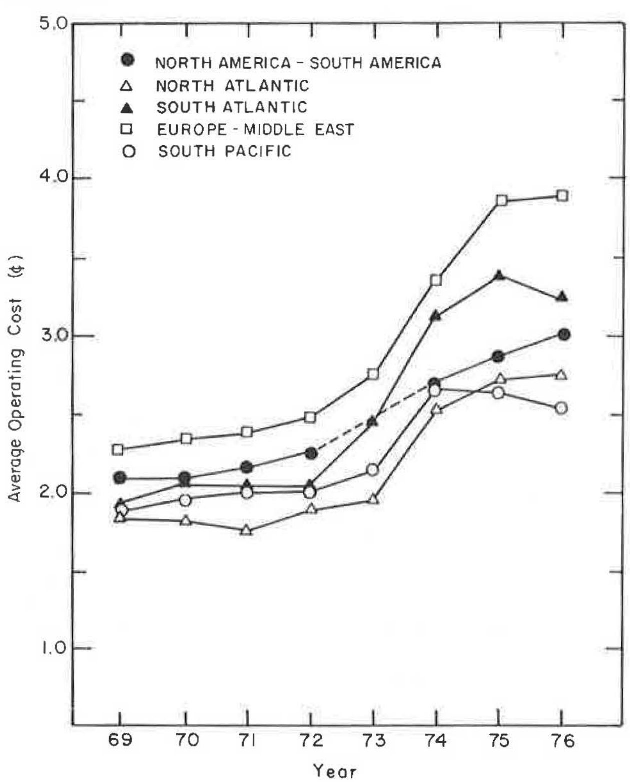
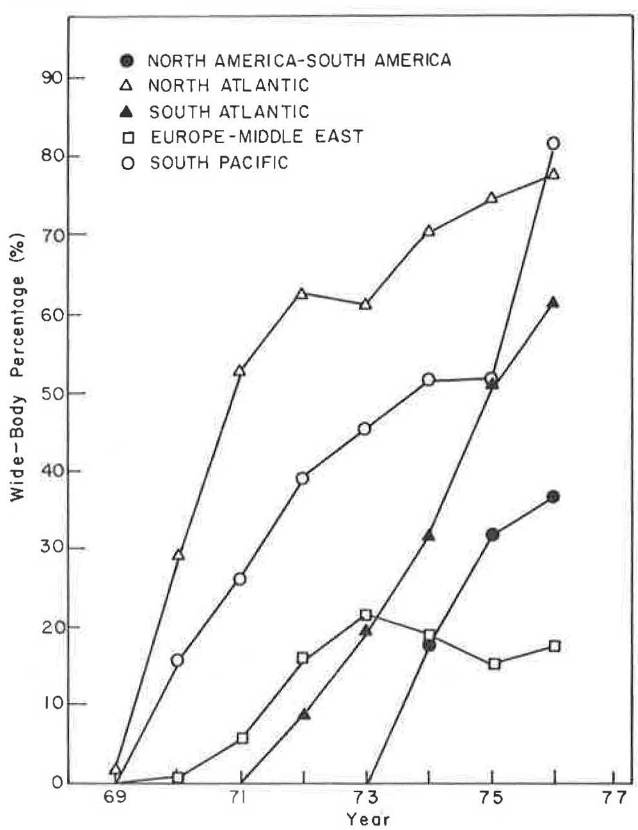


Figure 6. Comparison of wide-body percentages for different markets.



South Pacific market, where they are closer to 2.5 cents/seat-km (4 cents/seat mile). The differences between market trends are to be sought in the differences between some of the exogenous variables that affect costs in these markets. For that reason, and in order to permit the forecasting of costs, cost models are calibrated.

The explanatory variables for the cost models are allowed to vary from market to market. It appears from the results, however, that some explanatory variables are significantly universal. Fuel price is perhaps the single most important such variable and explains to a large extent the jump observed in costs in the 1973-1974 season. Other variations in costs have been explained by changes in fleet mix. In particular, the percentage of wide-body aircraft in the fleet appears to be significant in many markets. In fact, if one looks at Figure 6, which shows the historic trend of this variable, one sees the strong correlation between it and total operating costs. The North Atlantic market, which has the lowest costs, has the highest percentage of wide-body aircraft; conversely, the Europe-Middle East market, which has the highest costs, has the lowest percentage of wide-body aircraft. Seating configuration, represented by the percentage of total first-class available seat kilometers, appears in some markets. Finally, total capacity is examined to explain some of the cost variations.

As mentioned earlier, no significant economies of scale are expected. However, in some low-volume markets, it may be possible to find such economies because such markets would still be in the early stages of growth and might gain some cost advantages from capacity expansions. Thus, although one might not expect economies of scale in a market as mature as the North Atlantic market, it would be no surprise to find such characteristics in markets such as the Europe-Middle East market.

COST MODELS

In its simplest form, the cost model will have a linear specification with a constant term that indicates a fixed average operating cost per available seat kilometer and an additive modifier that reflects the effects of the exogenous variables. In markets that have scale economies, one of these modifiers will be capacity in available seat kilometers. The calibrations of the models for the five markets are discussed separately below.

North Atlantic

The North Atlantic, a mature market, has the largest annual volume of any international market. In 1976, North Atlantic carriers supplied 96 billion seat-km (60 billion seat miles) and carried almost 16 million passengers. The large proportion of wide-body aircraft in the North Atlantic fleet contributes to lowering average operating costs. The increase in costs shown in Figure 5 is attributable mostly to increased fuel prices. In attempting to isolate the effects of inflation, and since the forecasting of inflation rates is not within the scope of this analysis, costs are analyzed in real terms. To do this, a composite price index is constructed by weighing the price indices of eight countries in the North Atlantic market, including the United States, Canada, and six Western European countries.

The resulting linear model of real costs for the North Atlantic is

$$\begin{aligned} AVC &= 1.8234 - 0.005\,86(WB) + 0.3054(OIL) \\ &\quad (0.037)\ (0.0008)\ (0.0089) \qquad R^2 = 0.905;\ F_{(2,5)} = 24.0 \end{aligned} \tag{1}$$

where

AVC = average cost (cents/seat-km),
WB = percentage of total capacity in wide-body aircraft, and
OIL = price of U.S. no. 6 at New York Harbor ($\$/m^3$).

Figures in parentheses below the equation line are standard errors of the estimated parameters.

The results of this calibration are shown in Figure 7. In real terms, it is apparent that operating costs in the North Atlantic have not increased over the past seven years. In this market, increased use of wide-body aircraft is an important determinant of this result. The significance of wide-body equipment is not only that the larger aircraft offer scale economies in the production of seat kilometers but also that these aircraft are more fuel efficient and therefore permit carriers to absorb increases in fuel prices more easily than they could if they used smaller aircraft. For this reason, one would be tempted to specify a model with an interaction term between the two variables. Such an attempt does not seem to produce any statistically significant results, however, and the simpler linear cost model is preferred for forecasting purposes.

North America-South America

The North America-South America market is much smaller than the North Atlantic market, with 13 billion seat-km (8 billion seat miles) in 1976. It is characterized by the absence of wide-body aircraft until 1974, but it is favorably affected by lower fuel costs in Venezuela, where a sizeable proportion of the traffic passes. The low volume in this market suggests that economies of scale may still be present. Indeed, in a linear model of costs in the North America-South America market, available capacity appears with a significant, albeit small, effect:

$$\begin{aligned} AVC &= 2.9478 - 0.021\,215\,(WB) + 1.997\,(OIL) - 0.000\,189\,(ASK) \\ &\quad (0.415)\ (0.0061)\ (0.0952)\ (0.000\,06) \\ &\quad R^2 = 0.97;\ F_{(3,3)} = 33.9 \end{aligned} \tag{2}$$

where OIL is the price of fuel ($\$/m^3$), averaged for the United States and Venezuela, and ASK is available capacity in seat kilometers. All other variables are as indicated for the previous model. The real-term costs are obtained by using a price index based on a weighted average for Canada, the United States, Colombia, and Brazil.

The results of this calibration are shown in Figure 8 (data for 1973 are missing). Again, it can be seen that significant reductions in real costs have been possible in this market. The sharp increase in the use of wide-body aircraft, the increase in capacity, and the use of some scale economies are probably responsible for that. By 1976, the percentage of wide-body aircraft in this market had increased from 0 percent in 1973 to 36 percent of the total fleet; this contributed to a total decrease in real operating costs of almost 0.7 cent/seat-km (1 cent/seat mile). The low 36 percent figure, in comparison with the 80 percent of the North Atlantic market, indicates that a potential exists for further reduction in costs.

Available capacity in the North America-South America market increased from 9 billion to 13.5 billion seat-km (from 5.6 billion to 8 billion seat miles) in the period between 1969 and 1976. This increase contributed approximately 0.8 cents to the decrease in real operating costs. Whether such scale economies can be expected to continue in future years is not clear. Further analysis of cost trends in future years is needed to determine the extent to which these scale characteristics will continue.

The price of oil has an important effect on total costs in this market. Variations in real fuel price in the period of the analysis resulted in an increase in real operating costs of approximately 0.8 cent/seat-km (1.3 cents/seat mile).

South Atlantic

The South Atlantic market has an even smaller traffic volume than the North America-South America market. In 1976, total traffic in the South Atlantic market amounted to 5.5 billion revenue passenger-km (3.4 billion revenue passenger miles), and total capacity was 11.3 billion seat-km (7 billion seat miles). This market has experienced strong growth, however; 1976 volumes were almost double those of 1970. Although operating costs have risen sharply in market value (Figure 5), inflation rates in both Western Europe and the southern portions of South America (particularly Brazil) have been of such magnitude that real-term costs have in fact declined appreciably.

The cost model calibrated for this market has the same structure and specification as the previous one:

$$AVC = 2.2914 - 0.007\,(WB) + 0.6447\,(OIL) - 0.000\,095\,(ASK)$$
$$(0.168)\quad(0.0026)\quad(0.018)\quad(0.000\,023)$$
$$R^2 = 0.978;\ F_{(3,4)} = 59.3 \qquad (3)$$

The results of the calibration of this model are shown in Figure 9, where the sharp difference in the cost trends in real and current terms is clear. A rather sharp increase in the use of wide-body aircraft is instrumental in reducing real operating costs. Wide-body mix in the South Atlantic fleet increased from 0 percent in 1971 to 60 percent in 1976, and this contributed to the reduction of real operating costs by 0.42 cent/seat-km (0.67 cent/seat mile). The small effect of available capacity is indicated by the small (but significant) parameter value. The sharp increase in South Atlantic capacity from 4.9 billion to 11.2 billion seat-km (from 3 billion to 7 billion seat miles) during the analysis period contributed to a reduction of 0.6 cent/seat-km (0.96 cent/seat mile). With a net decline in total operating costs of 0.8 cent/seat-km (1.3 cents/seat mile), it follows that increases in fuel price resulted in an increase of real operating costs of only 0.2 cent/seat-km (0.32 cent/seat mile).

Europe-Middle East

The Europe-Middle East market is characterized by a sharp increase in traffic and capacity during the period of analysis. Total traffic rose from 3.9 billion to 9.4 billion revenue passenger-km (from 2.4 billion to 5.8 billion revenue passenger miles), and during the same period available capacity increased from 8.3 billion to 15.4 billion seat-km (from 5.1 billion to 9.5 billion seat miles). Interestingly, wide-body aircraft were not in common use until 1976. As Figure 6 shows, wide-body aircraft never constituted more than 15 percent of the total fleet in the market and, in fact, declined between 1973 and 1976.

Figure 5 shows that the Europe-Middle East market was consistently the market with the highest operating costs. Not surprisingly, the calibrated model for this

Figure 7. Actual and modeled operating costs per available seat kilometer: North Atlantic.

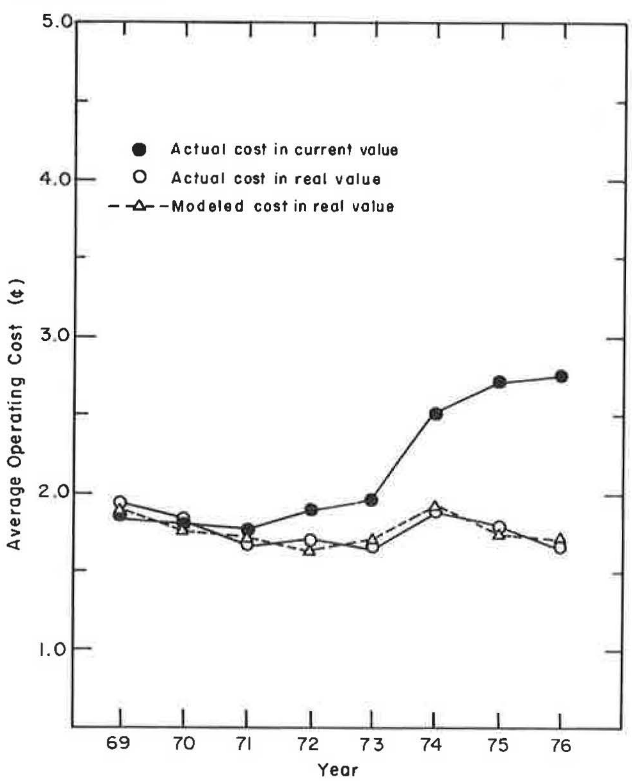
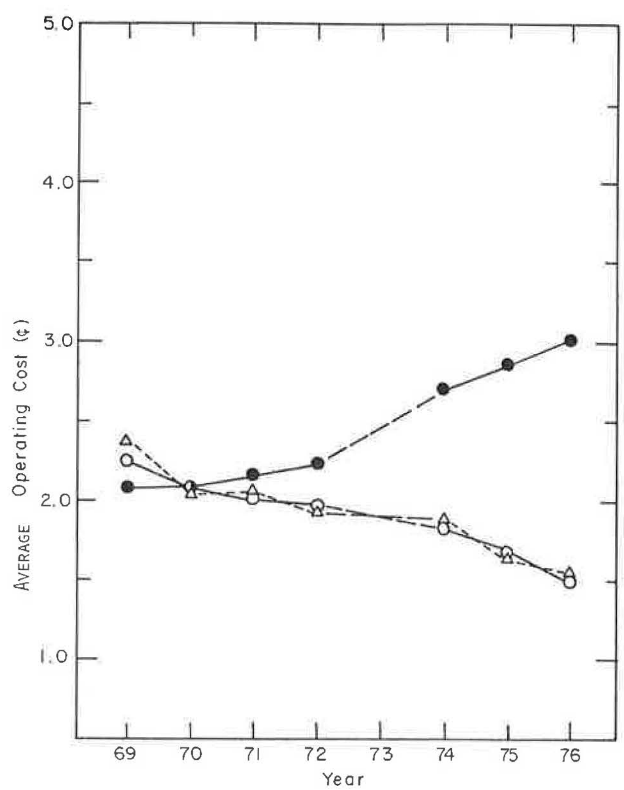


Figure 8. Actual and modeled operating costs per available seat kilometer: South Atlantic.



market does not include a WB variable:

$$AVC = 3.1462 + 0.2727\,(OIL) - 0.000\,119\,(ASK)$$
$$(0.0608)\quad(0.011)\quad(0.000\,01) \qquad R^2 = 0.98;\ F_{(2,5)} = 19.8 \qquad (4)$$

The calibration results of this model are shown in Figure 10, where, again, the effects of high inflation rates are shown in the large differences between costs in real and current terms. Economies of scale are probably the principal factor that permits costs to rise at a rate slower than that of inflation. Capacity increase according to this model was responsible for a reduction in real operating costs of approximately 1 cent/seat-km (1.6 cents/seat mile). The effect of trends in fuel prices in this market is much less than that in the other markets.

South Pacific

The South Pacific market has a medium traffic level and is characterized by relatively longer stage lengths than many of the other markets studied. It experienced strong growth during the analysis period: Traffic and capacity doubled between 1969 and 1976. The relatively lower operating costs of this market are probably due to the longer stage lengths in its operations, although there are a number of multiple-stop routes in it. Operations in this market do not exhibit any economies of scale, as shown in the following calibrated cost model:

$$AVC = 1.8914 - 0.006\,25\,(WB) + 0.311\,(OIL)$$
$$(0.027)\quad(0.0007)\quad(0.006) \qquad R^2 = 0.94;\ F_{(2,5)} = 39.2 \qquad (5)$$

The results of this calibration are shown in Figure 11, where it is seen that, because of the relatively low U.S. inflation rates, the difference between real and current costs is not as large as it is for the other markets. Changes in fleet mix contributed significantly to the reduction in real operating costs. The percentage of wide-body aircraft in the South Pacific rose from 0 percent in 1969 to 81 percent in 1976 and contributed to a reduction in operating costs of approximately 0.5 cent/seat-km (0.8 cent/seat mile) in real terms.

COMPARATIVE INTERPRETATIONS

Some insights into the evolution of airline operating costs can be gained from a comparative evaluation of the results of the model calibrations for the five study markets. First, the table below compares the current and real (1970 value) costs for the five markets in 1976 (1 cent/seat-km = 1.6 cents/seat mile):

Market	Cost (¢/seat-km) Current	Real	Deflator
North Atlantic	2.753	1.650	1.663
North America-South America	3.009	1.498	2.008
South Atlantic	3.225	1.271	2.537
Europe-Middle East	3.896	1.766	2.206
South Pacific	2.531	1.726	1.466

As mentioned earlier, the deflators used in calculating real costs are based, for each market, on an average of the consumer price indices for a selected number of representative countries in the market, weighted by the capacity offered by the carrier of each of these countries. The values of these deflators are shown in Figure 12. Notice that, although there are wide variations in current operating costs between the markets, the values in real 1970 terms are much closer to their mean value of 1.579 cents/seat-km (2.5 cents/seat

Figure 9. Actual and modeled operating costs per available seat kilometer: South Atlantic.

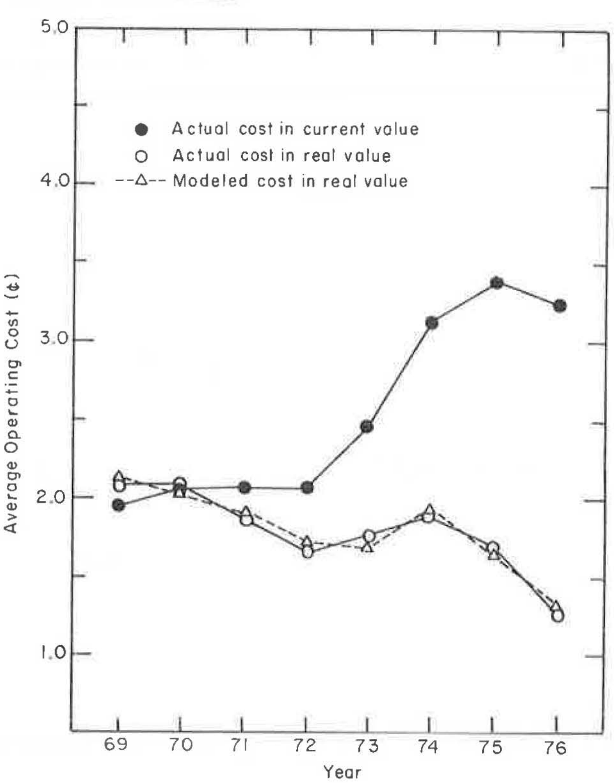


Figure 10. Actual and modeled operating costs per available seat kilometer: Europe-Middle East.

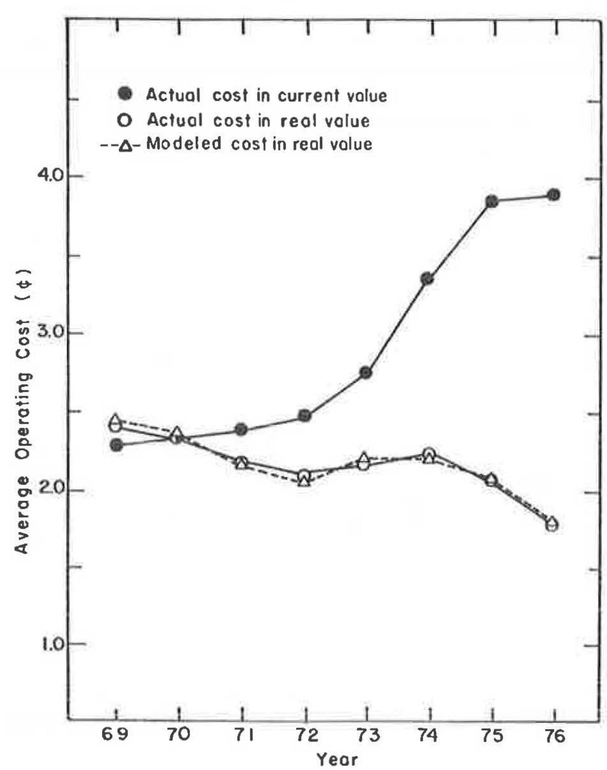


Figure 11. Actual and modeled operating costs per available seat kilometer: South Pacific.

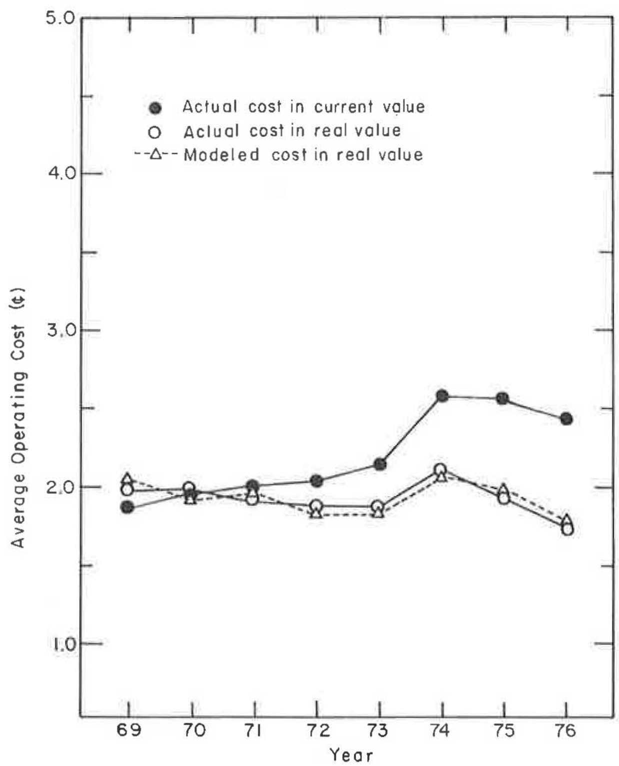
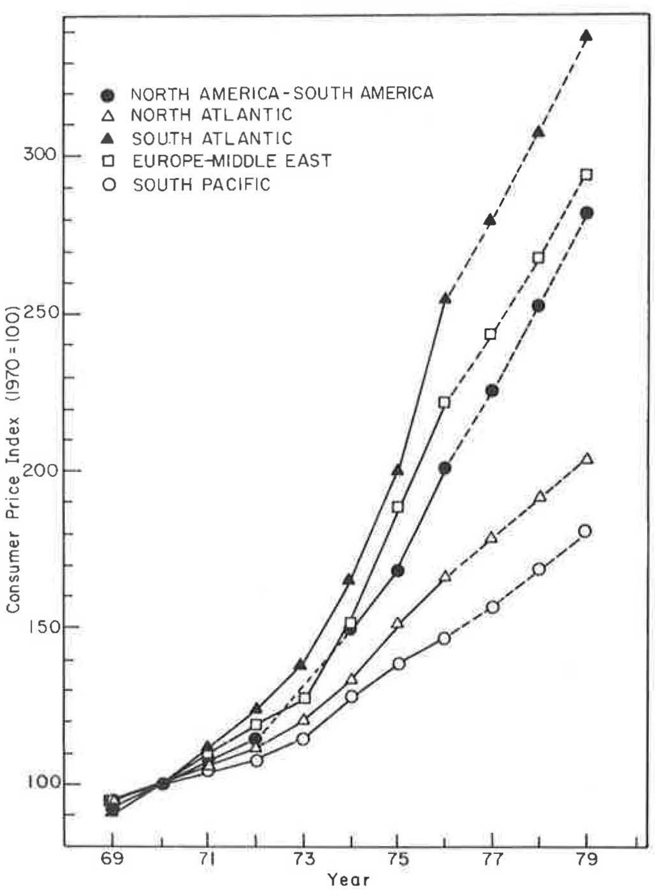


Figure 12. Actual and forecast consumer price index for five markets.



mile). This value is lower than the actual cost average in 1970—2.05 cents/seat-km (3.3 cents/seat mile)—which indicates that a significant reduction in real costs has been possible in these markets during the period from 1970 to 1976. Put in another way, it has been possible to keep the increase in operating cost to a rate lower than that of inflation. This also indicates that operating costs are "higher" in markets where everything else is costlier (as shown by the higher inflation index), markets such as the Europe-Middle East or the South Atlantic markets. If anything, this seems to indicate that there are not as many technological differences in the production of air transportation between the various markets as would be implied by the large variations in current-value operating costs. If that is the case, one cannot expect any more technological opportunities for cost reduction in the newer markets than in the more mature ones. Real operating costs in the North Atlantic and Europe-Middle East markets were indeed very close in 1976: 1.65 and 1.76 cents/seat-km (2.6 and 2.8 cents/seat mile), respectively.

A comparison of the effects of the various exogenous factors on cost trends for the five markets, as indicated by the elasticities of the cost function, is given below:

Market	Elasticity		
	Percentage Wide Body	Oil Price	Capacity
North Atlantic	-0.275	0.185	—
North America-South America	-0.51	1.275	-1.710
South Atlantic	-0.336	0.400	-0.847
Europe-Middle East	—	0.279	-1.045
South Pacific	-0.295	0.200	—

Since the cost functions are linear, implying variable elasticities, the elasticity values for 1976 are calculated for comparison. It is interesting to note the relatively small ranges for the elasticities with respect to wide-body fleet mix and capacity, the former being significantly lower than the latter. This does not, however, mean that capacity increase has had a more important effect on costs than fleet-mix changes, since the incremental changes in capacity are relatively much smaller than those of the percentage of wide-body aircraft. As mentioned earlier, capacity nearly doubled in all five markets during the 1969-1976 period, whereas the percentage of wide-body aircraft increased much more than that in all markets except the Europe-Middle East market.

An interesting feature of the elasticity values is revealed when one compares the elasticities of oil price and capacity for the North America-South America market with those for the South Atlantic market. These elasticities for the North America-South America market are large, which implies the presence of large but compensating effects of fuel price and capacity. For the South Atlantic market, the two elasticities are relatively small, which indicates that no single effect is dominating. It is hard with the present data base of seven yearly cost figures to infer much from this and other comparisons. Even though the parameter values obtained are highly significant, additional data would be needed to improve confidence in the parameter values and to allow more elaborate comparisons.

FORECASTING SCENARIOS

To forecast operating costs in the five study markets, it is essential to define, by assumption or by policy, the values of the exogenous variables of the cost models. There are in fact two types of variables: exogenous economic variables and policy variables. The former are outside the scope of airline policymakers, and their values for forecasting have to be assumed. The latter are under the control of policymakers, and their values are associated with a set of policies for which the forecasts are needed for evaluation.

The exogenous economic variables in the cost models include the inflation rate and the price of fuel. In dealing with these two variables, a basic assumption is made—that fuel prices will increase by the same rate as inflation, as measured by weighted consumer price indices, and will in effect remain constant in real terms. This assumption is made for all five markets and is only considered valid for the duration of the forecast, which extends through 1979. The assumptions regarding the inflation rates themselves are made essentially by projecting recent trends in the consumer price indices. When forecasting for such a short range as in this case (three years), simplifying assumptions of this type can be made without too much loss of confidence in forecasts.

The policy variables included in the cost models are available capacity in seat kilometers and the percentage of operations that is provided in wide-body aircraft. The determination of the values of these variables for planning is a major part of the airline planning problem, and it is here that the forecasts of cost can be helpful. In other words, the values used in a forecast should be thought of as policy alternatives subject to an evaluation, and the cost forecasts that correspond to these values are inputs to the evaluation process. Of course, it often happens that these variables are predetermined by other policies or constraints. For example, a constraint on fleet expansion may force a carrier, or carriers, to keep capacity unchanged or not to change the percentage of wide-body aircraft. In such cases, the values for cost forecasting are set and no assumptions are necessary. Other policy scenarios are possible in which a freeze is placed on total operating costs; in such a case, the cost model is used to determine the appropriate capacity and fleet policies required to meet that constraint.

For the forecasts presented here, the policy scenarios described briefly below have been defined for each of the five markets. The values of the assumed policy variables as well as the exogenous economic variables for these markets are given in Table 1. Again, the inflation rates are based on simple projections of recent trends, shown in Figure 12, and fuel prices are assumed to be constant in real terms.

North Atlantic

The North Atlantic market already has a large proportion of wide-body aircraft. An increase of 5 percent is assumed for 1977, and no further increases are assumed for 1978 and 1979. Capacity does not enter into the specification of this model and need not be set for forecasting future average costs. Note, however, that, in order to forecast future total costs, an assumption concerning capacity would be necessary.

North America-South America

There exists a further potential for increasing the use of wide-body aircraft in the North America-South America market. Many of the South American carriers operating in it are still in the stages of relatively vigorous fleet expansion. For this reason, the scenarios assumed for this market include a 10 percent increase in wide-body aircraft in 1977 and 5 percent increases in 1978 and 1979. Much of this increase will be the result of fleet replacement rather than pure expansion. Capacity will therefore not increase as fast. It is assumed that capacity in this market will increase by 5 percent in 1977 and 1978 and will not increase in 1979.

South Atlantic

Similar conditions exist in the South Atlantic market for the evolution of the fleet, and the same values pertain for the percentage of wide-body aircraft as those assumed for the North America-South America market: 10 percent in 1977 and 5 percent in 1978 and 1979. However, if the latest trends are any indication, capacity increases will be larger in this market. It is assumed that available seat kilometers would increase 10 percent in 1977 and 5 percent in 1978 and 1979.

Europe-Middle East

In the Europe-Middle East market, wide-body aircraft do not enter into the specification of the cost model, a situation that, as mentioned earlier, must reflect past trends and suggests strongly that the models be reevaluated by using more recent results. In any case, no assumption is made for this forecast concerning the percentage of wide-body aircraft. Capacity increases are assumed to be similar to those of the South Atlantic market, since both markets show vigorous, but not necessarily staggering, growth. Thus, 10, 5, and 5 percent are the assumed increases in capacity in this market in 1977, 1978, and 1979, respectively.

South Pacific

The South Pacific market has fleet characteristics that are similar to those of the North Atlantic market—namely, a large proportion of wide-body aircraft. A similar assumption is therefore made concerning the percentage of wide-body aircraft for the forecasting period: Because of a leveling off of opportunities to increase the use of wide-body aircraft in this short term, a 5 percent increase is assumed for 1977 and no increases are assumed for 1978 and 1979. As for the North Atlantic market, the cost model for this market does not include a capacity variable, and consequently no assumption on that variable is necessary for forecasting average costs.

COST FORECASTS

Forecasts of total average operating costs are obtained for each market for the period 1977 to 1979 by using the scenario values discussed above. These forecasts are given in Table 2 and shown in Figure 13. A range is obtained on each forecast by including the expected value within an interval of width equal to twice the standard error of the estimate.

Although the forecasts show rising costs in current terms, it can be seen, by comparing the data in Figure 13 and in Table 2, that costs will decline in real terms. In other words, costs will not rise as fast as other prices in the markets. Interestingly, the two markets that experience a significant increase in wide-body aircraft—the South Atlantic and North America-South America markets—show a decline in operating costs even in current terms. The Europe-Middle East market, which has no wide-body effect in the cost model, continues to show the highest cost figures and the sharpest rise. It is doubtful whether this will continue much beyond 1979. Recent fleet changes in that market are likely to result in an increased role for wide-body equip-

Table 1. Forecasting scenarios.

		Change (%)			
Market	Year	Percentage Wide Body	Capacity	Unit Price of Fuel	Inflation Rate
North Atlantic	1977	+5	-	+7	+7
	1978	+0	-	+7	+7
	1979	+0	-	+7	+7
North America-South America	1977	+10	+5	+12	+12
	1978	+5	+5	+12	+12
	1979	+5	+0	+12	+12
South Atlantic	1977	+10	+10	+10	+10
	1978	+5	+5	+10	+10
	1979	+0	+0	+10	+10
Europe-Middle East	1977	-	+10	+10	+10
	1978	-	+5	+10	+10
	1979	-	+0	+10	+10
South Pacific	1977	+5	-	+7	+7
	1978	+0	-	+7	+7
	1979	+0	-	+7	+7

Table 2. Forecast average operating cost per available seat kilometer.

	Cost ($)					
	1977		1978		1979	
Market	Forecast	Range	Forecast	Range	Forecast	Range
North Atlantic	2.906	2.866-2.947	3.110	3.071-3.151	3.327	3.289-3.370
North America-South America	2.918	2.857-2.979	2.828	2.768-2.890	3.047	2.988-3.111
South Atlantic	3.139	3.087-3.190	3.205	3.155-3.258	3.526	3.476-3.580
Europe-Middle East	3.844	3.814-3.874	3.961	3.933-3.995	4.358	4.330-4.391
South Pacific	2.668	2.636-2.701	2.855	2.825-2.889	3.055	3.026-3.090

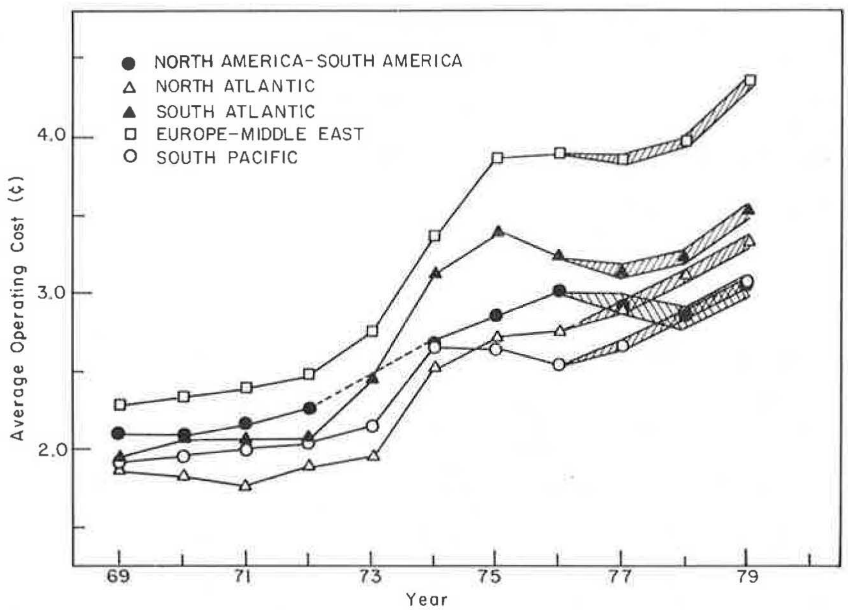


Figure 13. Actual and forecast operating costs per available seat kilometer for five markets.

ment and a savings in operating costs. These recent changes are not included in the current data base.

CONCLUSIONS

Short-term forecasts of operating costs can be made by using simple models with linear specifications. In many markets, average costs appear to be constant with respect to capacity and to indicate no economies of scale. The constant average cost per available seat kilometer in such markets is affected by the price of oil and by the percentage of wide-body aircraft in the fleet mix. In real terms, it seems that operating costs have managed to decline despite the rises in factor inputs. Most of this decline can be attributed to the introduction of wide-body aircraft in the fleet. Markets in which further changes in the fleet mix include more use of wide-body aircraft show promise of reducing operating costs even in current terms. For some markets, available capacity appears to have a negative effect on cost, which indicates economies of scale. This phenomenon seems to occur in the markets that have lower volumes; economies of scale tend to disappear as a market reaches higher traffic volumes, a characteristic often referred to as market maturity.

The results of this analysis indicate that the possibilities of controlling the rise of operating cost are linked to the possibilities of fleet modification and the introduction of wide-body aircraft. Of course, they also depend on the prospects of controlled rises in fuel prices. If it is assumed that fuel prices will not rise faster than the rate of inflation, costs can be expected to decline. This decline, however, is associated with the use of larger aircraft and implies an increase in available capacity if level of service, as measured by flight frequency, is to be maintained. Therefore, whether fleet changes in any one market are feasible cannot be evaluated on the basis of the cost implications alone. The evaluation would require an integration of cost forecasting with the analysis of demand in the market in question, particularly with regard to price elasticity. It is a known fact in air transportation that larger aircraft bring about unit cost savings and a reduction in break-even load factors. But the use of such aircraft is feasible only if it does not cause more reduction in actual load factors, which is a possibility when larger aircraft are used. In other words, productivity alone must not be evaluated in the absolute sense but within the framework of a given market and socioeconomic environment.

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Forecasting Airport Traffic: Mexico City as a Case Study

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A procedure for preparing forecasts of airport traffic is presented, and its use is illustrated through application to Mexico City. The underlying objectives are to identify the principal factors that cause changes in airport traffic and then to develop a model of how these causes specifically influence growth. In view of the demonstrably poor overall performance of purely theoretical forecasts, a pragmatic approach is recommended in which much emphasis is placed on identifying key causes of growth. The procedure recommended involves four phases: a detailed examination of the data to determine unusual or particular events, identification of the principal causes of past and future changes, introduction of these causal factors into statistical analyses to extend recent patterns of activity into short-range forecasts, and, finally, creation of long-range forecasts with suitably wide margins of uncertainty by use of scenarios of possible developments. The case study illustrates each of these phases. The results suggest that much of future airport traffic will be caused by external influences, such as the total recreational expenditures of the United States, and is beyond the influence of airport planners.

This paper treats two topics simultaneously: (a) the question of how to forecast traffic, particularly for airports, and (b) the specific application of this methodology to the current situation in Mexico.

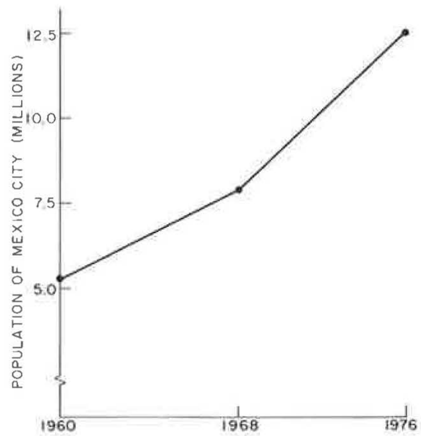
The general question of how best to forecast traffic is a troublesome one. Airport authorities typically spend a lot of money to obtain poor results. A traffic study for a major airport in the United States can easily cost about $250 000, yet the forecasts generated are notoriously inaccurate. An analysis of the five-year forecasts of total aviation traffic of the Federal Aviation Administration has shown that those forecasts were off by more than 20 percent half the time (1). And forecasts for any component of the aviation system, such as an airport, are necessarily more inaccurate since their errors do not cancel each other as they would in the aggregate. It does not take much to imagine that one might get equal value for less money by simply guessing at the future. It is easy to believe that the processes now used are highly cost-ineffective. The issue is, Can we deploy our engineering and analytic skills more productively to obtain reasonable, possibly better, results more cheaply?

This paper presents a suggestion as to how better forecasts of airport traffic might be obtained at less cost. The specific situation of Mexico City is used to illustrate the process. The discussion of Mexico City is also interesting as an example of how to prepare forecasts for nations similar to Mexico. The issue here is how to proceed when the kinds of data we are used to in the United States are unavailable and when the causes of growth are substantially different. This issue is particularly topical because most new airports are likely to be built in developing countries.

BACKGROUND

Essentially all of the participants in the planning, construction, and operation of the Mexico City International Airport were elements of the federal government of

Figure 1. Increase in population in Mexico City metropolitan area.



Mexico. This situation, which is typical of many countries similar to Mexico, is quite different from that prevailing in the United States.

The physical and demographic setting is also remarkable. Population and wealth are concentrated in the capital, coincidentally in the center of the country. In 1976, 20 percent of the population of the republic lived in the metropolitan area of Mexico City; that level has risen steadily from 15 percent in 1960 and could easily reach 25 percent by the end of the century. In absolute numbers, the population of the Mexico City metropolitan area has grown, at a compound rate of 5 percent annually, from 5.2 million in 1960 to more than 13 million in 1979 (see Figure 1) (2-5). Mexico City is now the size of New York City. Relative to the rest of the country, it is even more important than New York: A comparable U.S. city would have 45 million inhabitants and be growing by 2 million people a year. This degree of rapid growth of the central capital city, not uncommon in developing countries, can certainly be expected to influence the nature of the growth of airport traffic.

APPROACHES TO FORECASTING

Two major approaches to forecasting can be distinguished: trend extrapolation and causal modeling. Trend extrapolation consists of fitting a line or a function to past observations and simply extending it into the future. Causal modeling consists of trying to identify the several causes that affect a situation and thus create a formula that might forecast the future for a wide variety of situations, some of which might occur naturally and others through explicit policies directed toward changing the environment.

Trend extrapolation is by far the easier and the most commonly used method. The calculations necessary can be carried out almost without effort, now that sophisticated statistical computer-based procedures are available. The method is especially attractive because it is essentially always possible to obtain formulas that fit the data well. One merely has to rearrange the expressions or add new variables. In fact, the mathematics guarantee that one will always obtain an equivalent or better fit to the data by adding any variable, regardless of how irrelevant it may be to the real situation. Gullible clients beware!

Trend extrapolation can be useful for short-range forecasts. Indeed, if the environment changes slowly and if the fundamental causes stay fairly constant, it is reasonable to believe that the past is a good indication of the immediate future. The irony of this argument is, however, that if one justifies a forecast on this basis one does away with the rationale for any sophisticated analysis. All one has to do is to observe that traffic has grown at X percent annually over the past few years and is likely to change similarly in the future.

The difficulty with trend extrapolation is that underlying causes may change. Fares might suddenly jump, for example, because of changes in the market or because of policy decisions either on the fares themselves or on the costs of inputs such as fuel. To the extent that such changes were not part of the past, the forecast based on the trend will not account for their effect and will be wrong.

Planners thus really need causal models to help them to forecast traffic. As this becomes more obvious, more analysts are presenting models that are identified as causal or, equivalently, as behavioral. The problem at this stage is that calling a model causal does not make it so. To the extent that a model is developed by purely analytic, statistical techniques, there is indeed little justification for calling the result causal, however good the statistical fit. Correlation is not causality. Spending money on presents does not bring Christmas.

Evidence abounds of the inability of statistical techniques to detect the underlying motivations of the demand for travel. Consider the set of 59 econometric analyses of North Atlantic passengers discussed by Moore (1, 6). Each study identifies, among other things, how fares influence traffic. The range of estimates for this fare elasticity spreads rather evenly from about 0 to almost -3—that is, from no effect to a significant effect. Whatever the influence of fares might be, these studies did not determine it.

The justification for a causal model must rest on one or more of the following factors:

1. Prior knowledge of how parts of the system function—for example, of how airlines might schedule flights to maintain a desired level of load factor;
2. Theory, which should be substantiated by additional evidence as to how particular factors influence traffic; and
3. Specific evidence on how individual factors have shifted traffic, as obtained by before-and-after studies of the effect of sudden changes in major factors, such as fares, while all else remains substantially the same.

PROCEDURE ADOPTED

To develop forecasts for airport traffic for Mexico City, we attempted to develop a causal model. We used the several ways of justifying the components of the model outlined above and then used statistical analyses to establish its correspondence with the data.

The procedure adopted to develop the causal model consists of four steps:

1. Examination of the data,
2. Search for major causes,
3. Statistical analyses to develop short-range forecasts, and
4. Use of scenarios to create long-range forecasts.

Our recommendation to start with a detailed examination of the data is based on our experience, which indicates that the available data—however reputable the source—are often full of errors, inconsistencies, changes of definition, and other factors that introduce spurious jogs and jiggles into past trends. What we have in mind here is not a mathematical analysis but a

Table 1. Official data on passenger traffic through Mexico City International Airport.

	Passengers by Category (000s)			
Year	National	International	Transit	Total
1960	682	610		1292
1961	640	643		1283
1962	666	706		1373
1963	799	815		1684
1964	899	861		1761
1965	1112	1054		2176
1966	1167	1154		2321
1967	1027	1515	190	2732
1968	1164	1683	196	3042
1969	1258	1767	181	3207
1970	1329	1967	158	3454
1971	1576	2250	135	3961
1972	2264	2059	142	4465
1973	2697	2231	236	5165
1974	3383	2376	295	6064
1975	4145	2416	207	6767
1976	4966	2433	195	7594

Figure 2. Official statistics on passengers through Mexico City International Airport.

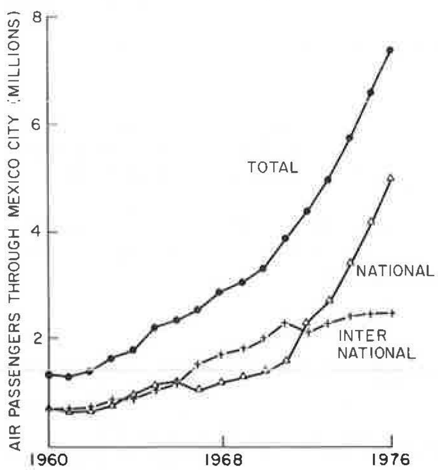
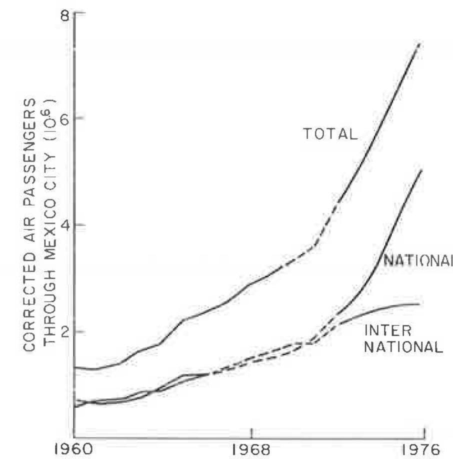


Figure 3. Corrected statistics on passengers through Mexico City International Airport.



careful look at the data by someone who is knowledgeable about the field and is thus capable of detecting anomalies in the reported data. The case study illustrates the advantages of this approach.

A search for major causes for changes in traffic is then appropriate. The question here is whether there are any factors peculiar to the situation—factors that would ordinarily not be included—that should be entered into the model. For Mexico City, the investigation of secondary sources revealed at least one major factor that should be considered but would not ordinarily be part of a theoretical model as typically developed in the United States. The statistical analysis then follows, focusing on the specific, presumably causal, factors identified both through theory and in the previous phase. At this point we find out which elements of the model are correlated significantly with traffic and whether the overall model fits the data. If it does, we have of course not proved that the model is correct but that it is at least plausible. For short-range forecasts, in which matters cannot change drastically, this justification is sufficient. And so we prepare a short-range forecast by using the model.

Finally, it is probably not reasonable to expect that the statistical model will provide reasonable forecasts for the long range, over which the situation may change drastically. Our approach, then, is to develop scenarios that describe how the major causes of airport traffic might change and use them to prepare order-of-magnitude forecasts of traffic. This is not elegant but, in our opinion, it provides an honest projection of likely and possible high and low levels of traffic.

The procedure adopted appears to have several advantages. The hope is that, by emphasizing the active use of the intelligence rather than the mechanical procedures of a computer, more insight into the problem can be gained. Since the results are consequently simpler, they are easier for airport planners to understand. Finally, of course, the total cost of the effort may be relatively low.

EXAMINATION OF THE DATA

The official statistics on national, international, and transit passengers through Mexico City International Airport are given in Table 1 and shown in Figure 2 (7, 8). Before our effort got under way, a number of econometric analyses had been run in an effort to model the data. From the standpoint of usual practice, these looked like good models—both theoretically, in that they included obvious factors such as fares, frequency, and gross national product, and statistically, in that the fit was excellent. Ultimately, however, these preliminary models were worthless because the data were, subtly but significantly, wrong.

Our suspicions concerning the data were aroused by peculiarities in the data. For instance, the level of transit passengers shifts dramatically between 1972 and 1973. In addition, the ratio of national and international passengers jumps suddenly in 1967 from about 1:1, which it had been for years, to about 1:1.5. These kinds of shifts are highly unlikely to be realistic, since patterns of travel are typically stable over the short term.

In looking at some of the supportive data on airport operations, we noticed that the numbers of passengers per airline operation also jumped anomalously in 1966 and 1973. Somehow the data did not reflect what our experience with airline operations indicated must be happening.

These operations prompted us to cross check the official statistics with all available airline sources (9-11), federal sources (12-15), and international sources such as the International Civil Aviation Organization (16). Not surprisingly, given our experience with comparable American and international data, we found a number of inconsistencies that seemed to deserve correction.

A major source of potential error was traced to institutional changes of the kind that occur everywhere. Specifically,

1. In 1966, the collection of airport statistics passed from the Ministry of Public Works to the newly created office, Aeropuertos y Servicios Auxiliares (ASA), which established the category of transit passengers and apparently subtracted them from what had previously been counted as national passengers.
2. In 1972, at the start of the next presidential term, a new administration altered the way in which international passengers were counted. Previously, a passenger was considered international if the ultimate destination of his or her flight was outside the country; afterwards, this same traveler was considered part of the national traffic if his or her flight made an intermediate stop in Mexico.

In addition, there appear to be a few mistakes that are attributable to typographical errors. For example, the official 1971 figure for total traffic seems too high by 300 000 passengers, both in comparison with other totals and with the sum of the parts reported by airlines and immigration officials. These conclusions thus led us to adjust the data to obtain the patterns shown in Figure 3 (17). These adjustments, justified in detail because of specific factors in the process for collecting the data, resulted in elimination of anomalies and jumps in the data that would be difficult to explain. It is our contention that there is usually a need for this kind of correction.

SEARCH FOR MAJOR CAUSES

The trends in traffic shown in Figure 3 indicate that the causal model must explain two phases: a period of steady growth in both national and international traffic, followed after 1972 by much more rapid increases in national traffic while international traffic tapered off. In looking for causes, we must therefore identify plausible reasons both for the shift in trends around 1972 and for the subsequent divergence between national and international travel.

The basic structure of the shift in trends is actually fairly obvious. Mexico discovered vast quantities of oil, estimated by some to equal the reserves of Saudi Arabia, and this domestic prosperity increased the ability of Mexicans to travel. Simultaneously, the fuel crisis depressed the economy of the United States and thus dampened the international traffic that, in fact, represents the influx of American tourists.

The preceding period of steady growth in traffic, on the other hand, is the expected pattern associated with steady demographic and economic expansion. Any of a number of variables would represent this effect.

In general, many variables might stand for the underlying causes we have described. To select likely factors, a wide variety of candidates were examined. By category, these included

1. Demographics—the population of the nation and the city and their ratio, the adult population, and the number of people gainfully employed (2-5, 18);
2. Economics—the distribution of income and the percentage of families earning enough to afford to fly, price indices for Mexico and the United States, the gross national product, real national investment and total capital, the expenditures on infrastructure in the nation and the capital, the level of imports and exports, and foreign economic factors, specifically the U.S. gross national product and recreational expenditures as reported by the U.S. Department of Commerce (5, 18-22);
3. Transport—airline tariffs, frequencies, and routes and levels of traffic on competitive modes such as highways and railroads (7, 9, 10); and
4. Tourism—the availability of accommodations for tourists (15).

From all of these possibilities, we selected the following causal variables:

1. To represent the overall level of activity in Mexico City, we took its population in thousands by year ($POBDF_t$), which is closely correlated with other exponentially growing factors, such as gross national product, and stands for them statistically.
2. To capture the actual market of Mexican passengers, we chose the number of families able to travel—that is, families with incomes greater than 10 000 (1968) pesos (1 peso = U.S. $0.08), by year and in thousands (FPV_t).
3. To represent the amount of international tourism, we selected U.S. recreational expenditures by year, expressed in 1967 dollars per person ($RECUS_t$). Figure 4 shows the recent evolution of this variable. Studies of North Atlantic air traffic indicate that this is a powerful explanatory variable (23-25).
4. The effect of the oil crisis was expressed by a dummy variable, equal to zero until 1973 and to one thereafter (DUMMY).
5. The cost of transportation for national traffic was represented by an index of fares expressed in constant pesos, by year ($TARN_t$). As Figure 5 shows, this measure fluctuated within a narrow range until the 1970s, when rapid inflation and prosperity sent the real prices tumbling. This is closely associated with the more rapid increase in traffic during this period.
6. Conversely, however, there is little point in including a figure for international fares, which are, as Figure 6 shows, so closely correlated—although inversely—with the trend of U.S. recreational expenditures. One could not distinguish statistically between these measures.
7. A final factor considered was the shift from rail to air for intercity travel in Mexico. As Figure 7 shows, this has been quite dramatic for the railroads. But, considering the small fraction of national air travelers this represents and the close correlation of this variable with Mexican air tariffs, it was not included.

These variables, three each for national and international traffic, completed the set of presumed major causes of change in air traffic for Mexico. More variables could easily be justified theoretically, but they would not make sense statistically. After all, the available data comprise only 16 independent points; more variables would severely restrict the ability to estimate the coefficients of the model.

SHORT-RANGE FORECASTS

The causal models were calibrated by ordinary least squares to obtain the following results. For national passenger traffic, by year,

$$PN_t = e^{-7.45}\, FPY_t^{3.32}\, TARN_t^{-0.95}\, POBDF_t \qquad R^2 = 0.98$$
$$(5.02) \quad (17.0) \quad (6.13) \qquad F = 289$$
$$d = 2.40 \qquad (1)$$

Figure 4. Evolution of U.S. recreational expenditures per person.

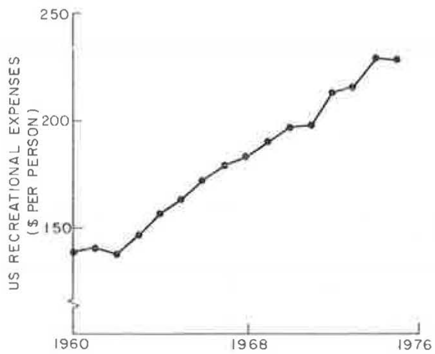
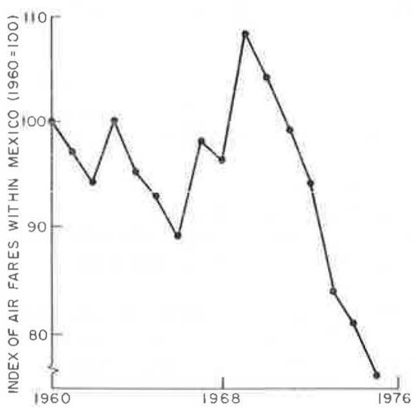


Figure 5. Trend of air fares within Mexico in constant pesos.



For international passenger traffic, by year,

$$PI_t = e^{-1.71}\ RECUS_t^{2.06}\ FPY_t - 76\,900\ DUMMY \qquad R^2 = 0.99$$
$$(4.92)\quad (31.0) \qquad F = 959$$
$$d = 1.90 \qquad (2)$$

Both models have reasonable coefficients, fit the data well, and are free from autocorrelation. Given our prior reasons for believing that these models make sense, the statistical tests encouraged us to use them for short-range forecasts.

It is easy to suggest more sophisticated—and more expensive—mathematical analyses that might lead to statistically more satisfying models. But would such extensions be worthwhile? And would they be cost effective?

We believe that further analyses would not be productive. Indeed, the creation of a formula for airport traffic does not solve the problem of generating a forecast. The development of the model merely displaces the forecasting problem: Instead of having to forecast traffic, we now have to forecast many other variables. It is hoped that the future trajectory of these variables will be reasonably obvious. But uncertainty still exists and is, in our opinion, bound to overwhelm any marginal improvements that might be made in the models.

In the event, we obtained short-term forecasts by using low, medium, and high estimates of each of our explanatory variables. The results are shown in Figures 8 and 9.

Fairly obviously, forecasts similar to ours could

Figure 6. Trend of international air fares at constant prices.

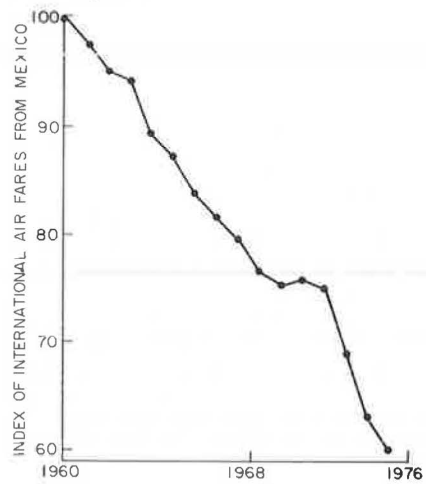
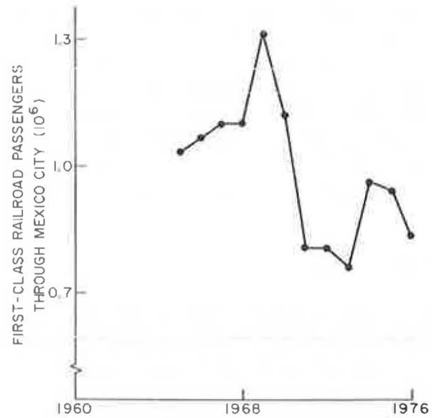


Figure 7. Decrease in first-class intercity rail travel in Mexico.



have been obtained at essentially no cost at all simply by drawing in lines freehand. How much is this, or any, analysis worth? We feel that the analysis is useful as a discipline to force us to examine the data, to think about the possible causes, and to develop a true understanding of the reasons why low or high levels of traffic might occur. We do not believe that this or any procedure can provide precise predictions. Consequently, we also believe that relatively modest efforts, such as the one described here, are most reasonable for airport planning.

LONG-RANGE FORECASTS

Given the uncertainties of past data, the fact that econometric models are valid only over a relatively short term, and the possibility of major technical and even political developments, long-range forecasts of airport traffic can at best be only estimates of the general magnitude of future traffic.

Our estimates are based on scenarios of how air traffic through Mexico might develop. The results are validated (to the extent that this is possible) by comparing the forecasts with the evolution of passenger traffic at other major airports that have already passed beyond the current level of traffic at the Mexico City airport. We prepared estimates of the level of population in Mexico, its spatial distribution, and the financial

Figure 8. Short-range forecasts of national passengers through Mexico City International Airport.

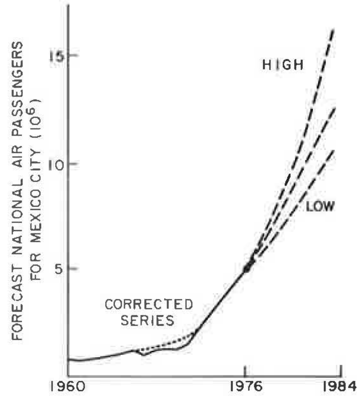


Figure 9. Short-range forecasts of international passengers through Mexico City International Airport.

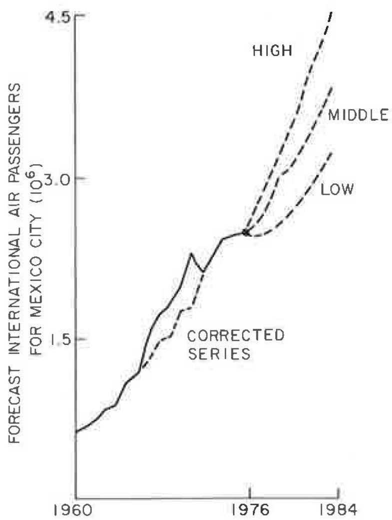
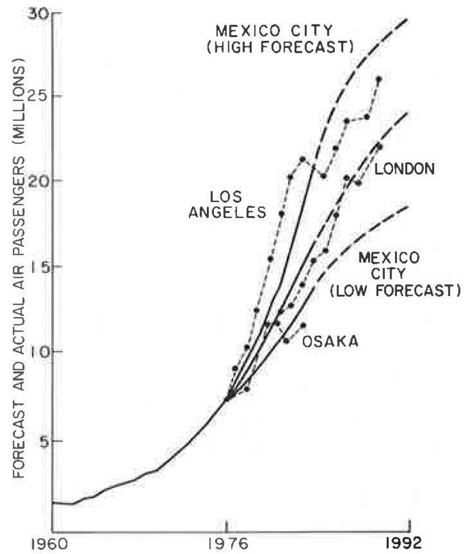


Figure 10. Long-term forecasts of total passengers through Mexico City International Airport and other major airports.



or touristic attractiveness of each city linked by air to Mexico City. Subjective estimates of the probability distributions of air passengers on each route were made and then merged to obtain a joint probability distribution. This led to a median forecast of 25 million passengers for Mexico City in 1992 and 80 percent confidence limits of about ±25 percent. Figure 10 shows these results.

These long-range forecasts turn out to be close to what has already happened at other major international airports that have grown beyond the 7.5 million passengers/year who currently use the Mexico City International Airport. That these airports either grew faster or slower than the upper and lower bounds of our forecasts does suggest, however, that our range of uncertainty may need to be even wider than ±25 percent.

CONCLUSIONS

This paper presents a procedure for forecasting traffic at airports and applies it to Mexico City. The validity of the process, for the purpose of airport planning and design, depends on how well it informs the decisions that must be made about how much and when to expand airport capacity. We believe that the procedure fulfills the needs inexpensively.

ACKNOWLEDGMENT

The forecast of passenger traffic for Mexico City's Benito Juarez International Airport was commissioned by the Airports Office of the Federal Ministry of Human Settlements and Public Works (SAHOP), the agency responsible for constructing airports in Mexico. We carried out the study as personnel of or consultants to the Instituto Mexicano de Planeación y Operación de Sistemas, working jointly with the director general for airports in SAHOP, architect Eduardo Luna Traill, and his assistant, engineer Jorge de la Madrid (18). The project was conducted in close cooperation with the office of Aeropuertos y Servicios Auxiliares (ASA) in the Secretaría de Comunicaciones y Transporte—the group actually responsible for operating the federal airports of Mexico—and with the major Mexican airlines, Aero Mexico and the Compañia Mexicana de Aviación, one private and the other public.

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Proposed Technique for Identification of Market Potential for Low-Cost Air Travel

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A mail-back survey conducted by the Maryland State Aviation Administration to assess the interest of Maryland residents in a low-fare, no-frills air service from the Baltimore-Washington region to the West Coast is described. The questionnaire used was designed to determine whether or not respondents had traveled by air from the Baltimore-Washington area to California during the past 24 months and whether they would have traveled more often to California (or for the first time) if a $99 one-way fare had been in effect between the Baltimore-Washington region and the Los Angeles and San Francisco areas. Results were tabulated and analyzed on a computer by using the Statistical Package for the Social Sciences. In addition to analysis based on statewide population data, tabulations were developed at the zip code, county, and regional levels for more detailed analysis of potential markets. The proposed technique shows how the use of existing computerized data on area population can be conveniently converted to a representative sample for public policy purposes.

The diversion of air passenger traffic from one market to another was an important factor in the economic regulatory environment of the Civil Aeronautics Board (CAB) prior to the recent passage of legislation deregulating the airline industry. The more diversion there was, the less likely the CAB would be to award the new authority. By attempting to show that additional air passenger demand could be produced by the new service, an argument could be made for allowing additional air carrier supply without apparent diversion of traffic from existing services. Such an argument removes one of the principal grounds for CAB disapproval of low-fare proposals.

With the evolution of a more procompetitive regulatory policy, the need for carriers (and communities) to argue the absence of diversion for new service has been eliminated. Moreover, communities are now in a position to seek to convince suitable air carriers, rather than the CAB, that their market would be the most advantageous for a carrier to commit its limited equipment and resources.

In an effort to demonstrate that new air passenger travel would be generated by low-fare, transcontinental service, the Maryland State Aviation Administration conducted a mail-back survey designed to measure objectively the additional traffic that would be produced by new service. The survey had, as a major constraint, the need to produce a mailing list that was representative of the entire geographic area under question—in this case, the state of Maryland.

In the design of surveys to elicit the general opinion of this potential market, it is inappropriate to use commonly "manufactured" mailing sources that may tend to be biased toward higher-income groups or to concentrate geographically on urban areas. In addition, it is

Figure 1. Proposed technique for identifying market potential for low-cost air travel.

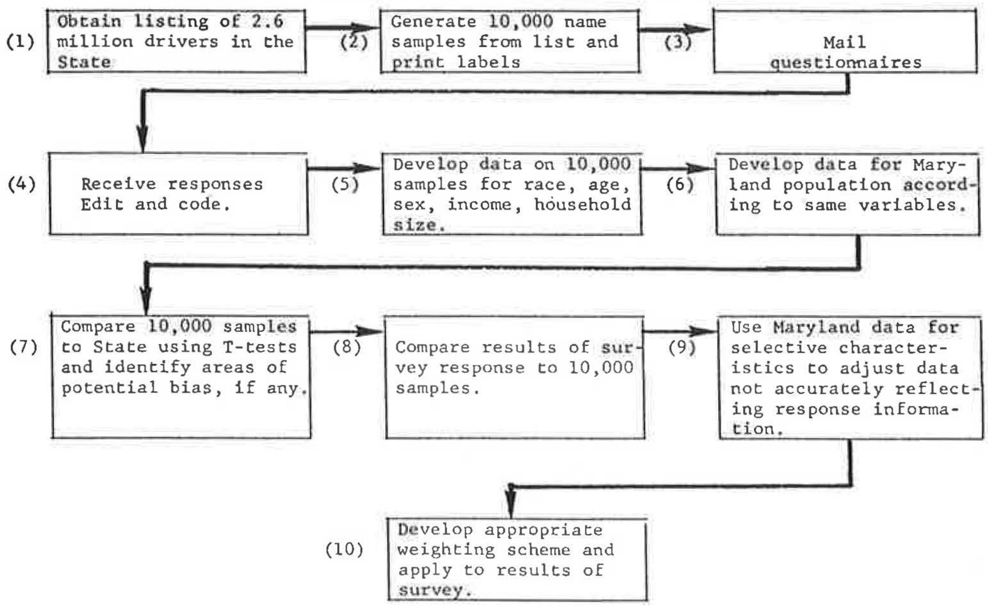

Table 1. Comparison of survey respondent characteristics with statewide population characteristics for variables of race and income.

	Sample Response		Households Statewide		
Variable	Number	Percent	No. (000s)	Percent	Ratio[a]
Race					
Black	90	5.5	215.3	15.6	2.80
White	1545	94.0	1156.0	83.8	0.89
Other	8	0.5	8.3	0.6	1.20
Total	1643	100.0	1379.6	100.0	1.00
Income ($)					
< 10 000	158	9.6	345.0	25.0	2.60
10 000-15 000	251	15.3	234.6	17.0	1.11
15 000-20 000	332	20.2	220.8	16.0	0.79
20 000-25 000	296	18.0	179.4	13.0	0.72
>25 000	606	36.9	400.2	29.0	0.79
Total	1643	100.0	1380.00	100.0	1.00

[a]The ratio of sample respondent characteristics with statewide population characteristics was compared to determine if there was a statistically significant difference in the proportions of the sample responses. If the sample response was significantly different, adjustments to the survey responses were developed to account for the differences.

necessary to identify a broad cross section of the market that includes residents of nearby areas who may be induced to take longer ground trips to take advantage of lower air service rates. By designing a computerized process to identify a representative sample of residents, a major step in developing an innovative and efficient procedure to rapidly elicit responses to air travel changes was created. With minor modifications, this procedure could be used in other states to produce similar results. Results of the analysis are weighted to deal with problems of reporting bias observed for low-income blacks, and a computerized matching program, in which zip codes from the original file of names are related to respondents' completed forms, is used to permit submarket analysis of particular geographic areas.

COMPUTERIZED TECHNIQUE

The sample selection program was constructed in the FORTRAN language for execution on a Burroughs 6700 series computing system. The program operated in two phases. First, a pseudorandom sequence of 10 000 floating point fractions (in the range 0., 1.), with a uniform distribution, was generated (see Figure 1). Each member of this sequence was multiplied by the number of records in the driver's-license master file, and the integer portion of the result was used to identify a record to be selected. A linear congruential method was used to generate the uniform sequence.

The second phase of this program was designed to read the driver's-license master file; it produced an output file that consisted of those records whose position in the input file was identical to a value in the transformed pseudorandom sequence. The resulting sample file contained 9923 records. Each record specified a value for the data fields: name, address, date of birth, sex, race, and survey number. The number of responses returned was 1702; these were keypunched and entered into a file that was manually edited, and 1643 responses were retained.

Another FORTRAN program was written to add the demographic variables—race, age, sex, and zip code—to each record in the respondent file that contained 27 variables. The first 22 are based on survey respondents' experience and preference. Income level was supplied by the respondent, whereas the other four demographic variables were obtained from the sample file.

A third FORTRAN program was written to partition the sample file into two subfiles. One subfile contained sample records that corresponded to respondents, and the other subfile represented nonrespondents. The selection criteria were based on the existence of a common set of record identifiers in both the sample and the respondent file.

A t-test comparison of sample means was performed for the variables of race, sex, and age. The two samples corresponded to the two subfiles, and tests required two independent samples. Tests given either common or unequal population variances were performed based on an F-test of sample variances. A pooled estimate of variance was used for the t-test on sex, whereas separate estimates of variance were calculated for the race and age tests. Only the null hypothesis (equal population means) for the variable of race was rejected at the 0.01 level of significance.

On the basis of the above statistical tests, joint multiplicative weights were computed. These weights were obtained by calculating the ratio of the proportion of each

Figure 2. Probability tree for analyzing sample responses.

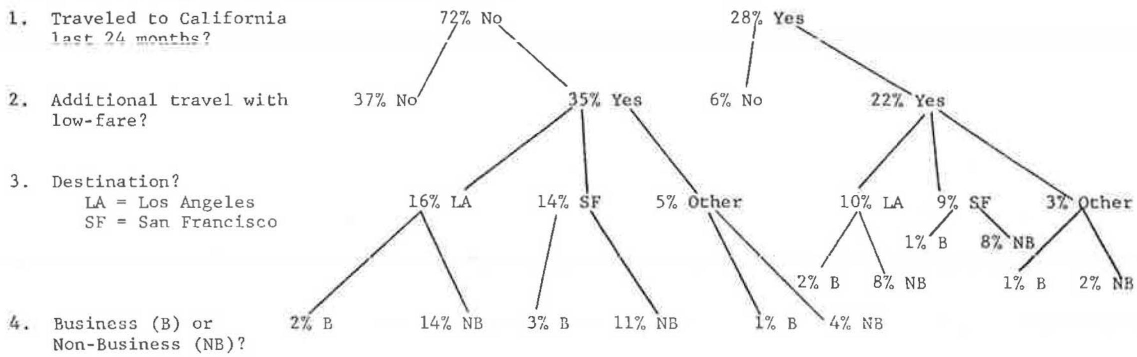

Table 2. Data on households whose members had previously traveled to the West Coast and would make additional trips if one-way fare were $99.

Trip Destination	Households Surveyed Number	Households Surveyed Percent	Number of Maryland Households
Los Angeles only	132	8.1	111 568
San Francisco only	119	7.3	100 780
Other California destinations only	27	1.7	22 819
Los Angeles and San Francisco	42	2.6	35 809
Los Angeles and other destinations	8	0.5	7 267
San Francisco and other destinations	9	0.6	7 965
Los Angeles, San Francisco, and other destinations	7	0.4	6 033
No response	26	1.6	22 399
Total	374	22.8	314 640

Note: Results are based on expanded results of Maryland State Aviation Administration survey. Use of the percentage of households surveyed causes minor errors in household estimates.

Table 3. Data on households whose members had not previously traveled to the West Coast but would travel if one-way fare were $99.

Trip Destination	Households Surveyed Number	Households Surveyed Percent	Number of Maryland Households
Los Angeles only	171	10.5	144 263
San Francisco only	154	9.4	129 490
Other California destinations only	50	3.1	42 556
Los Angeles and San Francisco	94	5.8	79 514
Los Angeles and other destinations	14	0.9	12 020
San Francisco and other destinations	8	0.5	7 235
Los Angeles, San Francisco, and other destinations	27	1.7	23 066
No response	25	1.6	21 396
Total	547	33.3	459 540

Note: Results are based on data from the Maryland State Aviation Administration. Use of percentages causes minor errors in household estimates.

level (value) of a given variable in the respondent file to the proportion of the same levels of the given characteristic of the population. This was done separately for the variables of income and race (see Table 1). There were 15 weights of income and race:

Income ($)	Black	White	Other
<10 000	7.38	2.31	3.12
10 000-15 000	3.15	0.98	1.33
15 000-20 000	2.24	0.70	0.95
20 000-25 000	2.04	0.64	0.86
>25 000	2.24	0.70	0.95

These weights were computed for each combination of income level and race category by multiplying the ratio of proportion for income by the ratio of proportion for race. They are based on the number of survey respondents who have particular characteristics. For example, there were 7.38 times the number of low-income blacks in the state as there were in the survey. The survey results therefore required a factor of 7.38 to adjust the responses so that there would be an accurate representation of statewide population characteristics.

The weights were conditionally assigned to respondents through the Statistical Package for the Social Sciences (SPSS) case-weight intrinsic variable (1). All weighted sample sizes were rounded to the nearest integer value. Adjusted frequency tables for all variables in the respondent file were computed by the SPSS procedure FREQUENCIES.

The SPSS COMPUTE and conditional compute (IF) facilities were used to generate composite variables for each entry in the respondent file. Eight variables were generated on the basis of survey results:

B = previous business travel,
NB = previous nonbusiness travel,
BINC = additional business travel,
NBINC = additional nonbusiness travel,
NTBINC = new business travel,
NTNBINC = new nonbusiness travel,
T = total previous travel, and
TINC = total additional travel.

These variables were aggregated by accumulating the sum of particular responses from the survey for each of the variables. For example, B = VARO2 + VARO3 + VARO4 and NB = VARO5 + VARO6 + VARO7. The difference between additional and new travel is, of course, that the former is generated by those who previously traveled and the latter is produced by those who previously did not.

Another computation of variables was performed to ensure that each set of variables could be defined in a mutually exclusive manner. This permits the use of probability-tree analysis such as that shown in Figure 2. For example, total previous travel is partitioned into three components:

TPB = total previous business travel,
TPNB = total previous nonbusiness travel, and
TPBNB = total previous business and nonbusiness travel.

Thus, a given entry in the respondent file will have a nonzero value for the computed variable TPB only if the value of the computed variable B (defined above) is nonzero and the value of the computed variable NB (defined above) is zero.

The sample was partitioned into 54 conditionally computed variables that represented all possible mutually exclusive combinations of previous, additional, and new travel for business and nonbusiness purposes to all possible combinations of California destinations.

The definition of the survey, the use of weighted results based on statistical tests, and the use of mutually exclusive variables are analytic features of the program that permit a clear and logical interpretation of the survey results. The use of various computer programs to manipulate files of survey data, socioeconomic data, and driver's-license data facilitates the development of a comprehensive and detailed set of data that can be used to generate an estimate that is representative of statewide and regional responses to proposed changes in air service.

RESULTS OF APPLICATION OF TECHNIQUE

By expanding the survey to encompass all Maryland households, the following conclusions can be drawn. First, 28 percent of total Maryland households (392 000) had traveled by air from the Baltimore-Washington region to California during the past 24 months. The response data on this question, which are based on expanded survey results, are given below:

Response	Households Surveyed		Maryland Households
	Number	Percent	
Yes	466	28.4	391 920
No	1176	71.6	988 080
Total	1642	100.0	1 380 000

Of the total expanded households, 23 percent (315 000) indicated that they would have made additional trips to California from the Baltimore-Washington International Airport (BWI) if the one-way fare had been $99. The greatest percentage of these respondents were interested in traveling to Los Angeles or San Francisco (see Table 2).

As data given in the table below indicate, 31 percent (121 000) of all respondent households that had traveled to the West Coast during the past 24 months had done so for business purposes, 47 percent (185 000) for nonbusiness purposes, and 20 percent (78 000) for both purposes:

Purpose	Households	
	Number	Percent
Business	121 103	30.9
Nonbusiness	184 986	47.2
Both business and nonbusiness	77 992	19.9
No response	7 839	2.0
Total	391 920	100.0

Seventy-three percent (231 000) of the respondent households in which one or more members made at least one air trip to California in the past two years indicated that they would have made additional trips for nonbusiness purposes if the $99 fare had been instituted:

Purpose	Households	
	Number	Percent
Business	31 464	10.0
Nonbusiness	230 631	73.3
Both business and nonbusiness	30 206	9.6
No response	22 339	7.1
Total	314 640	100.0

Eighty-one percent of the households that had not made trips (371 000) indicated that they would have traveled for nonbusiness purposes if the low fares had been in effect:

Purpose	Households	
	Number	Percent
Business	35 385	7.7
Nonbusiness	370 389	80.6
Both business and nonbusiness	32 168	7.0
No response	21 598	4.7
Total	459 540	100.0

The results presented in the final three tables above are based on expanded results of a Maryland State Aviation Administration survey.

Of the households that had not traveled to the West Coast during the previous 24 months, 33 percent (460 000 households) would have made trips with the reduced fares but 38 percent (529 000 households) would not have made trips (see Table 3).

Figure 2 shows this system of questions and responses presented in percentile figures in the form of a probability tree. Each branch of the tree represents one logical split in the respondent's set of decisions. A yes and no split, a destination, or a trip purpose are the three categories of decisions that face the respondent. This probability tree helps in analyzing, in a logical and unambiguous format, the results of a set of survey questions. The tree can be used to isolate particular elements of the travel decision-making process for further evaluation and comparison. For example, it is relatively easy to identify the proportion of respondents who have not previously traveled to the West Coast and would not take a West Coast trip if fares were reduced. This proportion of respondents can be identified by locating the relevant branch of the probability tree. Thus, the second level of the left branch shows 37 percent who made no previous trips and would not take additional trips if fares were reduced.

In addition, responses by income groups were classified by geographic area. In this way, an attempt was made to determine the number of trips that would be added from the Baltimore area versus those for Prince George's and Montgomery Counties in the Washington, D.C., area.

According to the survey results, the greater a person's income was, the more likely it was that he or she would have made a trip to the West Coast during the previous 24 months. For example, 42 and 46 percent of the households in the highest income category had traveled to the West Coast during the previous two years from the Baltimore and Washington suburban areas, respectively.

In the $20 000-$25 000 income range, there is nearly a doubling of the households in both areas that would have taken trips with the lower fares. In the $15 000-$20 000 bracket, approximately 2.5 times as many households would have traveled than actually traveled with the low fares. Finally, in both the $10 000-$15 000 and <$10 000 ranges, approximately three times as many persons as actually traveled would have traveled had the lower fares been in effect.

CONCLUSIONS

Changes in air service are usually the result of a complicated process that involves carriers, airport management, and various government agencies. The establishment, expansion, or contraction of service may have a vital impact on successful airport operation and is a matter for public policy analysis. Service expansion, if not supported by a potential market, could result in actual loss of service if existing service is eliminated because of the failure of the new service to develop a viable market. The economic vitality of regions depends on access to markets for goods and services; in our increasingly service-oriented economy, rapid service often requires air access. The methods currently used to test market availability and sensitivity range from small, nonrepresentative samples to the use of elasticity ratios to indicate whether new service will be acceptable and successful.

The technique proposed in this paper shows how the use of existing computerized data on the population of an area can be conveniently converted to a representative sample for public policy purposes. Although the technique requires the use of computers and the availability of socioeconomic data, the results of the application described here served as a cost-effective tool in policy development. This represents a new area for the application of methods of socioeconomic analysis in the formation of public policy as it relates to transportation improvements.

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**M. M. Stein and M. E. Tomassoni were with the Maryland Department of Transportation when this research was performed.*

Airline Deregulation and Its Impacts on Intercity Travel Demand

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Some of the policy questions that arise as a result of deregulation of the airline industry are examined. A national intercity travel demand model that is different in many respects from the conventional aggregate or disaggregate models is presented. The model uses travel distance as a variable of interest, calibrated on nonsurvey industrial data. The model is consistent with the neoclassical theory of consumer behavior and uses a representative consumer concept. It answers many transportation-related policy questions, such as questions about the impact of air-fare reductions and the impact of the introduction of faster aircraft on the intercity market shares of public transportation.

Economic efficiency through competition is the basic motivation behind the deregulation of the airline industry. The deregulation creates many interesting transportation policy questions. How does deregulation change the market structure of the intercity transportation industry? How does the fare reduction affect the demand for air travel and the other competing public modes? How does the introduction of faster airplanes, such as supersonics, affect the market structure of intercity passenger industries? What is the best strategy for the airline industry to expand its intercity market?

To answer these questions, we introduce a national intercity travel demand model that is, in many respects, different from conventional aggregate or disaggregate models (1-5). Conventional models use number of trips as the variable of interest, whereas the model discussed here uses distance of travel. Use of travel distance instead of trips simplifies the understanding of intercity travel demands by eliminating many trip-related variables such as origin, destination, and length. It ties in directly with many policy-related variables such as the energy consumption in intercity transportation, market shares of the intercity transportation industry, accident frequency, and pollution control measures. Distance, which is a continuous variable, can be meaningfully added to answer those policy questions.

Our demand model is designed to evaluate national transportation policies. Our interest is not to identify the travel behavior of individuals but to answer broad intercity travel-related policy questions, such as the impact of airline deregulation on market shares, energy consumption, substitution behavior, and so on.

Conventional travel demand models, both aggregate and disaggregate, are calibrated on survey data. Our model is calibrated on nonsurvey data. Survey data may reflect the travel behavior of an individual in the survey area. The problem of transferring survey data to other geographical areas and over time is still unresolved. Instead of answering national transportation policy questions from an aggregation of the disaggregate model, we answer those policy questions directly from a national intercity travel demand model that was built on national nonsurvey data.

The basic properties of the theory of consumer behavior—summability, homogeneity, and symmetry—are imposed. The substitutability of public travel modes is measured in terms of compensated cross elasticities. Conventional travel demand models have a loose tie with the neoclassical theory of consumer behavior, and market cross elasticities are a popular form of measuring substitutability. A previous study shows that compensated cross elasticities are theoretically more defendable and empirically more reliable (6).

Finally, we use the concept of the representative consumer instead of the individual consumer for the national transportation policy evaluation. The modal choice of an individual trip maker could be any one of three modes—airline, rail, or bus. But the representative trip maker, which is conceptually defined, could choose all alternative travel modes. When the representative trip maker chooses more air travel in response to the air-fare reduction, it should be interpreted as some portion of bus or rail riders switching to the air mode since they can now afford it because of the fare reduction.

THE MODEL

It is assumed that the consumer has an additively separable utility function in terms of highly aggregate group commodities such as intercity travel, urban travel, leisure, and all other consumption. Consumers have a time budget (TT). They may allocate the time budget to travel, work, and leisure. We assume that their working hours are exogenously determined. Their money budget (Y) depends on wage rate (w), number of working hours (H), and nonwage income (α); i.e.,

$$Y = w \cdot H + \alpha \quad (1)$$

Given income Y and nonworking hours (TT - H), consumers allocate their income to intercity travel (x), urban travel (z), and consumption (c) and allocate their nonworking hours to intercity travel, urban travel, and leisure (L) (the consumption is an aggregate quantity index of all consumption); i.e.,

$$\text{Max } U = U(x, z, c, L) \quad (2)$$

subject to

$$p_x \cdot x + p_z \cdot z + p_c \cdot c = Y \quad (2a)$$

$$v_x \cdot x + v_z \cdot z + L = TT - H \quad (2b)$$

where

- x, z, c = quantity indices of intercity travel, urban travel, and aggregate consumption, respectively;
- p_x, p_z, p_c = price indices of x, z, and c, respectively; and
- v_x and v_z = speed indices of intercity travel and urban travel modes.

Since L is unobservable, we can reformulate the model as follows:

$$\underset{x,z,c}{\text{Max}}\ U = U\,[x,z,c,(TT - H - v_x \cdot x - v_z \cdot z)] \quad (3)$$

subject to

$$p_x \cdot x + p_z \cdot z + p_c \cdot c = Y \quad (3a)$$

A convenient index for aggregation is the divisia index (7).

The money budget ($M = p_x \cdot x$) and the time budget ($T = v_x \cdot x$) are determined in the first-stage decision process. At the second stage, consumers allocate intercity travel money (M) and time (T) budgets to various travel modes to achieve the greatest personal satisfaction:

$$\underset{x_1,\ldots,x_m}{\text{Max}}\ v = U(x_1, \ldots, x_m) \quad (4)$$

subject to

$$\sum_{i=1}^{m} p_i x_i = M \quad (4a)$$

$$\sum_{i=1}^{m} t_i x_i = T \quad (4b)$$

where p_i is the user cost of intercity travel per unit distance by the ith mode and $(1/t_i)$ is the speed of the ith mode.

The usual Lagrangian solutions of intercity travel distance by the ith mode are

$$x_i = x_i(p_1, \ldots, p_m, t_1, \ldots, t_m, M, T) \quad (i=1,\ldots,m) \quad (5)$$

From Equations 4 and 5, we can formulate an indirect utility function of intercity travel demand; i.e.,

$$U = V(p_1, \ldots, p_m, t_1, \ldots, t_m, M, T) \quad (6)$$

We assume that the consumer has three alternative modes for intercity travel: airline, bus, and rail. (Including the automobile would provide much greater realism and predictive power, but difficulty in collecting a consistent set of national data for intercity automobile driving forces us to exclude automobile driving from the model.) We further assume that the consumer has a translog indirect utility function. Consider the following time- and speed-adjusted translog indirect utility function:

$$\log v = \sum_i a_i \log(p_i/M) + (1/2) \sum_i \sum_j b_{ij} \log(p_i/M) \log(p_j/M) + \sum_i b_{it} \log(p_i/M) \cdot t + \sum_i b_{is} \log(p_i/M) \log(SR) \quad (7)$$

We impose the following restrictions:

1. For symmetry, $b_{ij} = b_{ji}$, $b_{it} = b_{ti}$, $b_{is} = b_{si}$;
2. For normalization, $\sum_i a_i = -1$; and
3. For homogeneity, $\sum_i b_{ij} = \sum_i b_{it} = \sum_i b_{is} = 0$.

By means of these restrictions, we derive the following homogeneous indirect translog utility function:

$$\log v = \log M + \sum_i a_i \log p_i + (1/2) \sum_i \sum_j b_{ij} \log p_i \cdot \log p_j + t \sum_i b_{it} \log p_i + \log(SR) \sum_i b_{is} \log p_i \quad (8)$$

The homogeneous translog expenditure function can be obtained from Equation 8, as follows:

$$\log M = \log v - \sum_i a_i \log p_i - (1/2) \sum_i \sum_j b_{ij} \log p_i \log p_j - t \sum_i b_{it} \log p_i - \log(SR) \sum_i b_{is} \log p_i \quad (9)$$

The compensated demand equation is obtained from the expenditure function by taking a derivative of the equation with respect to $\log p_j$:

$$\partial \log M / \partial \log p_j = (p_j/M)(\partial M/\partial p_j) = -a_j - \sum_i b_{ij} \log p_i - b_{jt} \times t - b_{js} \log(SR) \quad (10a)$$

$$x_j \big|_{v = v_o} = -[a_j + \sum_i b_{ij} \log p_i + b_{jt} \cdot t + b_{js} \log(SR)]\,[M(v_o)/p_j] \quad (10b)$$

Table 1. Estimation of parameters.

Variable	Air Equation Parameter	Air Equation t-Statistic	Bus Equation Parameter*	Bus Equation t-Statistic	Rail Equation Parameter	Rail Equation t-Statistic
Air fare	-0.045 7	-2.87	0.012 7	1.94	0.033 0	2.53
Bus fare	0.012 7	1.94	-0.005 54	-0.786	-0.007 19	-1.93
Rail fare	0.033 0	2.53	-0.007 19	-1.93	-0.025 8	-2.26
Time trend	0.003 35	4.97	0.000 195	0.833	-0.003 54	-6.17
Speed ratio	-0.136	-6.20	-0.015 7	-2.79	0.152	7.96
Intercept	-0.642	-20.2	-0.027 5	-2.71	-0.330	-12.2
R^2	0.607		-	-	0.706	
Standard error of regression	0.006 37				0.005 53	
D-W statistics	0.784		-	-	0.979	

*Parameters are derived from those of air and rail equations by imposing the summability, normality, and symmetry constraints.

Table 2. Demand elasticities.

Demand	Change	Air Equation	Bus Equation	Rail Equation
Market	Air fare	-0.945	-0.315	-0.268
	Bus fare	-0.015	-0.863	0.058
	Rail fare	-0.039	0.178	-0.790
	Speed	0.163	0.390	-1.24
Compensated	Air fare	-	0.522	0.568
	Bus fare	0.025	-	0.099
	Rail fare	0.083	0.301	-

where

$$M(v_o) = \exp\left[\log v_o - \sum_i a_i \log p_i - (1/2) \sum_i \sum_j b_{ij} \log p_i \cdot \log p_j - t \sum_i b_{it} \log p_i - \log (SR) \sum_i b_{is} \log p_i\right]$$

By using the sample means of p_i, SR, M, and t and the estimated parameters of the equation, the utility level ($\hat{v}_o$) is estimated from Equation 8. With the given utility level $\hat{v}_o$, we simulate the compensated demand by using Equation 10. This simulation is the compensated simulation. Instead of fixing the utility level, we can assume that M is fixed and simulate the model. This is the market simulation.

By using Roy's identity (8, p. 94), we obtain the following:

$$s_j = -[a_j + \sum_{i\epsilon c} b_{ji} \log (p_i/M) + b_{jt} \cdot t + b_{js} \log (SR)] \qquad (11)$$

where $i, j \in c$ and c = (air, bus, rail), and

s_j = budget share of the jth mode,
p_i = user cost of the ith mode,
t = time trend,
SR = ratio of airline speed to bus-rail speed, and
$a_j, b_{ji}, b_{jt}, b_{js}$ = regression parameters.

The summability, normality, and symmetry conditions are imposed as follows:

1. For summability, $\sum_{j\epsilon c} s_j = 1$,
2. For normality, $\sum_{j\epsilon c} a_j = -1$ and $a_j < 0$, and
3. For symmetry, $b_{ij} = b_{ji}$ for $i \neq j$.

Various elasticities are derived from Equation 11 [for $j, k \in c$ and c = (air, bus, rail)]:

1. The market own elasticity—$e_{kk} = -(b_{kk}/s_k) - 1$,
2. The market cross elasticity—$e_{jk} = -(b_{jk}/s_j)$ for $j \neq k$,
3. The compensated own elasticity—$E_{kk} = -(b_{kk}/s_k) - 1 + s_k$,
4. The compensated cross elasticity—$E_{jk} = -(b_{jk}/s_j) + s_k$,
5. The Allen-Uzawa pairwise partial elasticity of substitution (9)—$d_{jk} = E_{jk}/s_k$, and
6. The speed ratio elasticity—$ES_j = b_{js}/s_j$.

DESCRIPTION OF DATA AND EMPIRICAL RESULTS

The data used are annual series data that cover the period 1947 to 1974 and were obtained from various sources. Intercity passenger kilometers, prices per passenger kilometer (calculated by dividing revenues by passenger kilometers and then deflated by the consumer price index for base year 1967), and the number of passengers by each mode were collected from the Transportation Association of America (10). Price per passenger kilometer is calculated by dividing revenue by passenger kilometers and deflating by the consumer price index for base year 1967. The average annual speed of airline service was obtained from the Civil Aeronautics Board (11). The average speeds of bus and rail were obtained from the Federal Highway Administration and Amtrak, respectively.

Data on rail speed include both intercity and suburban trains. Waiting time is included in the estimation of rail speed. The air and bus speeds are the average maximum trip speed excluding waiting time. There is not much difference in speed between the bus and rail modes. As the speed variable in this study, we used a ratio of air speed to the average of bus-rail speed.

The money budget for the representative consumer is obtained as follows:

$$M = p_a \cdot x_a + p_b \cdot x_b + p_r x_r \qquad (12)$$

where p_a, p_b, and p_r are the price of airline, bus, and rail service per kilometer, respectively, and x_a, x_b, and x_r are per capita passenger kilometers of respective modes.

We estimate the parameter of the share equations (Equation 11) by using a nonlinear maximum likelihood estimation method with proper constraints to meet the summability, normality, and symmetry conditions. Table 1 gives the parameter estimates and relevant statistics.

Table 2 gives both market and compensated demand elasticities. A 1 percent increase in air price decreases air passenger demand by 0.945 percent. It also decreases passenger demand for rail and bus service: Demand for bus decreases by 0.315 percent and that for rail by 0.268 percent. Such decreases in bus and rail demand are caused by income effects. When the air fare increases, the purchasing power of the intercity travel budget becomes smaller. We exclude the income effect and estimate the compensated cross elasticities for bus and rail service. A 1 percent increase in air fare results in a 0.522 percent increase in the compensated demand for bus and a 0.568 percent increase in the demand for rail. The model predicts that a change in air fares has the most significant impact on intercity travel demand and a change in rail fares the next most significant impact. A change in bus fares has a minimal impact on the intercity market structure. A 1 percent increase in bus fare causes a 0.863 percent decrease in the demand for intercity bus service. To evaluate the substitutability among alternative travel modes, we exclude the income effect and estimate the compensated cross elasticities. A 1 percent increase in bus fare results in a 0.025 percent increase in air travel demand and a 0.099 percent increase in rail travel demand.

The own price elasticity of rail demand is -0.79, the smallest among the three modes. The compensated cross elasticities of rail are 0.083 and 0.301 with respect to air and bus demand, respectively.

The market cross elasticities fail to show substitutability among alternative modes. Previous studies on intercity travel demand, such as the Northeast Corridor models (1-3) and some disaggregate models (4), had negative market cross elasticities; i.e., as the fare of one mode increases, there is a decrease not only in the demand for that mode but also in the demand for competing modes. Previous empirical studies attempt to correct this apparent inconsistency by using the inequality-constrained least-squares estimation method (12, 13). Our study shows that this inconsistency is caused by income effects and not necessarily by specification errors in the model. Actual average passenger kilometers during the sample period are 929, 248.4, and 100 km (576, 154, and 62 miles) for air, rail, and bus, respectively. The model predicts an average passenger demand of 913, 247, and 99.8 km (566, 153, and 61.9 miles) for the three modes, respectively (see Table 3).

It is interesting to observe how passengers react in response to various fare and speed changes. We consider two cases: (a) a market simulation in which the money budget (M) remains unchanged and (b) a compensated simulation in which the utility level remains unchanged. These results also are given in Table 3.

Our model does not assume a constant elasticity. The value of the price elasticities may vary depending on which point we evaluate. We decided to evaluate passenger kilometers by varying various passenger fares and the speed ratios.

The deregulation of air fare is expected to provide lower air fare by providing various types of discounted trips. We simulate the model by decreasing 10 percent of air fare. The 10 percent reduction should be interpreted as the average reduction per customer because of the introduction of more discounted classes of air fares. The 10 percent fare reduction increases the average passenger kilometers of airline service from 913 to 1009 km (from 566 to 626 miles), a 10.1 percent increase. The reduction in air fare increases the purchasing power of the intercity travel budget. Because of this income effect, passenger kilometers by bus and rail also increase. Passenger kilometers by bus increase from 99.6 to 102.8 km (61.9 to 63.9 miles) and passenger kilometers by rail also increase from 246 to 252 km (153 to 157 miles) because of the increased purchasing power of the intercity travel budget. The same simulation was done by excluding income effects, a process called compensated simulation. A 10 percent reduction in air fare increases air passenger kilometers to 922 (573 miles) from the original 913 (566 miles). As expected, bus passenger kilometers decrease from 99.6 to 94 (from 61.9 to 58.5 miles) and rail passenger kilometers also decrease from 247 to 232 (from 153 to 144 miles).

A fare reduction affects passenger demand in two ways: (a) through an increase in real income and (b) through the price attraction. Table 4 gives the details. For example, a 10 percent decrease in air fare increases air passenger kilometers by 96.7 (60 miles), of which the 85.4-km (53-mile) increase is a result of higher real income and the remaining 11.2-km (7-mile) increase is a result of the attractive lower fare. Higher real income also increases the demand for bus and rail service by 8.7 and 21 km (5.4 and 13 miles), respectively. However, since the prices of bus and rail are not attractive in comparison with the reduced air fare, intercity passengers switch to airlines. Therefore, bus demand and rail demand decrease by 5.5 and 14.5 km (3.4 and 9 miles), respectively, because of the substitution effects. It is interesting to observe that the largest income effects are on air travel demand, followed by those on rail and bus. This is attributable to the fact that air service has the largest share of the intercity travel budget (approximately 83 percent). Income effect is measured by budget share times the marginal change in demand attributable to income change [$s_j (\partial x_j / \partial m)$].

Another interesting question for transportation policymakers is how industries share their markets in response to fare and speed changes. Data given in Table 5 show that the predicted average market shares of the model for the sample period are 83.67 percent for the airline industry, 4.04 percent for the intercity bus industry, and 12.29 percent for the rail industry. A 10 percent reduction in air fare shrinks the air travel market share from 83.67 to 83.19 percent. Since the inelastic price elasticity of air fare (-0.945) has already been seen in Table 2, these results are not surprising (the revenue of a firm declines as the price is lowered if the firm is selling a product that has an inelastic price elasticity). However, the 10 percent reduction in air fare expands the market shares of the bus and rail industries. The bus industry expands its market share from 4.04 to 4.17 percent, and the rail industry expands its share from 12.29 to 12.64 percent. This is partially caused by income effects and partially by the inelastic price elasticity of air fare. Similar results are observed when bus fare or rail fare decreases. Because of inelastic fare elasticity, a reduction in fare reduces the market share of that industry. For example, a 10 percent reduction in bus fare reduces the bus market share from 4.04 to 3.98 percent. The airline industry is the only gainer from the reduction in bus fare. The air market gains from 83.67 to 83.80 percent, whereas there is a slight reduction in the rail market share. A 10 percent reduction in rail fare reduces the rail market share from 12.29 to 12.02 percent. It also reduces the bus market share from 4.04 to 3.96 percent. Such a reduction is caused by the expansion of the air passenger market. The airline industry boosts its market share from 83.67 to 84.02 percent.

The model is simulated by increasing air speed by 10 percent. Competition among airlines is expected not only to introduce lower fares but also to improve the quality of service by means of faster aircraft. A 10 percent increase in the speed of air service could expand the air travel market by as much as 84.97 percent, which is approximately a 1.54 percent increase. The loser from the air speed increase is the rail industry, whose market share decreases from 12.29 to 10.84 percent. The market share of the bus industry increases from

Table 3. Results of price simulation.

Measure	Market Simulation Air	Bus	Rail	Compensated Simulation Air	Bus	Rail
Average passenger kilometers predicted by the model before simulation	912.9	99.7	246.7	912.9	99.7	246.7
Kilometers with fare decrease						
Air						
10 percent	1009.6	103	253	924	94.3	232
25 percent	1198.3	108.8	266	943.5	85.6	209.6
Bus						
10 percent	914.5	97.9	245	911.3	108.8	243.5
25 percent	917.7	94.6	242	906.4	126.3	240.3
Rail						
10 percent	917.7	108.7	267.7	906.4	96.6	264.5
25 percent	924	127.7	309.6	893.5	91.4	298.3
Kilometers with fare increase						
Air						
10 percent	835.4	96.7	240.3	904.8	104.8	261.2
25 percent	740.3	92.7	232	892	112	280.6
Bus						
10 percent	913	92	248.4	916	92.3	250
25 percent	909.6	82.3	250	919.3	83	251.6
Rail						
10 percent	909.6	101.4	229	921	102.7	232
25 percent	904.8	103.7	206.4	930.6	106.7	213

Note: 1 km = 0.62 mile.

Table 4. Decomposition of income and substitution effects.

Measure	Change (km) Total	Due to the Real-Income Increase	Due to Price Incentive
Effect of 10 percent decrease in air fare on			
Air demand	1009.6 - 912.9 = 96.7	1009.6 - 924 = 85.4	96.7 - 85.4 = 11.2
Bus demand	103 - 99.7 = 3.3	103 - 94.3 = 8.7	3.3 - 8.7 = -5.4
Rail demand	253 - 246.7 = 6.3	253 - 232 = 21	6.3 - 21 = -14.7
Effect of 25 percent decrease in air fare on			
Air demand	1198.3 - 913 = 285.3	1198.3 - 943.5 = 254.8	285.3 - 254.8 = 30.5
Bus demand	108.8 - 99.8 = 9	108.8 - 85.6 = 23.2	9 - 23.2 = -14.2
Rail demand	266 - 246.7 = 19.3	266 - 209.6 = 56.4	19.3 - 56.4 = 37.1

Note: 1 km = 0.62 mile.

Table 5. Simulation of market revenue share.

Measure	Air	Bus	Rail
Predicted average market share before simulation[a]	83.67	4.04	12.29
Market share with fare decrease			
Air			
10 percent	83.19	4.17	12.64
25 percent	82.35	4.40	13.24
Bus			
10 percent	83.80	3.98	12.21
25 percent	84.04	3.88	12.08
Rail			
10 percent	84.02	3.96	12.02
25 percent	84.62	3.83	11.55
Market share with 10 percent fare increase			
Air	84.11	3.92	11.98
Bus	83.55	4.09	12.36
Rail	83.36	4.11	12.54
Market share with change in speed ratio			
10 percent increase	84.97	4.19	10.84
25 percent increase	89.18	4.68	6.14
10 percent decrease	82.24	3.87	13.89

[a] Average market share of each industry for the sample period.

4.04 to 4.19 percent. The increase in air speed hurts the rail industry and benefits the air and bus industries. One possible explanation is that the bus is used for short-distance trips and air and rail are used for long-distance trips.

What, then, are the best strategies by which the airline industry can expand its market share? The model suggests that increased air speed is the most effective way to increase the air share of the travel market. Fare reduction is not an effective way to improve the market share. The study shows that airline service is not a luxury but a necessity. The inelastic price elasticity reduces revenue as the airline industry lowers the air fare. The industry could expand its market share through the introduction of higher-speed aircraft, not through the reduction of air fares. Our conclusion is based on the given intercity travel budget. If the intercity travel budget increases, the airline industry becomes the largest beneficiary since the air mode has the largest income effect.

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Airport Planning: A Consultant's Viewpoint

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The evolution of airport development, the utility and benefits of airports, and the problems of expanding or implementing a major new airport facility in light of the many constraints imposed by opposition groups are briefly examined. The responsibility of government in planning airport operations and expansion is discussed. It is concluded that too many agencies are responsible for accomplishing a sound airport transportation system and that one overall agency should be responsible for ensuring adequate airport development in all areas—roads, the groundside, and the airside.

The past decade has witnessed extreme frustration in the evolution of aircraft, the forecasting of air travel, and the expansion of existing airports and provision of new airports to serve a growing need. This paper begins with a brief recap of the evolution of air travel and air facility development, highlighting some of my own experiences in planning for the growth and expansion of a number of regional airports in this country and abroad.

Between 1965 and 1970, there was phenomenal growth in air travel, in both passenger and goods movement. Government, state, and municipal groups responsible for airport planning became acutely aware of capacity restraints imposed on this growth and readied many plans and funding programs to proceed expeditiously with airport development.

In the past five years, there have been some major reductions in the growth of air travel as well as a number of major changes in the overall transportation industry. The oil crisis of 1972 and 1973 affected the airline industry harder than most. In contrast to the period of meteoric expansion during the 1960s, the situation has now somewhat reversed. Before the downturn, new aircraft were in the making and interface facilities were being constructed at airport terminals. But administrative officials have become very reluctant to spend additional money at the earlier pace. In addition, environmental considerations have moved to the forefront in the 1970s to such a degree that air quality and noise levels are considered as important as economic recession and inflation and the energy crisis in the decision making on all investments in airport planning and development.

OVERVIEW OF THE PAST 20 YEARS

The first era of air travel after World War II was one of general accord among aircraft, airports, people, and the environment. Propeller-driven aircraft predominated until the end of the 1950s, when turboprop engines were introduced. This was the golden age, in which aviation lived in a state of amity with all of its neighbors, but it was relatively short-lived. The image of aviation was by no means a negative one. The typical airport was rather modest, short on marble walls and multi-story parking facilities. Most airport terminals featured single-story buildings with a back door to the airport apron and a front door to the parking lot. You could actually see the aircraft!

In general, aviation was accepted by local communities as a good source of employment and a necessary support to local service industries and commerce. Although many problems had already been encountered in the development of new and existing airports, such as Idlewild in New York (now known as John F. Kennedy International), no one yet understood the severity of the problem of airport development.

Further development of aircraft into the jet age and the jumbo jet age—from the Viscount to the 707, the DC 8, the VC10, the BAC1-11, and now the Concorde, with its noise and negative environmental impacts—has practically stymied the development of new airports.

The past two decades have also seen marked increases in flying speed. From the operator's point of view, this produced an increase in the number of kilometers a plane could fly in a given period of time and especially reduced amortization cost per aircraft kilometer. Simultaneously, larger aircraft were being introduced, accompanied by projections of substantial economies in both capital and operating cost per seat per kilometer. This phenomenon triggered additional growth and a whole new market for leisure and holiday flying. It is not surprising that runway capacity, as well as groundside parking and access systems and terminal buildings themselves, came under pressure.

On the subject of noise, the emphasis has shifted from purely local issues to national and international issues.

FUTURE PROSPECTS

In the past two years, air travel in most corridors has grown by 10-15 percent annually. Most airlines are back in the black, and prognostications of future growth trends in air travel appear positive. Most experts now seem to agree that annual growth rates of approximately 15 percent/year will probably not recur, but growth in passenger travel in the range of 10 percent/year is now reasonable. This points up the necessity to continue planning and building airports, since it is doubtful that equilibrium or a ceiling level will be reached.

Today's problems and prospects in planning for future airport access facilities can be outlined as follows:

1. The difficulty of forecasting growth in patronage;
2. Confusion about responsibility for airports when there may be a state plan and a city plan and a question as to who is to fund improvements;
3. The question of who benefits from a proper response—(a) owners, (b) carriers, (c) owners of adjacent property, or (d) travelers;
4. The question of who is to pay for (a) energy costs, (b) environmental delays, (c) funding delays, and (d) congestion delays; and
5. How to plan compatibly to serve both existing and future needs.

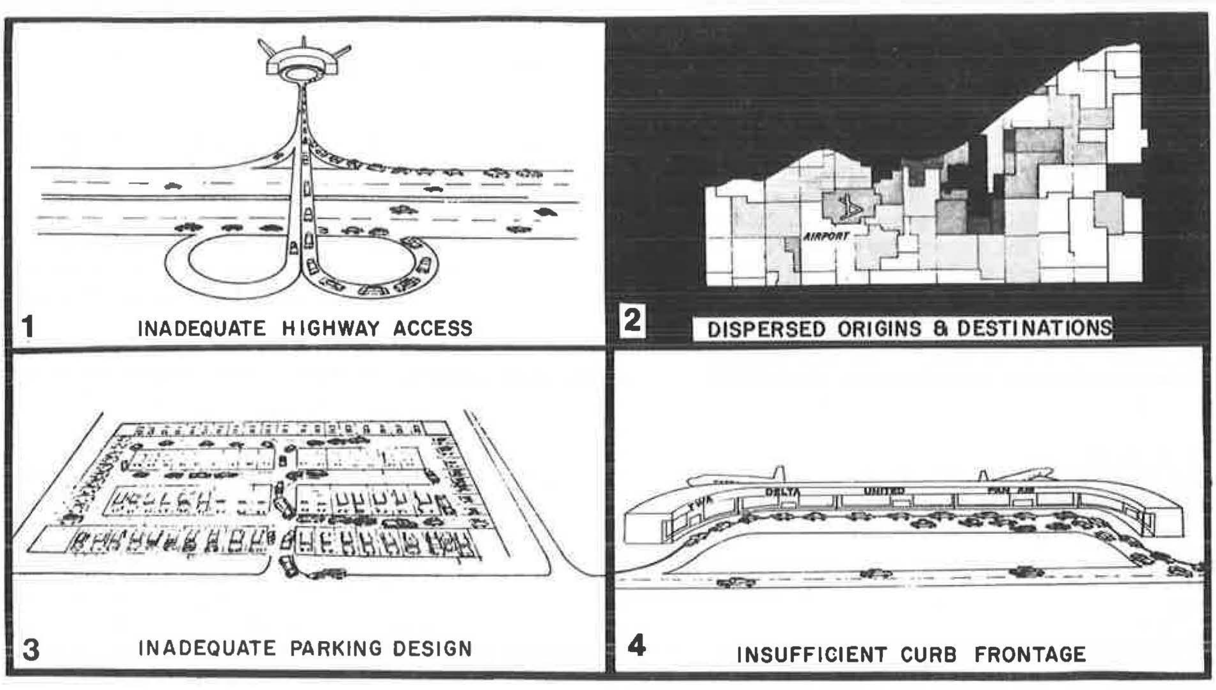
Technological advances will continue to reduce total cost, although these advances may well be less dramatic than those of the past 15 years. Additional marketing strategies to attract charter traffic will be developed. Essentially, more people will continue to use the air mode to link origins and destinations separated by great distances. International air travel is forecast to increase more drastically than domestic air travel, and a high proportion of the predicted growth in demand is in the leisure rather than the business sector.

Airlines will be placed under more pressure to develop greater fuel economy and reduce aircraft noise. They will have to accelerate the retirement of older equipment from main-line service, which will add to the need to reduce their capital for the purchase of new aircraft and ancillary facilities.

Another point that bears mentioning is that, with larger aircraft and greater payloads, airside facilities (runways and aprons) will reach capacity at a slower rate than groundside facilities (roads and parking facilities) and terminal buildings that accommodate person movements. The concentration of curb-frontage activity and related pressures in central parking areas will become a more serious problem on the groundside and necessitate major expenditures on vertical expansions of enplaning and deplaning levels and on parking areas and roads.

Twenty to thirty years ago, the airport was a major attraction for recreational trips and sightseeing. Because of land availability, the airport was viewed in a rural context and thought of only as a support facility to the community. Today, the airport is urban rather than rural in context and a most important part of the urban fabric. We must treat it accordingly, not only as

Figure 1. Major reasons for airport ground delays.



a place to arrive and depart by air but also as a place to shop, to work, and to conduct business.

FUTURE PROBLEMS

Previous studies have indicated that there are four prime issues in landside planning for airports (see Figure 1):

1. Origins of trips from home or work to the airport are so dispersed in urban areas that few, if any, justifiable transit corridors exist to facilitate the trip linkage between home or work and the airport. This makes it necessary to use private, semipublic, or public vehicles on the road system to effect the linkage, which further adds to demands for more and better highways.
2. Few major regional airports have more than one major highway linkage to the major regional highway networks. This adds to the problems of congestion and delay during hours of peak airport use, work-shift changes, and so on.
3. Too much parking has been placed in the central terminal area in close proximity to the airport terminal for a proper balance among terminal capacity, parking capacity, and roadway capacity. This further increases congestion and confusion in the central terminal area.
4. Too much pressure is placed on enplaning and deplaning linkage between vehicles and terminals. Curb frontage is perhaps the most precious real estate at any airport terminal facility because of this great need.

In my opinion, there are institutional constraints that are also paramount in the proper development of new and improved airport facilities. These constraints involve the interaction between the government groups responsible for airport planning and development. Airport development is largely supported by federal funds. Formulas have been conceived to facilitate this development, but they are not realistic, acceptable, and fair in all cases. This fact alone causes great concern among many people and results in animosities and disputes that stymie good, timely airport planning and development. Funds that were designated to be spent on the basis of zero-budget funding are thus encumbered and not used as intended.

Federal regulations are, in many instances, misused to delay airport development. Environmental impact statements alone can set back an airport program for as much as 10 years. It is easy to see that, when the growth of patronage continues and airport improvements are delayed, the problem is further compounded and the losers are usually travelers, their businesses, and their families and ultimately, in some cases, the community and the owners of the airport complex. From my vantage point, the most difficult institutional problem is the inertia and discord among airport planners, sponsors, and benefactors. It is unlikely that major changes or improvements will occur, but I believe that, if funding mechanisms at the federal level could be more streamlined and funds used more readily for their intended purposes, it would offer the greatest challenge and benefit to airport growth and development.

Another paramount issue in improving airports and expanding existing ones relates to the groundside components of roads, parking facilities, intra-airport transportation, and pedestrian linkage between the automobile and/or public transportation and the airport terminal building. Employee parking must be differentiated from public parking. Public parking should be differentiated as to short-, medium-, and long-term duration. Short- and medium-term parking should be accommodated close to the terminal; in most cases, long-term parking can be more remote from the terminal and some shuttle bus service can connect interim origin and destination at the airport.

Travel needs know no fixed areal subdivision, ownership, or municipal boundaries. Highway planning and fixed-rail planning for access to airports tend to be jeopardized because of the infrastructure of planning responsibility, airport ownership, and regional transportation development needs. Most airport road systems are primarily planned only by the owner, to the boundary of the airport property. The state or city or county responsible for the roads that lead to the airport from the regional network of highways is then responsible for the external road system. Case history after case history clearly emphasize the resulting breakdown in the planning and facilitation of roads that link highways and airports. In my view, if some changes could be made uniformly throughout the country to give the responsibility for airport access to a single agency, this situation would be markedly improved.

ACKNOWLEDGMENT

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Decision Tool for Analysis of Capacity of Airport Terminal Buildings

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A systems approach to the analysis of the airport system is presented. Airport managers currently do not have a viable tool for determining the effects on capacity of altering the location, operation, or design of individual components within an airport. Models currently exist for analyz-

ing airside capacity, but there has been no means available for comparing and balancing the capacity of all landside components. The technical literature does not contain a method for analyzing these units as a system. A new definition of the airport system and a new systems-analysis-based definition of capacity in relation to level of service are presented, and an algorithm and a computer program that analyze the flow of passengers through the airport system as a function of time are discussed.

Currently used methods of analyzing the capacity of airports may be termed a "component approach". In these methods, analytical models and simulations are used to determine the capacity of an individual component independent of the rest of the airport system. The problem with using such an approach is the absence of a mechanism for balancing flows in all the components, which results in providing excess capacity in some components and congestion in others.

The alternate approach to the problem of determining airport capacity is a systems approach. The systems approach forces the analyst to use a broader, more comprehensive frame of reference than that typically used in air transportation. Thus, the capacities of the individual components are computed and compared and all the components can be balanced.

A systems procedure for analyzing air terminal flow has been presented in a series of reports that were part of a research project sponsored by the U.S. Department of Transportation (DOT). A report by Gualda, McCullough, and Dunlay (1) outlines the basic modeling for the components. Chmores and McCullough (2) report on the collection, at a number of airports, of data that were used for model development and verification. Park and Dunlay (3) report on the development of models for intervening activities. Chambers and McCullough (4) report on the overall computer program and the development of a user's manual. These reports should be examined for a detailed explanation of the study.

The objective of this paper is to present an overall summary of the ACAP1 program and briefly demonstrate its capabilities and applications. More detailed information on the procedure is available in the development reports (1-4).

APPROACH TO THE PROBLEM

In a systematic approach to design, the limits of the system are first defined, then various approaches to capacity are discussed, and finally the approach used in the study is selected.

Airport System

For the purposes of this research, the airport has been designated as a system whose boundaries are specified as the airport entrance gate on the landside and the airspace under the control of the approach-departure air traffic control facility on the airside. However, sites of general aviation activity as well as sites of other noncommercial passenger-related airport activity, such as air cargo facilities, mail-handling facilities, and government agency and airport administration areas, are not considered.

To analyze a large, complex system such as an airport, it is necessary to divide the system into subsystems. In this study, the airport system was divided into four subsystems: (a) the on-airport access-egress subsystem, (b) the terminal building subsystem, (c) the apron subsystem, and (d) the airside subsystem.

The on-airport access-egress subsystem entails the movement and storage of vehicles that enter the airport grounds and proceed directly to the terminal building curbside or parking area. In this subsystem, the processing unit is vehicles. Within the terminal building subsystem, the processing unit changes from vehicles to passengers and baggage. After they are processed through the terminal building subsystem, passengers and baggage move into the apron subsystem, where both the loading of passengers and baggage and the cleaning and servicing of the aircraft occur. Here the processing unit changes from passengers and baggage to aircraft. The airside subsystem includes the movement of aircraft from the apron to the boundaries of the terminal airspace.

Because many activities occur in each of the subsystems, it is necessary to further divide each subsystem into individual components. In systems engineering terminology, a component is the smallest element into which a system is divided for the purpose of analysis. In this paper, the term "component" is used to describe an individual processing or storage unit.

A schematic representation of the airport system is shown in Figure 1. It should be noted that in the past most schematic diagrams of airports depicted an exact functional flow through the different components, especially in the terminal building, but this is not the case in Figure 1. The subsystems are fixed close to actual flow paths, but their exact linkages are left unspecified. The exact linkages between components are not defined in order to provide flexibility in adapting the system definition to any airport configuration.

This paper deals only with the terminal building subsystem and those components within the terminal building that are involved with passenger movements from the building entrance up to and including the jetway into the aircraft.

Airport Capacity

Capacity is an index of the performance and capability of an airport in servicing the processing unit. Historically, the capacity of an airport was assumed to be limited by the airside operation. As a result, research and development in airport capacity have concentrated primarily on airport runways and gates. However, the growth in the number of passengers processed at airports has shifted the emphasis of the capacity problem. There is increasing evidence that the landside is becoming the constraint on airport system capacity. Because of the prior work in airside capacity and the shift in emphasis to the landside, the terminal building subsystem was chosen as the starting point of this research study.

As it became evident that the landside was becoming the constraint on capacity, DOT asked the Transportation Research Board to convene a workshop conference to discuss problems that relate to airport landside capacity. The subjects for consideration at the 1975 workshop included (a) level-of-service methodologies to quantify airport landside capacity, (b) engineering techniques to increase landside capacity, and (c) analytic tools for use in improving landside level of service.

A review of papers presented at the conference (5-8) shows that it is becoming increasingly common to consider capacity with a corresponding level of service. For example, Heathington and Jones (5) point out that, "Capacity is the physical provision required for a given demand at a given time at a specified level of service" and "When capacity is defined as ultimate or maximum capacity, it is generally associated with the lowest level of passenger service." This concept is similar to the concept of highway capacity (9).

In order to develop a capacity that relates to level

Figure 1. Generalized schematic representation of the airport system (flow lines omitted).

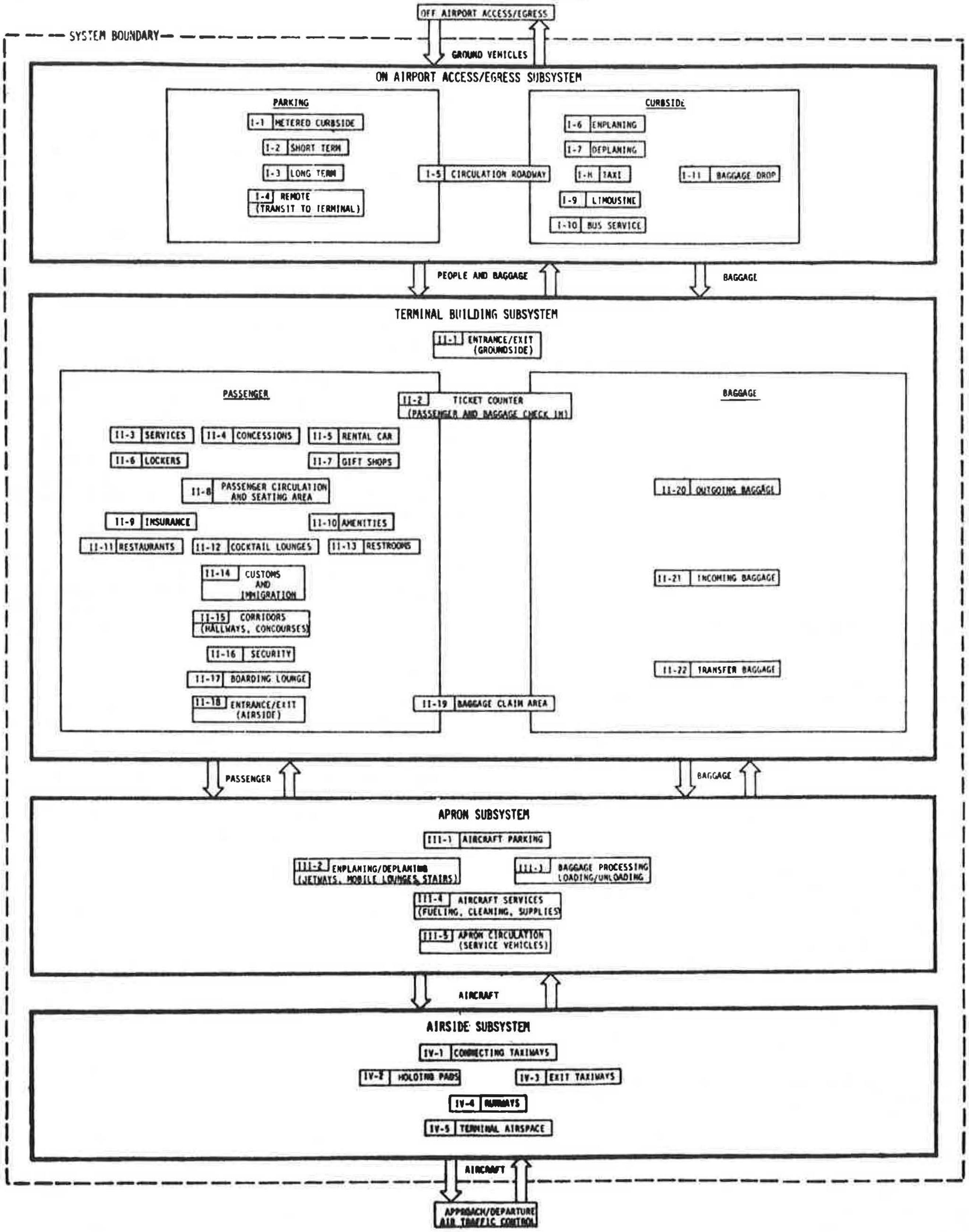
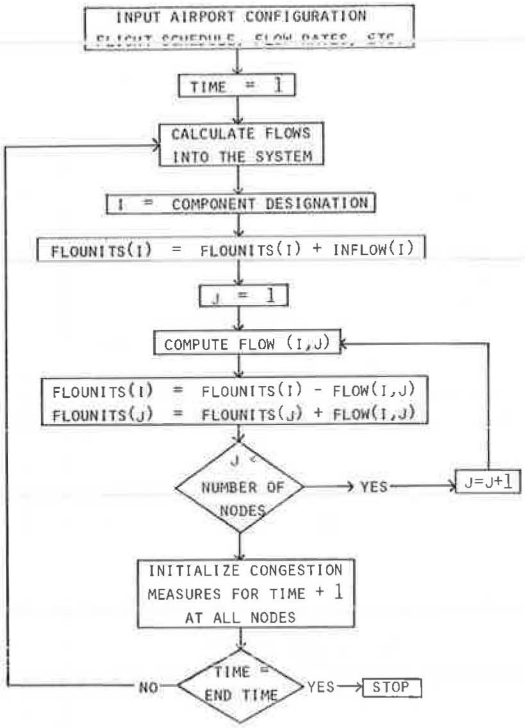


Figure 2. Calculation sequence of ACAP algorithm.



of service, definitions of the following terms are necessary:

1. Level-of-service measure—a physical measure of how a component subsystem or system performs, and
2. Level-of-service criterion—a specified maximum tolerable limit on the level-of-service measure.

The capacity of the airport system, as well as its subsystems and components, is a direct function of three concepts:

1. The level-of-service criteria for the system, subsystems, and components of the airport in question;
2. The period of time over which capacity is to be determined; and
3. The pattern of demand of passengers, aircraft, baggage, and ground vehicles for the airport in question.

The following definitions of airport capacity (designated ACAP) have been adopted for use in this study:

1. Airport system capacity—the maximum level of demand of a given pattern that can be imposed on an airport system in a given interval of time without violating any specified level-of-service criterion for the airport system as a whole for any of its subsystems or components,
2. Airport subsystem capacity—the maximum level of demand of a given pattern that can be imposed on a subsystem in a given interval of time without violating any specified level-of-service criterion for the particular subsystem or any of its components, and
3. Airport component capacity—the maximum level of demand of a given pattern that can be imposed on a component in a given interval of time without violating a specified level-of-service criterion for that component.

As defined above, a level-of-service measure is a physical measure of how a system or part of a system performs. But the opposite measure—level of congestion—is much easier to visualize and quantify. Level of congestion is defined as a measure of how poorly a system or a portion of a system performs. Thus, the more a level-of-congestion measure increases, the worse the system, subsystem, or component performs, and vice versa. In this paper, measures of congestion such as queue length and waiting time are used to denote system, subsystem, and component performance.

MODELING TECHNIQUES

To develop a computer program for modeling passenger and baggage flow within an airport terminal, a basic algorithm was established for the flow network and a series of submodels for various components in the terminal, e.g., ticket counters, security check, and lounge area. As mentioned previously, prior work in this area has been very limited because most of the development has been on the airside of the airport. Thus, we decided to either use previously developed models or develop mathematical models based on field observations.

The basic algorithm for the ACAP model is presented below, and two modeling procedures are demonstrated. One method is component modeling by the use of regression analysis of experimental observation; the other method is a conventional modeling process of mathematically describing experimental observations.

ACAP Algorithm

Since the number of people at a given component at any time is a function of the flow of people through preceding activities, a stagewise or recursive algorithm was selected as the most suitable means of modeling flow through an airport. Because of the complexity of many airports and the highly time-dependent nature of some passenger flows, a single steady-state description of the airport that applies for all times, or even for an interval of a few hours, was not possible. The arrival of passengers at a check-in is an example of a flow that varies dramatically with the flight schedule.

The algorithm adopted accomplishes two purposes: The first is to determine the change in the status of the demands at the various activities from one time interval to the next, and the second is to determine the congestion measures at each activity during the previous time interval. Reasonable time intervals for use in an analysis should be from 1 to 5 min.

The ACAP algorithm performs calculations in the following sequence, as shown in Figure 2.

1. Calculate the flows into the system during the next time interval from the groundside and from the airside on the basis of data input by the user. Increment the appropriate counters to indicate the increased numbers of units at all components affected by current flows.
2. Set I = 1.
3. Call a subroutine to calculate the flow from activity I to each activity J for which flow from activity I to activity J exists. Decrement the counter for component I to indicate this outflow.
4. Increment the counters for activities J to reflect the inflows that occur during the following time interval.
5. Test to determine if I is less than the total

number of components. If it is, increment I by one and go to step three; otherwise, go to step six.

6. Calculate the measures of congestion for each activity as a function of the flow to that activity during the following time interval, the service rate, the number of servers, and on to completion.

Because the capacity of an airport is affected by the number of users at the initial condition, it is usually suggested that the starting time for the calculations be midnight or early morning or some other time when the airport can be considered empty, except possibly for some long-term parking. These initial conditions, then, will have little or no effect on the calculations performed for the day or evening, when the capacity of the airport is most likely to be approached.

In its stepwise nature, the algorithm above, which is repeated once for each time interval for the period during the day to be analyzed, is reminiscent of simulation, but it differs from simulation in the following basic ways:

1. The method described above deals with network flows during discrete time intervals rather than stepping individuals through the airport and scheduling successive arrivals at all facilities for all persons as distinct events.
2. In the ACAP algorithm, the average waiting times and queue lengths during discrete time intervals are computed internally by using analytical models. In simulation, however, the exact number in each queue, transit, or service is tabulated continuously throughout the analysis period, and then the average measures of congestion are computed externally, on a strictly empirical basis, after the simulation is completed.

Because of these factors, the proposed method requires considerably less computer time than a simulation model would.

Component Modeling by Empirical Methods

The executive algorithm handles flows from node to node in a very general and computationally efficient way. Thus, each of the component models focuses on the activity at a particular node or type of node.

The executive algorithm handles the flows within discrete time steps, the durations of which are input by the user. At the beginning of a time step, at a given node, the present queue length Lq is known, as is the total number of people T who will desire service at that node during the time step. T, then, can be thought of as the number of people in the system at the beginning of the step plus new arrivals at the node during the step. The algorithm requires computation of (a) congestion measures at the end of the time interval and (b) the number of services during the interval.

In view of the fact that the user inputs the time step Δt, this quantity must be treated as a variable in the analysis.

The approach used for developing component models through regression analysis is illustrated below for the security check and the ticket counter to demonstrate the concepts.

Security Check

To treat the time step Δt as a variable, the data are grouped into successive time intervals with lengths that vary randomly from, say, 0.5 to 5 min. The data are then arranged as follows:

Lq_j = queue length at the beginning of the j th time interval,
T_j = number of people who desire service during the j th interval (Lq_j plus the number currently being served plus the number of arrivals during the interval),
$FOUT_j$ = number of services during the j th interval,
μ_j = average service rate during the j th interval, and
Δt_j = length of the j th interval.

Then the following regressions are performed on terminal observations:

$$\hat{Lq}_{j+1} = f(Lq_j, T_j, \mu_j, \Delta t_j) \quad (1)$$

$$\hat{FOUT}_j = g(Lq_j, T_j, \mu_j, \Delta t_j) \quad (2)$$

An estimate of Lq_{j+1} can be obtained from $\hat{FOUT}_j$:

$$S_{j+1} = T_j - FOUT_j \quad (3)$$

is the number in the system at the end of the j th time interval. Then,

$$Lq_{j+1} = \begin{cases} 0 & \text{if } S_{j+1} = 0 \\ S_{j+1} - 1 & \text{otherwise} \end{cases} \quad (4)$$

But an attempt to compute $FOUT_j$ in terms of $\hat{L}_{j+1}$ involves an ambiguity of one if $\hat{Lq}_{j+1} = 0$.

The treatment of μ_j requires additional consideration, since observations indicate that the service rate increases as the queue length increases. It is convenient, however, to use a constant overall service rate μ and allow the predictors Lq_j and T_j to account for increased numbers of services when there is congestion.

There are analytical methods for computing the average time spent in the queue as a function of queue length (10). However, the following is more consistent with the calculation of measures of congestion for a point in time and requires no assumptions regarding stationarity. As discussed previously, the queue length Lq at the end of an interval is calculated; thus, the time spent in a queue of this length is

$$\sum_{i=0}^{Lq-1} X_i \quad (5)$$

where X_i (i = 1, 2, ..., Lq - 1) = service time for other members of the queue who arrived earlier and X_0 = time required for the service currently being performed. But the mean of this sum is Lq/μ.

The fact that the current service may be partly completed when the Lqth person entered the queue has been disregarded above. The average waiting time Wq so obtained is the average waiting time that corresponds to a queue length of Lq, not the average waiting time during a period of time during the day. This calculation of Wq, moreover, involves no prior assumptions regarding probability distributions, services, or interarrival times; the only assumption is that the average service time is known. Whatever random properties are exhibited in the data, however, are reflected in Wq.

Ticket Counters and Check-In Stations

The check-in stations and ticket counters are modeled as discussed above, except that the number of servers must be treated as another variable. Thus, the following regression formats were developed:

$$Lq_{j+1} = f(Lq_j, T_j, \mu_j, C_j, \Delta t_j) \quad (6)$$

$$FOUT_j = g(Lq_j, T_j, \mu_j, C_j, \Delta t_j) \quad (7)$$

where C_j is the number of servers during the j th interval.

Empirical Limitations

A weakness of this approach is that the models developed are, strictly speaking, valid only for the airports for which data are included in the analysis or for other airports that are very similar to them. This problem was partially solved by collecting data from as diverse a set of circumstances as possible and including meaningful parameters in the regression models so as to allow the models to be adapted to a wide set of conditions.

It should also be noted that any approach to component modeling would involve either developing empirical models or using analytic queueing models on the basis of empirical validation. Thus, the only way to avoid the limitations of empiricism is to refrain from developing any models at all.

Intervening Activities Modeling

A method was used to include an "intervening activities" model in the airport capacity algorithm. This involved characterizing the intervening activities engaged in by airline passengers from an algorithmic standpoint and modeling the activity at the intervening activity nodes. The calculation of measures of congestion at intervening activities, which are less important than measures of congestion for essential activities, is a subject for future discussion. The algorithm deals with measures of congestion for essential activities.

Algorithmic Considerations

Technically, there is an opportunity for some sort of intervening activity (IA) by passengers between essentially any pair of nodes within an airport terminal building. Practically speaking, however, some points are much more likely to involve significant IA time than others. At some airports, for example, there is limited opportunity for intervening activities beyond the security check. Although one could go to an intervening activity before going to the ticket counter, it is reasonable to think that most people would go to the ticket counter—an essential activity that sometimes generates long queues and involves unpredictable waiting times—before engaging in unessential intervening activities. Thus, the single most likely point for significant IA time for people who have to buy tickets is between the ticket counter and the security check.

It is clear, however, that the most probable points for intervening activity are highly variable from airport to airport. It is reasonable, then, to allow the user to define the position of the major intervening activity nodes along with the rest of the airport configuration. It is anticipated that each path through the system will have at most two IA nodes, but this is not a constraint.

This approach for including intervening activities is very compatible with the executive algorithm that has been developed. Moreover, an approach that involved the modeling of intervening activities after each node would require much more core and execution time and would probably be less flexible than the suggested method.

Finally, it is more effective to handle intervening activities on a collective basis; that is, a given IA node can actually represent several separate activities, such as a restaurant, a gift shop, and a magazine stand that are all in the same area. Representing all of these activities as separate nodes would greatly increase core requirements and execution time, and it is doubtful that the additional modeling detail would yield significant useful information.

Component Modeling

At the beginning of a time step, the following information is available for any given IA node: (a) OCCUPY (L, I, IFL), or the number of units available to be serviced during the time step at node I, following path L, and destined to take flight IFL (the index IFL has an artificial meaning for deplaning units of flow); and (b) FLTIM (L, IFL), or the time of departure of flight number IFL, which is reachable through path L.

It was necessary to develop a mechanism for scheduling flows out of the IA nodes. To achieve this, a function f(t) was developed that gives the probability that a person in an intervening activity, who has available or excess time t before his or her flight, leaves the intervening activity during a time interval of length Δt.

Suppose, for path L and flight IFL, the available time at the beginning of the current time step is $\Delta t'$, which is not necessarily the same as Δt. The number of "service" completions at IA node I in one time step is given by

$$\text{OCCUPY}(L, I, IFL)\ f(t)(\Delta t'/\Delta t) \quad (8)$$

It has been assumed above that the probability of leaving the intervening activity is approximately constant during small intervals of time—say, up to 5 min. A single f function can thus be used for any reasonably small time step $\Delta t'$.

Next, the "available" time t must be calculated. The most obvious way to compute t is simply to form the difference between the flight departure time and the present time. This does not, however, take into account the inevitable path-to-path variations in the expected time required for necessary activities beyond the IA node. It was therefore decided that the user should input this expected required time following each IA node. The user can only make a rough estimate of the required time, of course, but this is exactly what a passenger would do in the process of deciding whether to engage in an intervening activity.

Time t, then, is

$$t = \text{FLTIM}(L, IFL) - T_1 - T(I) \quad (9)$$

where T_1 is the current time and T(I) is the estimated required time for further required activities beyond IA node I.

The development of the f function must be in discrete tabulated form: $f(t_i)$ $(i = 1, 2, \ldots, n)$, where $f(t_i)$ is the probability that a person in an intervening activity, who has available time equal to t_i, will leave the activity within a time interval of length Δt, the step size for the t_i array. The value of Δt is considered to be on the order of 2-5 min.

ACAP1 COMPUTER PROGRAM

It is not possible to present all of the input in the ACAP1

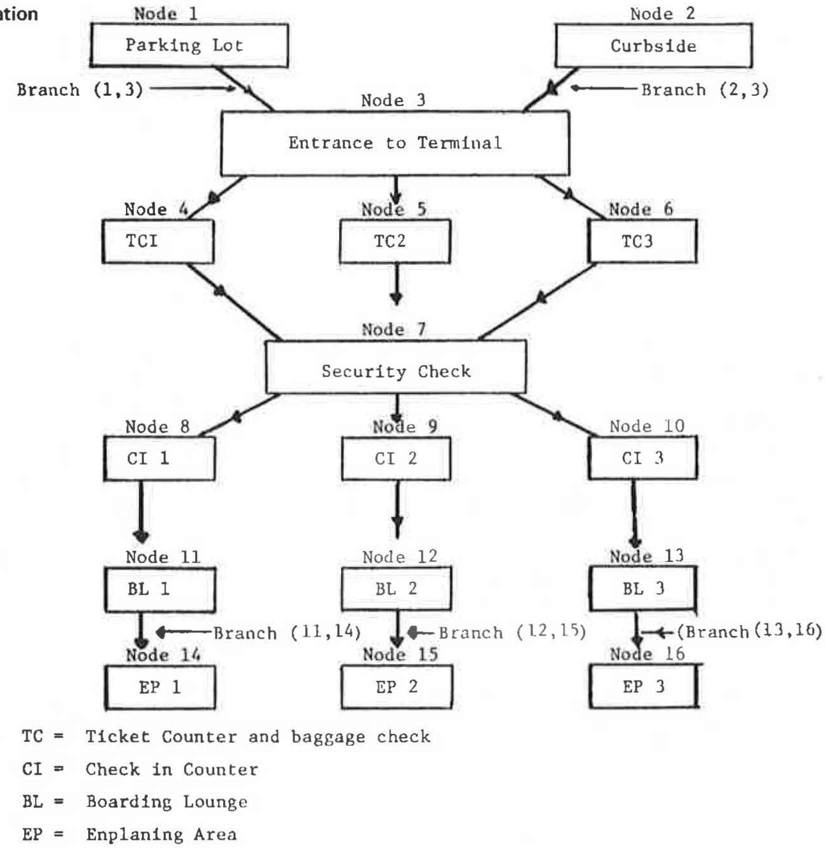
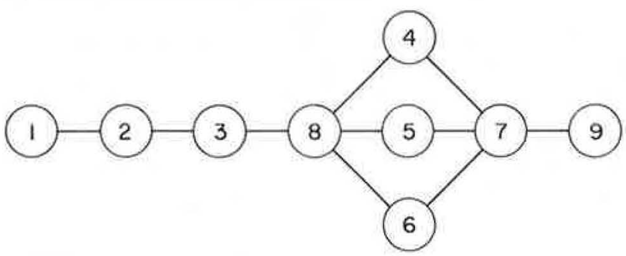


Figure 3. Enplaning portion of airport transportation network.



PATHS	SEQUENCE IN COMMON	PATH REWRITTEN USING SEQUENCES
1,2,3,8,4,7,9	(1) 1,2,3,8	(1),(2),(5)
1,2,3,8,5,7,9	(2) 4	(1),(3),(5)
1,2,3,8,6,7,9	(3) 5	(1),(4),(5)
	(4) 6	
	(5) 7,9	

Figure 4. Path-to-sequence transformation.

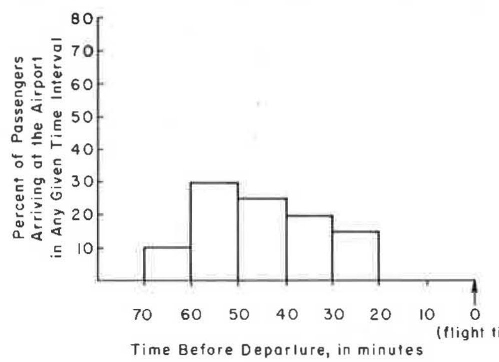


Figure 5. Distribution of passenger arrivals by intervals.

program, but a brief overview is given to demonstrate the concepts.

Description of the Program

The ACAP1 program was written in FORTRAN IV computer language for use with the CDC 6600/6400 computer system at the University of Texas at Austin. However, it is written in a form that should be relatively easy to use with other computer systems.

Since the program analyzes the flow of passengers through an airport system that has a given demand, as a function of time, the configuration of the airport is a required input to the computer program. The program is structured so that an airport design or subsystem design of any configuration or layout can be input by the user. It should also be noted that congestion caused by flows from outside a particular subsystem under consideration can be handled. Inputs from outside the system, such as the time-varying arrivals of passengers, are also defined by the user as input to the program.

It should be noted here that ACAP1 was developed as a preliminary program to test the overall algorithm. It was designed in modular form to permit the addition and deletion of individual component models as new component models are developed or existing models are updated, without affecting the overall algorithm. In fact, new component models are currently being developed and implemented into the program as part of the continuing ACAP research.

Conceptual Description of Input

It may appear at first glance that the input to this program model is somewhat intricate, but the generality of use as well as the accuracy of the program requires complicated input so that the program will be applicable to the wide variety of shapes, sizes, and configurations of either existing or planned airports.

Input of the Airport Configuration

An airport can be viewed as a transportation network. By defining the nodes of the network and the branches between nodes, the user can define any airport configuration. Consider, for example, the very simple case shown in Figure 2. The enplaning part of the system will be used to demonstrate the concepts. The required input would include (a) the number of nodes, (b) the activity type of each node, and (c) the sequence of nodes.

The number of nodes is equal to the total number of separate individual nodes. In the example shown in Figure 3, the number of nodes is equal to 16. Note that it is possible, in fact probable, to have more than 1 node of a particular type; for example, in Figure 3 there are 3 ticket-counter nodes.

The activity type of each node, although seemingly insignificant, is indeed critical. The program selects the specific model for use in computing the capacity of that node based on the type of activity that occurs at that node.

As mentioned above, the user-defined airport configuration is based on the network concept. In this concept, all components in the system (such as ticket counters, security checks, boarding lounges, and baggage claims) and paths through the system are represented by a series of nodes and links. There are two approaches to inputting the configuration of the system into the model. One approach is to input all paths through the system or subsystem with each node in sequence, as shown in Figure 4. This method, although simple, is very cumbersome. The second approach is slightly more complicated, but its primary advantage is that it drastically reduces the number of calculations, thereby reducing program running time and thus cost. In this method, the layout is first examined and the paths are categorized by the sequences they have in common. The paths are then input as a series of common sequences of nodes rather than a series of nodes. This transformation from paths constructed of nodes to paths constructed of sequences is demonstrated in Figure 4.

Input of Flows to the System

As mentioned above, the external flows of passengers to the system or subsystem must be input by the user. It was assumed that passengers arrive at the system or subsystem boundary according to an unspecified defined distribution that has one end at or near the flight departure time. This distribution can approximate a uniform, a normal, or some other known distribution. The arrival distribution is considered to be made up of the time differences between the departure time of the flight and the times at which the passengers arrive at the airport for the flight. If the distribution is divided into small time intervals, the arrival rate can be assumed to be constant over these intervals. For example, the arrival distribution curve shown in Figure 5 is divided into smaller time intervals over which the arrival rate is considered to be constant. Then the ending time of each of the smaller intervals and the constant arrival rates are input for each flight on each path.

Figure 6. Plan view of Hobby Airport terminal building.

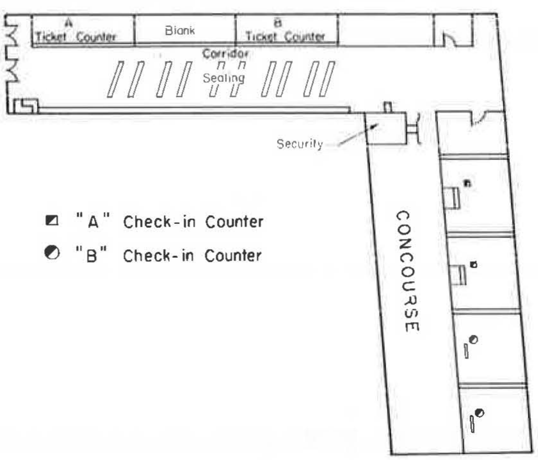


Figure 7. Input data for node characteristics.

AIRPORT SAMPLE PROBLEM NOV 18 1976

NETWORK PARAMETERS

NUMBER OF NODES = 10 NUMBER OF NODE SEQUENCES = 9 NUMBER OF PATHS = 8 SUMMARY TABLE TIME INTERVAL = 30 MIN

BEGINNING TIME = 6:00:00 ENDING TIME = 22:30:00 TIME STEP = 1.00 MIN NUMBER OF STEPS = 990 PRINT SAMPLE RATE = 60

ALL NODES WERE INITILIZED TO ZERO

NODE CHARACTERISTICS

NODE NUMBER	COMPONENT LABEL	MODEL NUMBER	AVG SERVICE RATE PER MIN	NUMBER OF SERVERS	MAX ALLOWABLE AVG QUEUE LENGTH	MAX ALLOWABLE AVG WAITING TIME(MIN)
1	TERM ENTR	2	20.00	2	4.00	.33
2	A TKT CTR	2	.60	4	8.00	15.00
3	B TKT CTR	2	.60	2	6.00	15.00
4	CORRIDOR	2	20.00	4	5.00	.50
5	SECURITY	2	5.00	1	20.00	5.00
6	CONCOURSE	2	20.00	6	2.00	.50
7	A CHECKIN1	2	2.50	1	15.00	6.00
8	A CHECKIN2	2	2.50	1	15.00	6.00
9	B CHECKIN1	2	2.50	1	15.00	6.00
10	B CHECKIN2	2	2.50	1	15.00	6.00

Figure 8. Input data for network characteristics.

NETWORK CHARACTERISTICS

** PATHS SHARING EACH NODE SEQUENCE **

NODE SEQUENCE NUMBER								
1	1	2	3	4	5	6	7	8
2	1	2						
3	3	4						
4	1	2	3	4	5	6	7	8
5	1	2	3	4	5	6	7	8
6	1	5						
7	2	6						
8	3	7						
9	4	8						

** NODES IN EACH SEQUENCE **

NODE SEQUENCE NUMBER		
1	1	
2	2	
3	3	
4	4	
5	5	6
6	7	
7	8	
8	9	
9	10	

** NODES SUCCEEDING SEQUENCE K FOLLOWING PATH L **

NODE SEQUENCE NUMBER K	PATH NUMBER L	SUCCEEDING NODE
1	1	2
1	2	2
1	3	4
1	4	4
1	5	4
1	6	4
1	7	4
1	8	4
2	1	4
2	2	4
3	3	5
3	4	5
4	1	5
4	2	5
4	3	3
4	4	3
4	5	5
4	6	5
4	7	5
4	8	5
5	1	7
5	2	8
5	3	9
5	4	10
5	5	7
5	6	8
5	7	9
5	8	10
6	1	-1
6	5	-1
7	2	-1
7	6	-1
8	3	-1
8	7	-1
9	4	-1
9	8	-1

** BEGINNING NODES FOR EACH PATH **

PATH	NODE
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1

APPLICATIONS

This program can be a valuable tool for making estimates of airport capacities for use by airport planning and design consultants, airport administrators, and other interested persons. It has application both to the analysis of existing airport components and the prediction of the capacities of components of future airports. The applications take two basic forms: (a) identification and specification of research and capital improvement priorities for various components of the airport system and (b) preliminary testing of alternate designs and sizing components so that individual capacities are adequate to meet projected demand and at the same time are balanced with the capacities of other components.

Since the measures of congestion are calculated for each time step at each component, it is possible to determine whether minimally acceptable service criteria are met at each component. Thus, if, at any time during the daily operation of the airport or candidate design of an airport, the measures of congestion become excessive at any component, the program then prints out a list of the components, the times at which the violations occurred, and the type of offending measure of congestion. The criteria for determining when a measure of congestion is "excessive" are specified in the input by the user. This type of output permits the user to analyze the sensitivity of these level-of-service measures of the airport by changing the flight schedule or available components, inputting the changes, performing another run, and analyzing the output. Thus, to examine the level-of-service effects of adding a second channel for

Figure 9. Input rates.

CONSTANT INPUT RATES

PATH NUMBER	RATE NUMBER	ENDING TIME OF RATE INTERVAL	INPUT RATE PER MIN
1	1	6:30:00	2.90
1	2	7:00:00	.01
1	3	7:30:00	3.00
1	4	8:00:00	.02
1	5	8:30:00	3.20
1	6	10:30:00	.01
1	7	11:30:00	3.00
1	8	12:30:00	.02
1	9	13:00:00	2.20
1	10	13:30:00	.01
1	11	14:00:00	2.20
1	12	14:30:00	.01
1	13	15:00:00	2.10
1	14	6:00:00	.01
1	15	16:00:00	2.00
1	16	16:30:00	.01
1	17	17:00:00	1.40
1	18	18:00:00	.01
1	19	18:30:00	.70
1	20	19:00:00	.01
1	21	19:30:00	.60
1	22	20:30:00	.01
1	23	21:00:00	.50
1	24	21:30:00	.01
1	25	22:30:00	0
2	1	6:30:00	.04
2	2	7:00:00	3.00
2	3	7:30:00	.05
2	4	8:00:00	3.10
2	5	8:30:00	.04
2	6	9:00:00	2.90
2	7	9:30:00	.10
2	8	10:00:00	2.50
2	9	10:30:00	.10
2	10	11:00:00	2.30
2	11	6:00:00	.10
2	12	12:00:00	2.10
2	13	13:30:00	.10
2	14	6:00:00	1.80
2	15	15:00:00	.08
2	16	15:30:00	2.50
2	17	16:00:00	.02
2	18	16:30:00	2.20
2	19	17:30:00	.03
2	20	18:00:00	1.90
2	21	18:30:00	.01
2	22	19:00:00	1.10
2	23	19:30:00	.01
2	24	20:00:00	.86
2	25	20:30:00	.02
2	26	22:30:00	0
3	1	6:30:00	.70
3	2	11:25:00	.01
3	3	11:55:00	3.20
3	4	18:00:00	0

CONSTANT INPUT RATES

PATH NUMBER	RATE NUMBER	ENDING TIME OF RATE INTERVAL	INPUT RATE PER MIN
3	5	18:30:00	2.60
3	6	22:30:00	0
4	1	8:45:00	0
4	2	9:15:00	3.40
4	3	15:10:00	.01
4	4	15:40:00	2.86
4	5	22:30:00	0
5	1	6:30:00	.40
5	2	7:00:00	.01
5	3	7:30:00	.50
5	4	8:00:00	.01
5	5	8:30:00	.60
5	6	10:30:00	.01
5	7	11:30:00	.20
5	8	12:30:00	.01
5	9	13:00:00	.17
5	10	13:30:00	.01
5	11	6:00:00	.15
5	12	14:30:00	.01
5	13	15:00:00	.13
5	14	15:30:00	.01
5	15	16:00:00	.10
5	16	6:00:00	.01
5	17	17:00:00	.08
5	18	18:00:00	.01
5	19	18:30:00	.05
5	20	19:00:00	.01
5	21	19:30:00	.03
5	22	20:30:00	.01
5	23	21:00:00	.03
5	24	21:30:00	.01
5	25	22:30:00	0
6	1	6:30:00	.01
6	2	7:00:00	.50
6	3	7:30:00	.01
6	4	8:00:00	.60
6	5	8:30:00	.01
6	6	9:00:00	.40
6	7	9:30:00	.02
6	8	10:00:00	.30
6	9	10:30:00	.01
6	10	11:00:00	.25
6	11	6:00:00	.01
6	12	12:00:00	.18
6	13	13:30:00	.01
6	14	14:00:00	.14
6	15	15:00:00	.01
6	16	6:00:00	.17
6	17	16:00:00	.01
6	18	16:30:00	.16
6	19	17:30:00	.01
6	20	18:00:00	.08
6	21	18:30:00	0
6	22	19:00:00	.04
6	23	19:30:00	.01

security checking, for example, the user would perform two runs of the program. The first run would have only one channel for security check whereas the second run would include two. The effect of two channels could be determined by analyzing the results for the two runs. This type of analysis would be useful in determining whether an existing airport is adequate for meeting future demand and, if not, in identifying the areas in need of expansion. In the case of a planned airport, the user would be able to determine whether a design under consideration is suitable for demands projected during the design life.

SAMPLE PROBLEM

The use of the concepts presented above is perhaps best demonstrated through the presentation of the solution of an example problem by use of ACAP1. The example is a relatively simple, hypothetical one used only for illustrative purposes. The example is designed to resemble flows of enplaning passengers within the terminal building at Hobby Airport in Houston, Texas, and illustrates that, although the inputs are extensive, they do not place an unreasonable burden on the user.

The Hobby Airport was selected primarily because it is of rather simple design. The airport serves primarily as a relief airport for Houston Intercontinental Airport. The commercial traffic is composed of intrastate commuter service and connecting service to the Dallas-Fort Worth area. A plan view of the terminal building is shown in Figure 6.

The input data for this problem are shown in echoprint form in Figures 7-9. The echo print is used because of the labeling, which makes the problem input easier to understand.

In the construction of the input data deck, several steps must be taken. The first step is to designate the bounds of the analysis period. As mentioned previously, a beginning time should be selected so that the airport can be considered empty. For the example problem, 6:00 a.m. and 10:30 p.m. were chosen as the beginning and end of the analysis period, respectively.

The second step is to delineate the airport configuration in terms of a node-link network. Each component of the system or subsystem is considered to be a node. Thus, each of the ticket counters and each of the checkpoints (Figure 6) is treated as a separate node. Each node is then arbitrarily assigned a node number. The node number, node label, model number, measures of congestion, and number of available servers and their service rates for each node are all required input. The links of the node-link network are implied in the path-sequence construction discussed above, which is also a required input.

The final step in assembling the information for the input deck is the inclusion of the arrival-flow distributions. This is accomplished by examining the distributions relative to the flight schedule on each path in a manner similar to that described above.

As Figure 7 shows, there are four servers at the ticket counter of airline A and only two servers at the ticket counter of airline B. Airline A has five times as many flights as airline B at this airport. In addition, note that there are four servers and six servers at the corridor and concourse components, respectively, because it is assumed that as a result of layout constraints only those numbers of people can, at any given time, pass abreast a given imaginary line that crosses those components. The figure shows that the time interval selected was 1 min.

Figure 8 shows the network information, such as which nodes are in each sequence and which nodes follow which sequence. For example, for path 1, nodes 1, 2, 4, 5, and 6 are included, whereas for path 6, only nodes 1, 4, 5, and 7 are included. In the section that contains the succeeding nodes, the negative numbers indicate the end of a path.

Figure 9 shows the constant input rates chosen for this example based on the flight schedule shown in Table 1. These input rates are assumed to be relatively low on all paths except for a period 30-60 min prior to the scheduled departure time of a flight on that path. Thus, on path 2, the fourth input rate is a constant 3.10 passengers/min for the time interval from 7:30 to 8:00 a.m. In addition, note that the input rate on all paths between the last flight departure time on a path and the closing time of the airport or the end of the period under consideration has been set to zero.

The program then calculates the flows into and out of

Table 1. Departures from Hobby Airport.

Airline	Flight Destination	Departure Times
A	Dallas Love Field	7:00, 7:30, 8:30, 9:30, 10:30, and 11:30 a.m.; 12:30, 1:30, 2:30, 3:30, 4:30, 5:30, 6:30, 7:30, 8:30, and 9:30 p.m.
	San Antonio	8:00 a.m.; 12:00 noon; 4:00 and 8:00 p.m.
	Harlingen	9:00 and 11:30 a.m.; 2:30, 5:00, and 7:00 p.m.
B	Dallas-Fort Worth	7:00 and 9:45 a.m.; 12:25, 4:10, and 7:00 p.m.

Figure 10. Calculation of passenger flows for one time step.

** NODE CONDITIONS FOR TIME STEP 181 FROM 9:00:00 TO 9:01:00 **

NODE NUMBER	COMPONENT LABEL	INFLOW RATE PER MIN	TOTAL OUTFLOW	AVG WAITING TIME(MIN)	AVERAGE QUEUE LENGTH	MAX AVG WAITING TIME ALLOWED	MAX AVG WAITING TIME EXCEEDED	MAX AVG QUEUE LENGTH ALLOWED	MAX AVG QUEUE LENGTH EXCEEDED
1	TERM ENTR	4.1	7.2	4.56E-02	1.02E+00	.33	NO	4.00	NO
2	A TKT CTR	2.9	2.4	1.19E+01	2.86E+01	15.00	NO	8.00	YES
3	B TKT CTR	3.4	1.2	1.21E+01	1.45E+01	15.00	NO	6.00	YES
4	CORRIDOR	6.7	6.7	8.53E-03	6.02E-01	.50	NO	3.00	NO
5	SECURITY	4.5	4.5	7.04E-01	3.52E+00	5.00	NO	20.00	NO
6	CONCOURSE	4.5	4.5	0	0	.50	NO	2.00	NO
7	A CHECKIN1	.9	.9	0	0	6.00	NO	15.00	NO
8	A CHECKIN2	1.9	1.9	3.66E-01	9.15E-01	6.00	NO	15.00	NO
9	B CHECKIN1	.0	.0	0	0	6.00	NO	15.00	NO
10	B CHECKIN2	1.7	1.7	2.79E-01	6.96E-01	6.00	NO	15.00	NO

** FLOW INTO EACH NODE ALONG EACH PATH DURING THE TIME STEP **

NODE NUMBER	TOTAL FLOW	PATH NUMBER 1	2	3	4	5	6	7	8
1	4.1	.0	.1	.0	3.4	.0	.0	.0	.5
2	2.9	.0	2.9	0	0	0	0	0	0
3	3.4	0	0	.0	3.4	0	0	0	0
4	6.7	.8	1.6	.0	3.4	.0	.4	.0	.5
5	4.5	.8	1.6	.0	1.2	.0	.4	.0	.5
6	4.5	.9	1.5	.0	1.2	.0	.4	.0	.5
7	.9	.9	0	0	0	.0	0	0	0
8	1.9	0	1.5	0	0	0	.4	0	0
9	.0	0	0	.0	0	0	0	.0	0
10	1.7	0	0	0	1.2	0	0	0	.5

** NUMBER OF UNITS FOLLOWING EACH PATH REMAINING AT EACH NODE AT THE END OF THE TIME STEP **

NODE NUMBER	TOTAL UNITS	PATH NUMBER 1	2	3	4	5	6	7	8
1	4.1	.0	.1	.0	3.4	.0	.0	.0	.5
2	118.5	39.1	79.4	0	0	0	0	0	0
3	32.1	0	0	.1	32.0	0	0	0	0
4	6.7	.8	1.6	.0	3.4	.0	.4	.0	.5
5	4.5	.8	1.6	.0	1.2	.0	.4	.0	.5
6	4.5	.9	1.5	.0	1.2	.0	.4	.0	.5
7	.9	.9	0	0	0	.0	0	0	0
8	1.9	0	1.5	0	0	0	.4	0	0
9	.0	0	0	.0	0	0	0	.0	0
10	1.7	0	0	0	1.2	0	0	0	.5

** CURRENT CONSTANT INPUT RATES **

PATH NUMBER	RATE NUMBER	INPUT RATE PER MIN
1	6	.01
2	7	.10
3	2	.01
4	2	3.40
5	6	.01
6	7	.02
7	2	.01
8	2	.50

each component and the associated measures of congestion at each component for each time step throughout the period being examined. As Figure 10 shows, the results of these calculations are printed for the individual time steps at a sample rate to be determined by the user. Figure 7 shows that the results are printed once for every 60 time steps.

At the end of each run, a final summary is presented that shows when and where the congestion criteria have been exceeded. As can be seen in Figure 11, the congestion appears to be concentrated at the ticket counters, the most congestion at the counter of airline B. Since airline B has only two agents at this component, it would appear that more agents are needed. Two addi-

Figure 11. Final summary with two servers at ticket counter of airline B.

** SUMMARY OF OVER-CONGESTED NODE CONDITIONS **

			MAX ALLOWABLE AVG WAITING TIME		MAX ALLOWABLE AVG QUEUE LENGTH	
TIME INTERVAL	NODE NUMBER	COMPONENT LABEL	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS
7:00:00 TO 7:30:00	2	A TKT CTR	0	0	100.0	2.50E+00
7:30:00 TO 8:00:00	2	A TKT CTR	0	0	100.0	7.62E+00
8:00:00 TO 8:30:00	2	A TKT CTR	0	0	100.0	1.34E+01
8:30:00 TO 9:00:00	2	A TKT CTR	0	0	100.0	1.86E+01
	3	B TKT CTR	0	0	23.3	4.10E+00
9:00:00 TO 9:30:00	2	A TKT CTR	0	0	100.0	1.26E+01
	3	B TKT CTR	86.7	7.70E+00	100.0	1.98E+01
9:30:00 TO 10:00:00	2	A TKT CTR	0	0	100.0	3.84E+00
	3	B TKT CTR	40.0	2.95E+00	100.0	1.02E+01
10:00:00 TO 10:30:00	2	A TKT CTR	0	0	26.7	2.52E+00
	3	B TKT CTR	0	0	6.7	7.90E-01
10:30:00 TO 11:00:00	2	A TKT CTR	0	0	56.7	6.46E+00
11:00:00 TO 11:30:00	2	A TKT CTR	0	0	100.0	1.54E+01
11:30:00 TO 12:00:00	2	A TKT CTR	0	0	100.0	9.51E+00
	3	B TKT CTR	50.0	5.62E+00	90.0	1.29E+01
12:00:00 TO 12:30:00	2	A TKT CTR	0	0	3.3	2.97E-01
	3	B TKT CTR	56.7	4.09E+00	100.0	1.30E+01
12:30:00 TO 13:00:00	3	B TKT CTR	0	0	23.3	2.03E+00
15:00:00 TO 15:30:00	3	B TKT CTR	0	0	33.3	4.39E+00
15:30:00 TO 16:00:00	3	B TKT CTR	63.3	2.66E+00	100.0	1.33E+01
16:00:00 TO 16:30:00	3	B TKT CTR	0	0	43.3	3.80E+00
18:00:00 TO 18:30:00	3	B TKT CTR	6.7	4.17E-01	63.3	6.55E+00
18:30:00 TO 19:00:00	3	B TKT CTR	20.0	1.31E+00	86.7	7.90E+00

Figure 12. Final summary with three servers at ticket counter of airline B.

** SUMMARY OF OVER-CONGESTED NODE CONDITIONS **

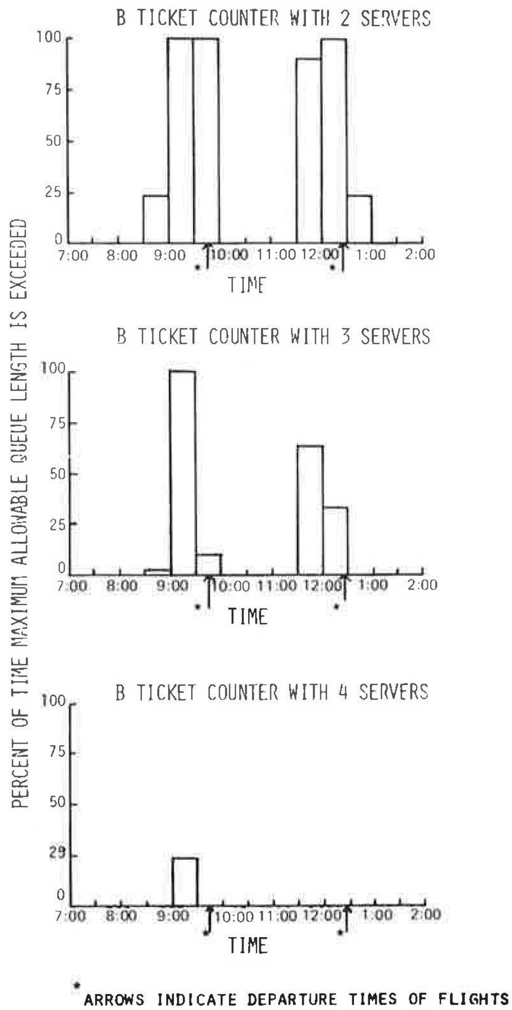
			MAX ALLOWABLE AVG WAITING TIME		MAX ALLOWABLE AVG QUEUE LENGTH	
TIME INTERVAL	NODE NUMBER	COMPONENT LABEL	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS
7:00:00 TO 7:30:00	2	A TKT CTR	0	0	100.0	2.50E+00
7:30:00 TO 8:00:00	2	A TKT CTR	0	0	100.0	7.62E+00
8:00:00 TO 8:30:00	2	A TKT CTR	0	0	100.0	1.34E+01
8:30:00 TO 9:00:00	2	A TKT CTR	0	0	100.0	1.86E+01
	3	B TKT CTR	0	0	3.3	3.08E-01
9:00:00 TO 9:30:00	2	A TKT CTR	0	0	100.0	1.26E+01
	3	B TKT CTR	0	0	100.0	5.44E+00
9:30:00 TO 10:00:00	2	A TKT CTR	0	0	100.0	3.84E+00
	3	B TKT CTR	0	0	10.0	1.10E+00
10:00:00 TO 10:30:00	2	A TKT CTR	0	0	26.7	2.52E+00
10:30:00 TO 11:00:00	2	A TKT CTR	0	0	56.7	6.46E+00
11:00:00 TO 11:30:00	2	A TKT CTR	0	0	100.0	1.54E+01
11:30:00 TO 12:00:00	2	A TKT CTR	0	0	100.0	9.51E+00
	3	B TKT CTR	0	0	63.3	4.39E+00
12:00:00 TO 12:30:00	2	A TKT CTR	0	0	3.3	2.97E-01
	3	B TKT CTR	0	0	33.3	2.93E+00
15:30:00 TO 16:00:00	3	B TKT CTR	0	0	63.3	2.09E+00
18:00:00 TO 18:30:00	3	B TKT CTR	0	0	13.3	5.33E-01
18:30:00 TO 19:00:00	3	B TKT CTR	0	0	16.7	9.53E-01

Figure 13. Final summary with four servers at ticket counter of airline B.

** SUMMARY OF OVER-CONGESTED NODE CONDITIONS **

			MAX ALLOWABLE AVG WAITING TIME		MAX ALLOWABLE AVG QUEUE LENGTH	
TIME INTERVAL	NODE NUMBER	COMPONENT LABEL	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS
7:00:00 TO 7:30:00	2	A TKT CTR	0	0	100.0	2.50E+00
7:30:00 TO 8:00:00	2	A TKT CTR	0	0	100.0	7.62E+00
8:00:00 TO 8:30:00	2	A TKT CTR	0	0	100.0	1.34E+01
8:30:00 TO 9:00:00	2	A TKT CTR	0	0	100.0	1.86E+01
9:00:00 TO 9:30:00	2	A TKT CTR	0	0	100.0	1.26E+01
	3	B TKT CTR	0	0	23.3	5.54E-01
9:30:00 TO 10:00:00	2	A TKT CTR	0	0	100.0	3.80E+00
10:00:00 TO 10:30:00	2	A TKT CTR	0	0	26.7	2.52E+00
10:30:00 TO 11:00:00	2	A TKT CTR	0	0	56.7	6.46E+00
11:00:00 TO 11:30:00	2	A TKT CTR	0	0	100.0	1.54E+01
11:30:00 TO 12:00:00	2	A TKT CTR	0	0	100.0	9.51E+00
12:00:00 TO 12:30:00	2	A TKT CTR	0	0	3.3	2.97E-01
15:30:00 TO 16:00:00	10	B CHECKIN2	43.3	7.18E-01	43.3	1.79E+00
18:00:00 TO 18:30:00	9	B CHECKIN1	20.0	7.60E-01	20.0	1.90E+00
18:30:00 TO 19:00:00	9	B CHECKIN1	33.3	2.11E+00	33.3	5.28E+00

Figure 14. Percentage of time maximum allowable average queue length exceeded versus time of day.



tional runs of the program were made, and each time the number of servers at this component was incremented by one and all other input values were kept at the same level. Figures 12 and 13 show that a marked decrease in the amount of congestion at this component occurs with each additional server. A clearer view of this decrease in congestion can be seen in Figure 14, in which the percentage of time the maximum allowable queue length is exceeded is plotted versus time and the flight departure times are indicated by arrows on the time axis. As the plot for two servers shows, the congestion is so great that at times the queues do not dissipate until after the scheduled departure time of the aircraft. This problem is at least partially cured by the addition of an agent.

There is, however, a limit to the number of servers that can be added above which nothing is really gained. Notice in Figure 14 that, when four servers are used, the percentage of time the maximum allowable average queue length is exceeded is zero except for the interval between 9:00 and 9:30 a.m., but in Figure 11 the use of four servers produces a combined service rate so great that the queue length at the check-in counters becomes excessive. If each passenger is to be served adequately throughout the airport, additional servers must be provided at the check-in counters of airline B.

SUMMARY

This paper presents an introduction to a computer program that is designed to be a decision-making tool for use in airport capacity analysis and planning. The program has the flexibility to be used for either existing airports or planned airports of any configuration. The inputs to the program include the airport configuration, the flows into the system, and a description of the components that make up the system. This description of components includes measures of congestion and the number and service rate of servers.

The output of the program contains an echo print of all of the input data, a sample of the calculations for each time step, and a summary of when, where, and by how much each of the specified measures of congestion was violated. This type of output enables the user to determine the effect of using different methods of operation to eliminate the violations; these methods include adding more servers to the components at which the violations occur and rearranging the flight schedule to eliminate congestion by shifting the passenger flow in time. By reducing or eliminating the number and/or frequency of violations of measures of congestion, the capacity of the airport is increased.

The program is currently being revised and updated as new component models are developed. The revised version should be ready for publication in the near future.

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The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation.

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Guidelines for Evaluating Characteristics of Airport Landside Vehicle and Pedestrian Traffic

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Results of a study of the characteristics of landside vehicle and pedestrian traffic at Miami International, Stapleton International, and LaGuardia Airports and one terminal at John F. Kennedy International Airport are presented. Vehicle and pedestrian flow rates at all terminal buildings, curbside areas, parking facilities, and airport entrance and exit roadways were measured simultaneously and related to levels of air-passenger activity by using enplanements and deplanements as indices. Processing time and service rates were also sampled at several locations at three of the four airports. These data were obtained at ticket counters, automobile-rental areas, passenger security checkpoints, parking cashier operations, and other locations within the terminals. Representative per-passenger flow rates and processing times for pedestrians and vehicles are presented as rules of thumb to assist other airport planners.

Many agencies and organizations are attempting to analyze and derive solutions for the congestion problems encountered on the ground at airports, specifically on access roads and at terminal buildings. This paper results from several studies prepared for two organizations—the Transportation Systems Center of the U.S. Department of Transportation (1) and American Airlines (2, 3)—both of which are interested in airport congestion problems but from different viewpoints. Since the studies were designed to meet the distinctive needs of each organization, there were variations between them in the methods of data collection and the analyses performed.

Data were collected at four airports that represent, in total passenger enplanements, a cross section of the 20 largest airports in the United States. In 1978, John F. Kennedy International and LaGuardia Airports in New York, Stapleton International Airport in Denver, and Miami International Airport ranked fourth, seventh, eighth, and ninth, respectively, among U.S. airports in terms of total annual enplanements served. Data collected at John F. Kennedy International focused on the curbside area and access roads that serve the American Airlines terminal. At the other three airports, data were collected at each area of the airport where a passenger might encounter delays before boarding or after disembarking from an aircraft. This included all public areas in the terminal building, road curbside areas, and parking facilities. The data collected in those four studies form the basis for the guidelines and characteristics presented in this paper.

PURPOSE AND SCOPE

The purpose of this paper is to provide the airport planner and other interested groups with basic general guidelines for evaluating the reasonableness of vehicle and pedestrian forecasts for various sectors of the airport landside system and to present observed distributions of process times that can be used to plan passenger service facilities for airport terminal buildings. The findings presented relate to groundside vehicle characteristics, such as modal choice, traffic generation rates on airport roads and at parking facilities, and use of curb-frontage roadways; pedestrian trip-generation rates for airline passengers and visitors; and processing or service times for ticketing, security, and parking-cashiering operations at the subject airports.

AIRPORT CHARACTERISTICS

During 1979, Miami International Airport (MIA) handled about 8 248 000 enplaning passengers. MIA, which serves Dade County, Florida, is a major entry point for passengers arriving from South and Central America. During the study period (March 17 and 18, 1978), tourist traffic made up the largest portion of passenger demand. The proximity of Miami Beach and the cruise ships that berth at Miami generates a large portion of the tourist traffic. More than 25 percent of all enplaning air passengers are transfer passengers who do not have an impact on the terminal roadway system.

MIA provides more than 6000 public parking spaces, including 4700 spaces in the central terminal area in three garages and a surface lot. The terminal complex is on two levels and has approximately 1060 m (3500 ft) of arrival curb space and 1135 m (3750 ft) of departure curb space. A central island that has a dual curb separates the six-lane curbside roadways.

Stapleton International Airport (DEN) serves the Denver region and the largest volume of passengers of any airport between Chicago and the Pacific Coast. In 1978, DEN, which is classified as a major hub airport by the

Federal Aviation Administration, handled a total of about 9 481 000 enplaning passengers, of whom more than 35 percent were transferring passengers.

DEN provides more than 6200 parking spaces in a garage and surface lot in the central terminal area and adjacent peripheral lots. DEN has a two-level terminal complex that has approximately 275 linear m (900 linear ft) of departure curb frontage and 320 linear m (1050 linear ft) of arrival curb frontage. The departure-level road is three lanes in width, and the arrival-level road is four lanes in width.

Of the three airports studied, LaGuardia Airport (LGA) has the least percentage of interline transfers (during the survey, approximately 8 percent). In 1978, a total of about 8 547 000 enplaning passengers were accommodated at LGA, which makes this the second most active of the four airports under study. Because it is so close to midtown Manhattan, in comparison with JFK and Newark airports, LGA serves a higher percentage of business travelers than most airports. During the survey, more than 50 percent of all air-passenger enplanements were on business-related trips.

LGA provides public parking spaces for about 8300 vehicles; a garage located in the central terminal area has a capacity of about 2800 spaces. Five separate curb-frontage roadways serve the terminal—three on the upper level and two on the lower level. Approximately 515 linear m (1700 linear ft) of enplaning curb frontage is provided, 300 m (1000 ft) of which is located on the roadway adjacent to the terminal and an additional 210 m (700 ft) of which is within the parking garage. About 425 linear m (1400 linear ft) is provided on the arrival level. The inner roadway, which accommodates all commercial vehicles, has approximately 275 m (900 ft) of curb frontage; the outer roadway, which serves private automobiles, has a curb frontage approximately 150 m (500 ft) in length. In addition, a remote shuttle terminal complex is also provided at LGA for the shuttle operations of Eastern Airlines. Activities at this terminal, however, have been excluded from the study.

The American Airlines terminal at JFK (AA/JFK) is one of nine terminal facilities within the airport complex. The terminal is a two-level facility that, at the time of the survey, had 115 linear m (380 linear ft) of available departure curb frontage and 135 m (450 ft) of available arrival curb frontage. The American Airlines terminal is served by both parking in the central terminal area and remote long-term parking.

In 1978, JFK accommodated about 12.4 million enplaning passengers.

FIELD INVESTIGATIONS

Extensive data were collected at all four airports. Field studies were conducted over six consecutive hours on two specified days at each of the three grouped airports and for one day at AA/JFK. The 1978 surveys were timed jointly with the airport operating agencies and carriers for peak activity periods during the day and, if possible, during months of above-average patronage. Surveys at MIA were conducted between 11:00 a.m. and 5:00 p.m. on Friday and Saturday, March 17 and 18. The survey period preceded Easter week, which historically has proved to be a peak activity period at MIA. Surveys at DEN were conducted on Thursday, April 20, and Friday, April 21, near the end of the ski season, between the hours of 2:00 and 8:00 p.m. The LGA surveys were conducted between 2:00 and 8:00 p.m. on Wednesday and Thursday, May 24 and 25, the week before the Memorial Day weekend. Surveys were conducted at AA/JFK between the hours of 4:00 and 10:00 p.m. on Friday, January 27.

To determine the appropriate number of samples that would be required to ensure a 95 percent confidence level for the survey data at MIA, DEN, and LGA, pilot studies were conducted to determine data variability and thus enable the researchers to ascertain required sample sizes. Where required sample sizes were found to be greater than the flow rate (or sample universe), the maximum practical sample size was obtained. Because of the number of samples and the number of observation locations required, more than 125 field observers were used simultaneously at each airport over the two-day period to ensure complete coverage and accurate data collection. The table below summarizes the number of usable samples obtained for various types of data collected by sampling methods:

Type of Data	MIA	DEN	LGA
Passenger interview	950	1620	1560
Processing time			
Ticket counters	970	830	770
Security areas	680	1530	1460
Parking-lot exits	665	860	310
Vehicle dwell time	1725	1225	2220

(These data represent totals for the two-day survey period at each airport. A one-day survey conducted at the American Airlines terminal at JFK resulted in a total of 900 for vehicle dwell times.)

As noted, 950 passenger interviews were obtained at MIA, 1620 at DEN, and 1560 at LGA, for both enplaning and deplaning passengers. Processing times at ticket counters were obtained for 970 samples at MIA, 830 at DEN, and 770 at LGA. Other sample sizes obtained for processing times at security areas as well as at parking lot exits are also noted.

Continuous flow rates (number of entities) were collected simultaneously at all of the following locations by using 5-min increments: airport entrance roadways and exit roadways, parking lot entrances and exits, enplaning roadways, deplaning roadways, recirculation roadways, and terminal entrance and exit doors.

In addition, various characteristics of vehicle activity on the airport landside sector were measured. These included the processing times required to exit parking facilities (cashiering), vehicle dwell times on the enplaning and deplaning curb-frontage sections, and vehicle unloading and loading times on the enplaning and deplaning curb-frontage roadway sections.

Processing times were measured at several locations within the terminal buildings, including express and full-service airline ticket counters, customs and immigration, automobile-rental counters, and security locations. This information was collected at several processing points at each airport. In addition, passenger modes of arrival, bags per passenger, and group size were determined in passenger interviews. To obtain and ensure overall control, volumes of enplaning, deplaning, and transferring passengers were provided by the individual air carriers at each airport for each of the 6-h study periods. When passenger volumes were unavailable, the numbers of passengers that passed security stations were used to indicate activity levels. These values have been related to vehicle and pedestrian volumes measured during the same time intervals.

Table 1. Average patterns of modal choice for trips to and from the airport.

	Passengers (%)							
	MIA		DEN		LGA		AA/JFK	
Mode	Enplaning	Deplaning	Enplaning	Deplaning	Enplaning	Deplaning	Enplaning	Deplaning
Private automobile	42	47	56	70	25	31	46	47
Automobile-rental bus	11	20	14	8	9	4	3	2
Taxi	22	18	13	10	46	35	35	37
Airport limousine	10	10	5	5	13	20	7	5
Bus	15	5	3	5	5	5	9	9
Other	-	-	9	2	2	5	-	-
Total	100	100	100	100	100	100	100	100

Note: Transfer passengers excluded.

Table 2. Average air-passenger volumes.

	Number of Passengers[a]			
Type of Passenger	MIA[b]	DEN[b]	LGA[b,c]	AA/JFK
All				
Enplaning	14 900	10 400	14 400	3950
Deplaning	15 150	9 250	12 200	3350
Total	30 050	19 650	26 600	7300
Excluding transfer passengers				
Originating	11 200	5 950	12 300	3200
Deplaning	11 750	5 600	10 300	2750
Total	22 950	11 550	22 600	5950

[a]Data represent more than 95 percent of total passengers.
[b]Average of two-day survey.
[c]Excluding Eastern Airlines shuttle passengers.

Table 3. Average airport traffic generation relations: pedestrians.

Planning Ratio	MIA[a]	DEN[a]	LGA[a]	AA/JFK[b]
Ratio of total persons entering terminal to originating passengers	2.00	2.03	1.45	2.00
Ratio of total persons exiting terminal to deplaning passengers	2.01	2.18	1.51	1.91
Ratio of total persons entering and exiting terminal to				
Originating passengers	4.10	4.08	2.71	4.03
Deplaning passengers	3.91	4.34	3.23	3.75
Combined total	2.00	2.10	1.47	1.95

[a]Based on air-passenger volumes excluding transfer passengers.
[b]Excluding intraline passengers and including interline passengers (transfer passengers between terminals).

Table 4. Average airport traffic generation relations: vehicles.

Planning Ratio	MIA[a]	DEN[a]	LGA[a]
Ratio of total vehicles entering airport to			
Originating passengers	0.87	1.34	1.02
Total passengers	0.43	0.69	0.56
Ratio of total vehicles exiting airport to			
Deplaning passengers	0.93	1.26	0.99
Total passengers	0.48	0.61	0.45
Ratio of total vehicles entering and exiting airport to			
Originating passengers	1.84	2.54	1.83
Deplaning passengers	1.75	2.70	2.18
Combined total	0.90	1.30	1.00

[a]Excluding transfer passengers.

Table 5. Airport traffic generation relations: use of curb-frontage roadway.

Planning Ratio	MIA[a]	DEN[a]	LGA[a]	AA/JFK[a]
Ratio of total vehicles using curb frontage roadways to originating passengers	0.49	0.53	0.54[b]	0.68
Ratio of total vehicles using curb frontage roadways to deplaning passengers	0.54	0.53	0.51[c]	0.75

[a]Excluding transfer passengers.
[b]Including curb in garage.
[c]Excluding vehicles forced to traverse the deplaning roadway in exiting from the metered parking lot and the garage.

STUDY FINDINGS

Modal Choice

An important consideration in planning airport landside facilities is the landside modal choice of air passengers traveling to and from the airport. Passenger interviews were conducted to determine the modes of arrival and departure of enplaning and deplaning passengers, respectively. The results of these studies are summarized in Table 1.

Patterns of modal choice were found to vary according to time of day. At LGA, for example, use of automobiles in the morning by enplaning passengers is greater than the daily average. Possibly, this results from arriving business travelers parking their vehicles at the airport for the duration of the trip. Arriving passengers in the evening hours use more taxis. It is suggested that this is a result of business travelers who spent the day in New York returning to the airport for the reverse leg of their journey.

At all airports except LGA, the primary modal choice for both enplanements and deplanements is the automobile. During the survey, about 42, 56, and 25 percent of enplaning passengers used automobiles at MIA, DEN, and LGA, respectively. The pattern of modal choice observed at these airports compares favorably with earlier data, which indicate that 45, 68, and 38 percent of enplaning air passengers at MIA, DEN, and LGA, respectively, use private automobiles (4).

Passenger Volumes

The passenger activity level for the 6-h period at each facility is summarized in Table 2. The daily average volume of the two 6-h study periods at each of the four airports is given. For purposes of clarity, the information is presented for total enplaning, originating, and deplaning passengers. These values were used to arrive at planning factors and ratios.

The numbers of passengers served during the survey periods were 30 050, 26 600, 19 650, and 7300 at MIA, LGA, DEN, and AA/JFK, respectively. Transfer passengers were observed to represent about 24 percent at MIA, 41 percent at DEN, 8 percent at LGA, and 18 percent at AA/JFK during the survey periods.

Pedestrian Generation Ratios

In planning airport terminals, an important considera-

Table 6. Mean unloading or loading and dwell times at airport curbs by type of vehicle.

			Time (min)					
Curb	Airport	Type of Time	Automobile	Taxi	Bus	Limousine	Other	Total Average
Departure	MIA	Unloading or loading	1.3	3.0	1.3	1.0	0.9	1.2
		Dwell	3.0	1.8	2.9	1.7	1.5	2.6
	DEN	Unloading or loading	1.0	0.7	0.8	0.6	0.6	0.9
		Dwell	2.3	1.2	1.8	1.3	0.7	1.9
	LGA	Unloading or loading	0.6	0.5	0.7	0.5	0.4	0.5
		Dwell	1.2	1.1	2.2	1.3	1.2	1.4
	AA/JFK	Unloading or loading	1.2	0.8	1.3	1.7	0.7	1.1
		Dwell	2.5	1.3	1.7	2.6	1.0	2.0
Arrival	MIA	Unloading or loading	2.8	0.9	2.8	-	0.5	2.0
		Dwell	4.3	NA	3.5	-	1.5	3.9
	DEN	Unloading or loading	2.9	1.0	2.6	-	-	2.7
		Dwell	4.2	NA	3.2	-	-	3.9
	LGA	Unloading or loading	1.2	0.3	1.2	3.8	-	1.9
		Dwell	2.4	NA	1.6	4.5	-	2.4
	AA/JFK	Unloading or loading	1.6	-	1.2	2.5	1.0	1.5
		Dwell	3.3	-	1.7	4.4	1.5	3.0

Note: NA = not applicable.

tion is the volume of pedestrians that are expected to use the terminal. This value is a function of many factors, including air-passenger activity, passenger-visitor ratios, points of passenger loading and unloading, group sizes, and non-passenger-related activities at the terminal building.

Determining the volume of passengers entering and exiting a major airport terminal building is an expensive and difficult task because of the number of entrances and exits. At MIA, for example, 35 observers were required to monitor all doors simultaneously during the survey.

Table 3 gives the ratios of total persons observed entering and exiting various terminal buildings to enplaning, deplaning, and total passengers excluding transfer passengers. LGA has the lowest ratio of persons entering and exiting per passenger—about 1.5 pedestrians/air passenger. At MIA, DEN, and AA/JFK, which are more oriented to tourist and international travel, the ratio is about 2 pedestrians/passenger. It is suggested that the lower ratio at LGA is a result of the many business-oriented trips, which typically have a lower visitor-passenger ratio than social and recreation trips. Because the business trip is frequent and routine, few visitors are likely to accompany the business traveler.

Traffic Generation Relations

Traffic entering and exiting the central terminal areas at the study airports was observed to be quite variable because of its dependence on many factors, such as passenger arrival rates, modal-choice patterns, characteristics of vehicle occupancy, passenger-visitor ratios, and characteristics of employee traffic. The amount of use and volume of courtesy-type vehicles, hotel vans, rented automobiles, and shuttle buses are believed to substantially affect these values. As the data given in Table 4 indicate, the ratio of total vehicles observed entering and exiting the airport to total originating and deplaning passengers varies from 0.90 at MIA to 1.30 at DEN.

Vehicles traveling the curb frontage were also compared with the number of air passengers (see Table 5). Vehicle activity on the enplaning roadway was observed to vary from 0.49 vehicles to 0.68 vehicles/originating passenger at MIA and AA/JFK, respectively. The ratio for JFK can be attributed to the number of public vehicles required to serve all the terminals at JFK—that is, intra-airport vehicle traffic such as buses, rental vehicles, hotel vans, and others, which are routed so that they generally use the curb-frontage roadways of each terminal.

Activity on the arrival level varies from 0.51 vehicles/passenger at LGA to 0.75 vehicles/passenger at AA/JFK, again reflecting the additional intra-airport vehicles that use the facilities. It should be noted that including those vehicles that use the deplaning-level roadway in exiting from the garage and the metered parking lot at LGA would produce a 0.76 ratio of vehicles to passengers. These vehicles have been excluded since, because of the roadway configurations, all traffic that exits the garage at LGA must traverse the deplaning roadway.

Vehicle Dwell Times

Dwell time is the difference between the time at which a vehicle stops at a curb and the time at which it departs from the curb. Table 6 gives data on average curbside loading, unloading, and dwell times obtained at each airport on both departure (enplaning) and arrival (deplaning) curbs by type of vehicle. At an efficiently used curb, the difference between average dwell time and average loading or unloading time should be no more than about 0.5 min, the time required to enter the vehicle and depart the curb. A large difference in these times suggests that drivers are leaving vehicles unattended, which results in less efficient use of the terminal curb areas.

Departure Curb

As noted, LGA has the lowest average vehicle dwell time—1.4 min—compared with 1.9 min at DEN, 2.0 min at AA/JFK, and 2.6 min at MIA. It is believed that the smaller difference between dwell and unloading time at LGA reflects both the high level of curb parking enforcement and the nature of the air passengers (i.e., a low average number of bags per passenger). The higher value at MIA might be affected by the tourist orientation of the greeters.

Specific values by vehicle type are also given in Table 6. As noted, mean automobile unloading time varies between 0.6 min at LGA and 1.3 min at MIA. Similarly, observed mean dwell times for automobiles range between 1.2 and 3.0 min. Taxicabs were observed to have the lowest mean unloading and dwell times at each airport. Unloading and dwell times for buses, limousines, and other types of vehicles, including rented automobiles, are largely dependent on vehicle occupancy.

Arrival Curb

Activity at the deplaning curb also revealed that LGA has the lowest observed overall vehicle dwell time—2.4 min. MIA has the highest dwell time—3.9 min—and the greatest difference between parking and loading times—3.0 min. During the study period at MIA, many vehicles were observed to remain at the curb waiting for a passenger despite the resultant traffic congestion and queues.

Vehicle automobile loading time at the deplaning curb varied from a low of 1.2 min at LGA to more than 1.6 min at DEN, MIA, and AA/JFK.

Processing Times

Processing times at ticket counters, automobile-rental counters, and parking lot exits were recorded as the difference between the time at which a person or vehicle approached the service area and the time at which that person or vehicle left the area. Processing time at the security counter embraces the complete security procedure. This was measured from the time the passenger tendered an item to be X-rayed or checked until the passenger passed through the security area (the magnetometer), received the examined item, and was free to depart from the area to the gate.

Table 7 gives various processing times observed throughout the study airports. The observed aggregate data for all airports are also shown in a frequency-distribution format in Figures 1 and 2.

Full-Service Ticket Counters

As might be projected, the survey data revealed a wide range of process times at full-service ticket counters. Factors such as the type of trip (international versus domestic) or seat assignment, the equipment used in ticket verification, the operations of the individual air carriers, the volumes of passengers to be served, and human factors all influenced this activity. The 3.8-min difference between the mean high value (5.6 min) and the mean low value (1.8 min) reflects the diversity of this function.

Typically, air carriers are aware of the peak demand periods and the number of ticket-counter agents needed to serve this demand, given the factors cited above that affect processing times during the demand period.

Express Ticket Counters

As anticipated, the high and low mean values observed at express ticket counters are somewhat closer than those at full-service counters, ranging from 1.2 to 2.7 min/customer.

Security Areas

Processing times at security areas varied from a low of 9 s to a high of 46 s. The majority of the mean values recorded were in the 15- to 30-s range.

Automobile-Rental Counters

Mean processing times at the automobile-rental counters were the longest observed processing times, ranging from 2.6 to 7.7 min. In many instances, the duration of this processing time may depend on the availability of automobiles. Thus, longer processing times may result during periods of peak use of rented automobiles.

Parking Lot Exit Lanes

Cashier operations at exit lanes from parking facilities were also monitored. Results indicated a 30-s range between the lowest mean processing time—29 s at DEN (0.48 min)—and the highest—63 s at LGA (1.06 min). The majority of the values, however, were in the 30- to 50-s range.

SUGGESTED GUIDELINES AND PROCESSING TIMES

It is anticipated that the data produced by the surveys discussed in this paper will form the basis of many detailed studies that, it is hoped, will provide useful tools to assist planners in the evaluation of airport landside activities. As we stated initially, the analyses presented here are intended to form two initial steps to this end:

1. The development of guidelines that can be used to evaluate the reasonableness of vehicle and pedestrian forecasts and
2. The provision of observed distributions of process times that can be used to plan future and expanded passenger service facilities at terminal buildings.

Generation of Vehicle and Pedestrian Traffic

Table 8 gives suggested planning criteria for evaluating estimates of the impact of vehicle and pedestrian traffic at airports. These suggested criteria have been developed from the data obtained at the four airports studied. The range of values indicates the observed mean value; the recommended values are, in our opinion, the most useful values for planning.

As the table indicates, a ratio of 0.95 to 1.25 entering and exiting vehicles/total originating and deplaning passengers appears to be valid for forecasts of total traffic. The directional split (inbound versus outbound) is dependent on the anticipated distribution of enplanements and deplanements during a time period. The lower value—0.95—could be experienced at an airport that is business-trip oriented (about 50 percent business trips). The higher values of vehicles per passenger could occur at airports that serve many courtesy-type vehicles such as automobile-rental buses and hotel vans. The recommended planning range of vehicles per passenger is shown in Figure 3.

Curb-Use Factor

A typical factor for use of curb frontage appears to be one vehicle for every two enplaning or deplaning passengers. Thus, about 50 percent of all vehicles entering the airport use the curb-frontage roadways. The curb-use factors are shown in Figure 4.

Pedestrian Volumes

Total persons entering and exiting the terminal typically account for between 1.50 and 2.10 pedestrians/passenger. At a business-oriented airport, about 1.5 persons/passenger appears to be an appropriate value for planning purposes. At an airport that has a large number of international flights or is tourist oriented, a higher volume of pedestrians may be generated—up to 2.10 persons/passenger—as shown in Figure 5.

Table 7. Mean processing time at various airport facilities.

	Time (min)					
	MIA		DEN		LGA	
Type of Facility	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Full-service ticket counter	2.7	1.9	3.1	3.7	5.5	4.4
	3.0	4.1	1.8	2.5	3.7	3.4
	4.0	3.6	3.9	2.6	2.8	3.3
	5.6	-	-	3.5	-	-
Express ticket counter	2.3	2.2	1.5	1.7	3.1	2.4
	-	-	2.7	2.5	1.2	1.3
Security area	0.47	0.50	0.31	0.22	0.59	0.32
	-	0.51	0.38	0.56	0.56	0.52
	-	-	0.18	0.19	0.15	0.77
	-	-	-	-	0.30	0.50
Automobile-rental counter (pickup)	5.2	6.0	4.3	7.7	4.2	5.1
	-	-	4.4	5.0	4.5	4.2
	-	-	-	-	4.0	2.6
Parking-lot exit (cashier lanes)	0.58	0.45	0.53	0.48	0.63	1.06

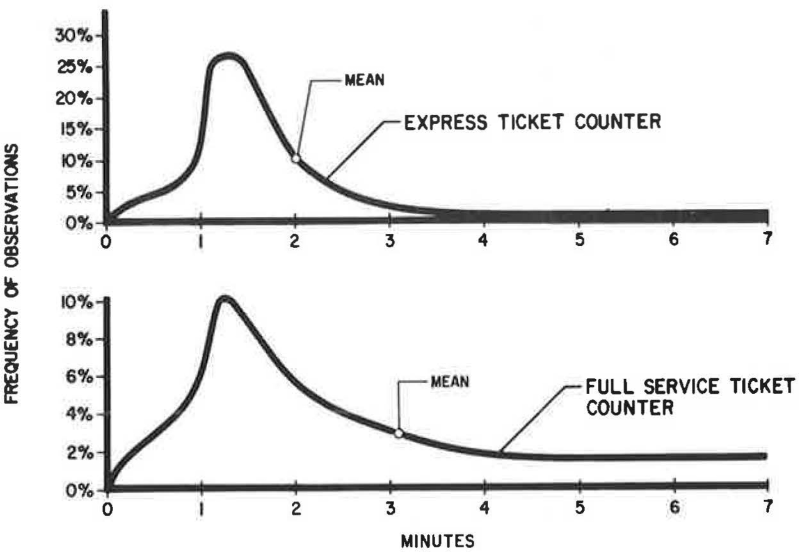


Figure 1. Distribution of ticket-counter processing time.

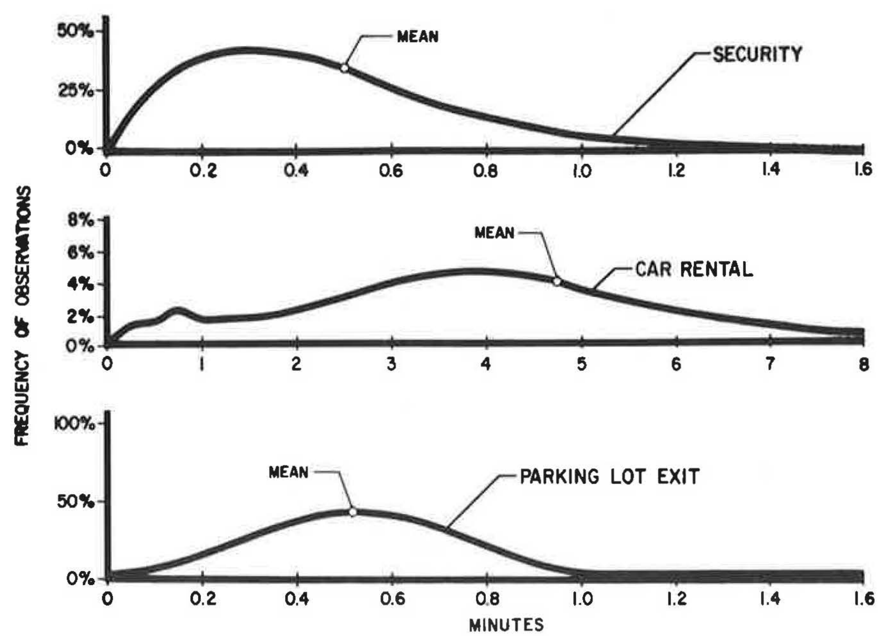


Figure 2. Distribution of landside processing time.

Processing Times

Processing times are relatively localized and reflect the individual passenger service areas. Some parameters to be used in evaluating some of these areas are given below:

Service Location	Suggested Processing Time (min)
Enplaning curb	
All vehicles	1.5-2.5
Automobile	1.2-3.0
Taxi	1.0-1.5
Deplaning curb	
All vehicles	2.5-4.0
Automobile	2.0-4.0
Parking lot exit lanes, cashier operation	0.50-0.60
Ticket counters	
Full service	2.0-5.0
Express	1.2-2.5
Security areas	0.15-0.50
Automobile-rental counters	2.5-5.0

The low values of time for enplaning and deplaning curbs reflect a high level of enforcement. The higher values for full-service ticket counters reflect operations oriented to international travel.

Vehicle dwell times on the departure roadway (enplaning curb) can vary an average of between 1.5 and 2.5 min for all vehicles. Dwell times for automobiles could vary between 1.2 and 3.0 min and, in some instances, higher values can be experienced when the curb is used for parking rather than unloading. Taxi dwell times vary from 1.0 to 1.5 min. Where strict enforcement and less baggage per person can be expected, the lower value should be used. At airports oriented to tourist and international travel, the higher values should be used to estimate curb-frontage needs. On the arrival roadway (deplaning curb), a range of 2.5-4.0 min is suggested. The practice of tolerating parking accounts for the higher values observed on the deplaning curb at MIA and DEN.

Processing times at parking lot cashier exits are also given in the table above. As noted, an average of 20-40 s/transaction is required. The longer times experienced reflect the paperwork involved in accepting checks, lost tickets, and the associated paperwork typical at an airport.

Other suggested ranges of process times, for ticket counters, automobile-rental counters, and security areas, are also given above. In most cases, processing times in these areas depend on the type of equip-

Table 8. Suggested airport planning criteria for vehicle and pedestrian traffic.

Item	Ratio per Passenger: Originating	Ratio per Passenger: Deplaning	Total
Airport vehicle traffic			
Entering	0.90-1.35	-	0.45-0.70
Exiting	-	0.95-1.25	0.45-0.65
Total	1.85-2.55	1.75-2.70	0.95-1.25[a]
Curb-frontage-roadways traffic			
Enplaning	0.50-0.55[b]	-	-
Deplaning	-	0.50-0.55[b]	-
Pedestrian traffic			
Entering terminal	1.50-2.00	-	-
Exiting terminal	-	1.50-2.20	-
Total	-	-	1.50-2.10[c]

Note: Recommended values are boxed. Transfer passengers are excluded.
[a]Maximum values reflect the predominance of courtesy-type vehicles.
[b]At individual terminals within a major airport, increase the value to 0.65-0.70.
[c]Commuter-type airports = 1.50; international-tourist airports = 2.10.

Figure 3. Vehicles entering and exiting the airport versus numbers of originating air passengers.

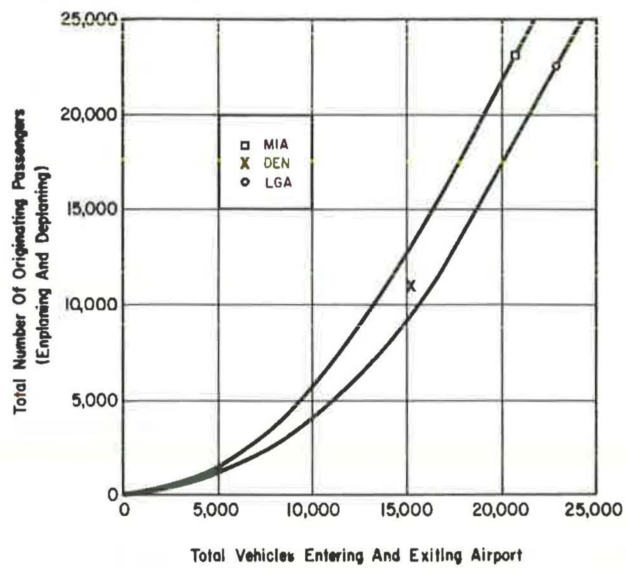


Figure 4. Curb-frontage utilization.

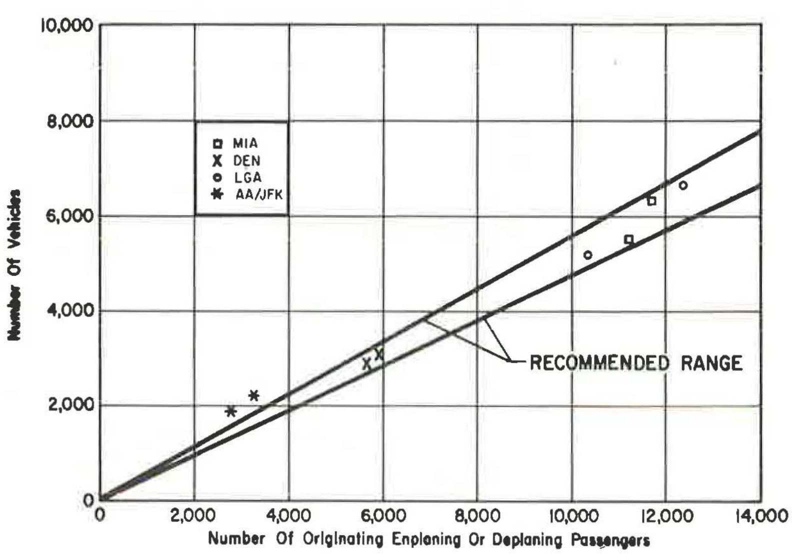
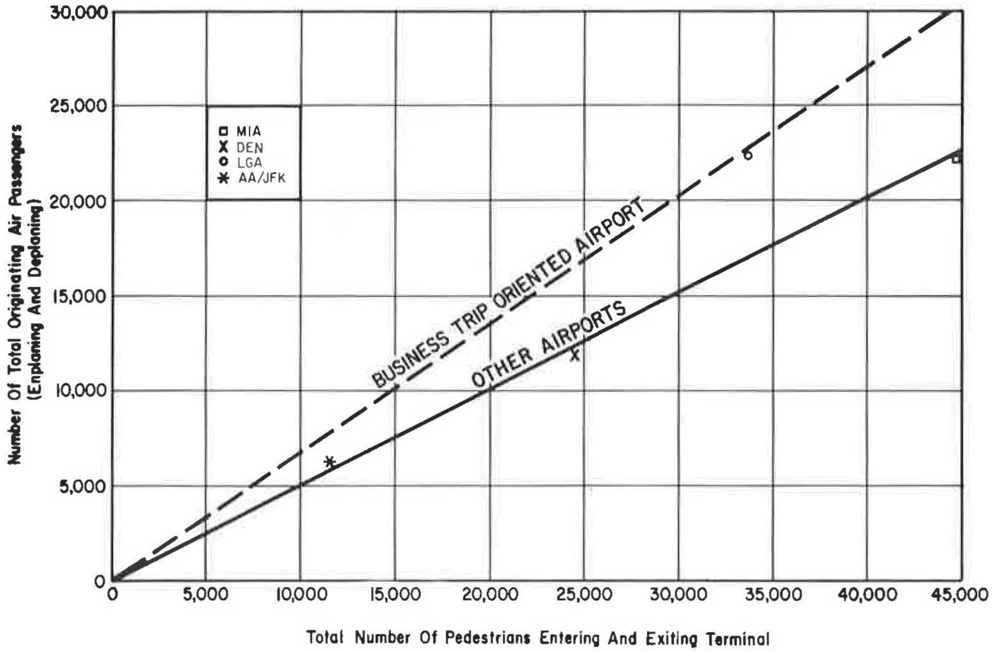


Figure 5. Pedestrians entering and exiting the air terminal versus numbers of originating air passengers.



ment used and the nature of the passenger. For functional planning purposes, however, these values have been presented to indicate the levels of activity that can be expected.

These values have been prepared as an aid to the user in forecasting levels of activity that may be expected at airports. Since each airport has its own peculiarities, only ranges and levels of activity for overall planning purposes are presented and not absolute factors.

ACKNOWLEDGMENT

We would like to thank the Transportation Systems Center, U.S. Department of Transportation, and American Airlines as well as the air carriers, airport operating agencies, and officials who supported and cooperated in the data collection for this research.

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Two Programs to Ease Automobile Congestion at Los Angeles International Airport

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Two programs that have had a positive impact on alleviating automobile congestion at Los Angeles International Airport are discussed. One program consists of reduced-rate off-airport parking lots and free tram service to the terminal buildings. Two lots that provide a combined total of about 11 400 parking spaces are currently in operation. The other program, the FlyAway Bus, is an express bus service that transports people to and from Van Nuys, a large suburban community 32 km (20 miles) north of the airport. The service includes low-cost parking for up to 15 days at the suburban bus terminal. The success of both programs is significant not only because of their current impact on airport congestion but also because of their potential for expansion to broader uses in the future and because they prove that the public can be persuaded to trade the privacy and control of the automobile for the efficiency and convenience of public trams and buses.

It has become increasingly obvious over the past 10 years that the item most likely to inhibit the orderly growth and development of Los Angeles International Airport (LAX), as well as some other major airports, is the automobile. Those who are familiar with the Los Angeles metropolitan area know that it is a large, sprawling complex that encompasses more than 2500 km^2 (1000 $mile^2$) of dense urbanization and houses roughly 7 million persons. Mild weather promotes an active out-of-doors life-style characterized by a pervasive and casual mobility. Although there is no high-density mass transit and only a recently developing municipal bus system, there is a rather comprehensive roadway and freeway system: hence, our love affair with the automobile. In Southern California, when most people want to go somewhere, they take their automobile because it is not only the quickest, most direct, and most convenient way to get there but perhaps the only way.

Unfortunately, this holds true for getting to the airport as well. As LAX grew from 18 million passengers in 1967 to 23.5 in 1973, a squeeze developed in the roadway and parking components of the system. In the early 1970s, the Los Angeles Department of Airports began to look for alternate modes of transporting people to and around the airport and more land-efficient places to sequester automobiles.

To provide relief from vehicle congestion on roadways and in parking lots—the most critical and impending problem—the department initiated two major programs:

1. A program to provide peripheral parking lots attempts to address the problem by inducing airport patrons who are determined to travel to LAX in private automobiles (automobile trips account for more than 80 percent of all trips to and from the airport) to park in lots some distance from the central terminal area and take a free tram to the terminal of their choice.
2. The FlyAway Bus program attempts to motivate airport patrons to leave their automobiles either at home or at a suburban low-cost parking facility and take a limo-bus to LAX.

PERIPHERAL PARKING LOTS

The concept of the peripheral parking lot had already been in operation at LAX for nearly 10 years. Its benefits were somewhat obscure, however, until recently, when increasing passenger volumes began to affect roadway and parking lot service levels. At some point, especially during periods of peak activity, supply and demand began to converge, and the peripheral parking lot became an alternative whose time had come.

The original lot—for "very special parking" (VSP)—initiated service in June 1968 on a 10.4-hm^2 (26-acre), department-owned site located on airport land 3.2 km (2 miles) southeast of the central terminal area (see Figure 1). For a nominal fee ($0.25 for 6 h or $1 for 24 h), patrons used a 1000-space lot and got a free tram ride to the central terminal. The trams ran every 10-15 min. By July 1969, the lot had been doubled in size to 2400 spaces and was showing a small profit. Today, the 17-hm^2 (43-acre) VSP lot provides almost 6000 parking spaces, an enclosed waiting area with restrooms and vending machines, porter service to handle bags, and bus service to the ticketing buildings—all for a parking fee of $0.50 for 6 h or $1.50 for 24 h. Last fiscal year the VSP lot served well over half a million persons.

The second peripheral lot, lot C, is located in the easterly clear zone of the north runways, about 0.8 km (0.5 mile) northeast of the terminal area, on a 64-hm^2 (160-acre) parcel that was once residential (Figure 1). The land had been determined unsuitable for residential use because of aircraft noise and subsequently condemned. Since clear-zone uses permit automobile parking—and there was a great need for more parking—the Los Angeles Department of Airports began a complicated 10-year acquisition program that involved more than 50 public hearings and much legal involvement to remove the single-family residences. The next obstacle to be tackled was obtaining clearance from a number of governmental bodies to change this residentially zoned and developed land into a parking lot. The actions were undertaken in stages, and acquisition of certain parts of the land is still in process.

The first phase of lot C was completed, however, and opened for business in October 1975. It provided 2200 parking spaces plus tram service to the terminal area ticketing buildings for a parking fee of $0.50 for 3 h and up to $2 for 24 h. The lot was quickly expanded to its present size of 5400 spaces, including a tram terminal, porter service, and a lift-van service for the handicapped. Patronage has grown steadily, and during fiscal year 1976/77 lot C served more than half a million persons.

Expansion of both the VSP lot and lot C is currently programmed. The 5000-space expansion of lot C has larger implications because it includes provisions for the relocation of all U-Drive rental automobiles and ready-up equipment currently based in the central terminal area. This would make approximately 3.2 hm^2 (8 acres) available for much-needed short-term public parking. LAX currently provides nearly 19 000 automobile parking spaces for the traveling public. For short periods of time during the 1977 Christmas holidays, the remote parking areas operated at capacity.

A major planning study will soon be completed by DeLeuw, Cather, and Company that will provide recommendations for long-range capital improvement projects to maximize vehicle and passenger access to the LAX terminal area. Some of the alternatives being evaluated in the study include an elevated two-lane roadway for high-occupancy vehicles, an elevated semi-automated guideway, and an elevated four-lane roadway that would be open to all types of vehicles. An important benefit of any one of these systems will be reliable service to the peripheral parking areas, which by 1985 may be servicing as many as 8 million passengers annually, or approximately 20 percent of all passengers who use the LAX facility.

FLYAWAY BUS

The FlyAway Bus was designed to transport to LAX persons who are located in the San Fernando Valley, which is centered about 32 km (20 miles) north of LAX (see Figure 2). The purposes of the program were to (a) promote decreased roadway congestion, (b) reduce parking facility requirements, (c) delay passenger capacity saturation, and (d) provide better levels of service.

The Van Nuys area was chosen as an ideal test area for several reasons: It was reasonably far away and was served by only one freeway, I-405, which runs directly to LAX; it contributed a large market share (about 15 percent) of LAX's passenger volume, about 88 percent of which traveled to and from the airport in private automobiles; and right in the middle of it was located a large piece of real estate owned by the Los Angeles Department of Airports—the Van Nuys Airport, a general aviation facility. Van Nuys Airport had a building that, with a modicum of remodeling, was suitable for use as a bus terminal, as well as an adjacent piece of land large enough to accommodate about 1400 automobiles. An economic feasibility study completed in May 1973 concluded that, if given active promotion and support, a

Figure 1. LAX peripheral automobile parking.

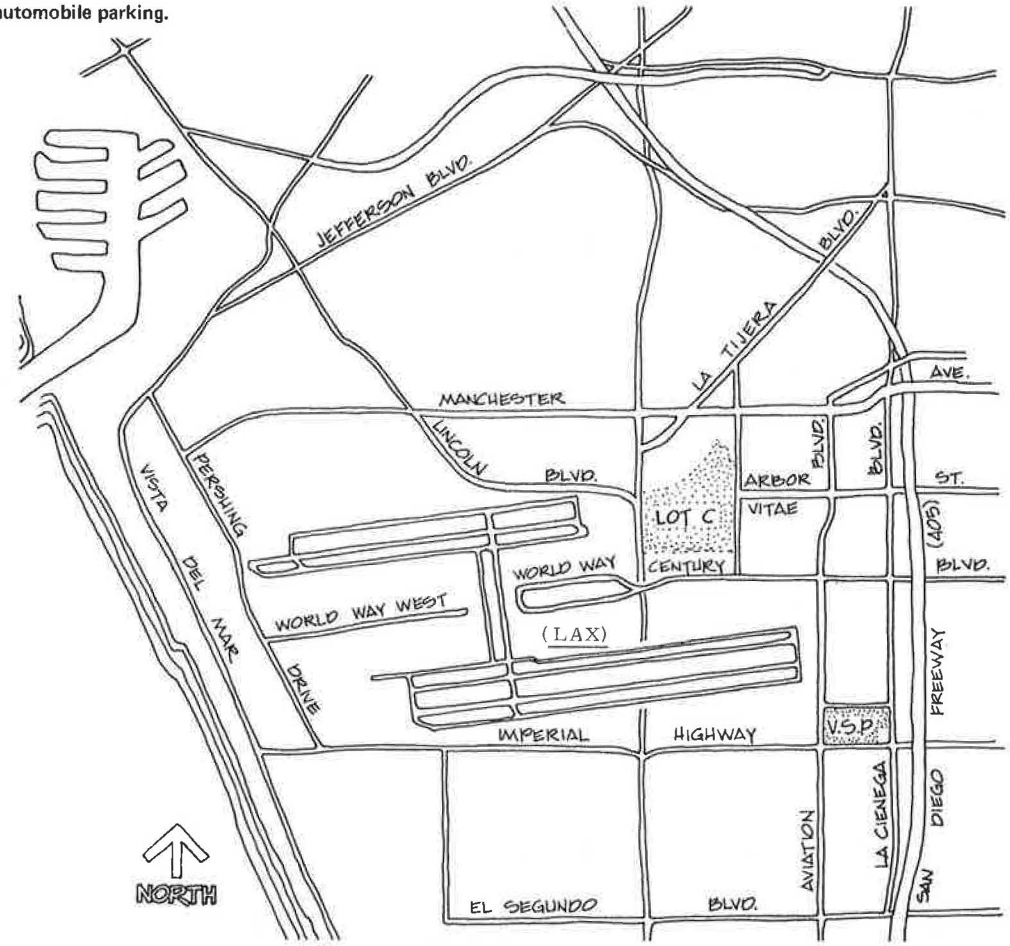
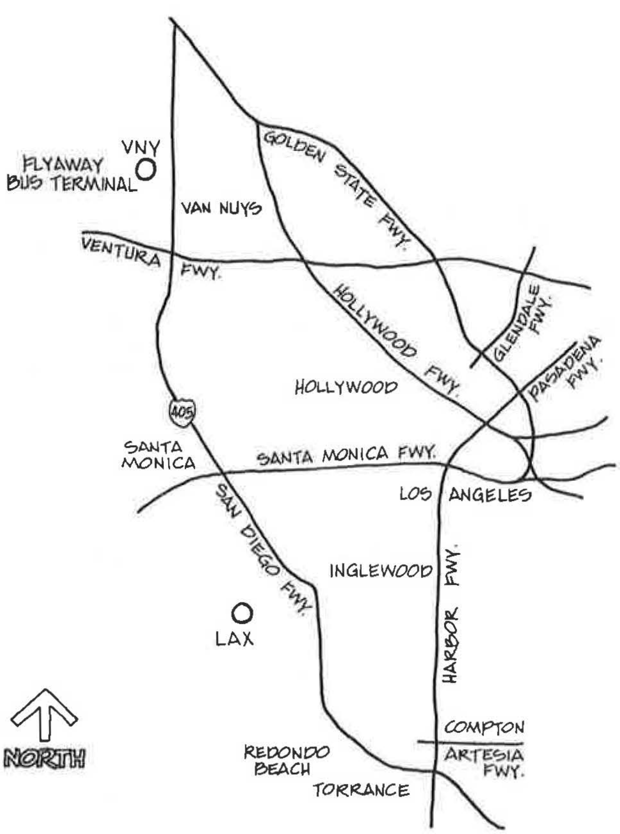


Figure 2. Location of FlyAway Bus terminal in relation to LAX.



limo-bus service from Van Nuys to LAX would capture 270 000 riders/year within six years of operation. It was felt that a successful operation would depend on frequent service, something not previously offered to the traveling public.

Service was inaugurated on July 10, 1975. Six 38-passenger Neoplan buses, purchased for the purpose by the department, made 44 round trips/day. The adult fare was $5/round trip or $3 one way, and the children's fare was $1.50 one way. Once arrived at LAX, the buses circled the central terminal loop, making stops at each ticketing building.

The system got off to a relatively slow start, but within a year it was exceeding predictions, serving more than 27 000 passengers/month. By the end of 1976, the annual passenger volume exceeded 275 000, and by the end of 1977 it was more than 315 000. One unexpected occurrence was the degree of participation among airport employees.

The FlyAway Bus service operates out of a 300-m^2 (3300-ft^2) area in a building nearly twice that size and utilizes a 1400-space parking lot. Passenger fares remain the same as they were when the program began, but parking fees have been increased to $1 for a maximum of 15 days' parking to discourage long-term parkers. In comparison, parking in the central terminal area at LAX is $6/day and, in the two peripheral off-airport lots, $1.50 and $2/day, which includes a free tram ride to and from the terminals.

In view of the rapid growth of patronage experienced during the short operating life of the FlyAway Bus, we are now looking at several expansion alternatives for the Van Nuys bus terminal. One is to modify and put to use the additional area in the existing building and expand the existing parking lot by 35 percent to about 1900 spaces. Such improvements should be adequate to handle the 620 000 annual bus passengers expected by 1985, when LAX is expected to be serving 40 million annual passengers. Another alternative is to replace the existing facility with a new one on an available piece of land about 0.8 km (0.5 mile) away, perhaps combining it with terminal facilities and administrative offices. This does not appear to be cost effective at this time.

The most promising aspect of the FlyAway Bus program is its potential for accomplishing the very goals for which it was created—that is, reducing roadway congestion (especially in the central terminal area) and parking facility needs, delaying passenger capacity saturation, and providing better levels of service.

Although the current impact of the FlyAway Bus on the LAX system is relatively small, the implications of the concept are decidedly large. An expansion of the service to cover suitable population centers throughout the service area could and would have considerable impact on ground transportation activity, reducing congestion both on roadways and in parking lots and ultimately constituting a first step in changing the automobile-dependent traveling habits of the local population.

CONCLUSIONS

In calendar year 1977, LAX served more than 28 million annual passengers. This represents a growth of about 9 percent over the previous year. Average daily automobile traffic in the central terminal area grew less than 4 percent over the same time period. This substantiates the success of both the FlyAway Bus program and the expansion of the peripheral parking lots. An expanded and improved FlyAway Bus program and a faster, more convenient transportation system from the peripheral parking lots to the central terminal area should make it possible to efficiently accommodate the forecast demand of 40 million annual passengers at LAX in the mid-1980s. Beyond that point, because of the constraints of off-airport traffic, the Los Angeles Department of Airports must look to other airports—most notably Ontario and Palmdale International—to carry the load.

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Behavioral Analysis of Verbal Interaction Between Pilots and Air Traffic Controllers

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The principles of behavior theory are used as the basis for a study of the verbal interaction between air traffic controllers and airplane pilots. The danger created by the diversity of rules and regulations that govern the behavior of pilots and controllers is shown to be a primary reason for such an analysis. Basic concepts of behavior theory are discussed in relation to air traffic control operations. Graphs compiled by using tape recordings of pilot-controller conversations are used to analyze cumulative word rates and speech content. The analysis reveals problems such as a high speech rate among air traffic controllers and aberrant patterns of behavior and response among pilots. Further application of the principles of behavior theory to air traffic control operations is recommended.

Demands are continually made on people to respond to an untold variety of "signals". How they react to those signals determines how they will respond to comparable signals in the future. The lack of a consequence can alter their future reaction to comparable signals even if their first reaction was appropriate.

The formalized study of such phenomena has developed into a body of knowledge referred to as "behavior theory" (1, 2). The most important aspect of behavior theory is the three-part reinforcement contingency: In reaction to a discriminative stimulus, a response occurs, which in turn evokes a reinforcing stimulus. It is the reinforcing stimulus that can modify the nature of future responses, for it can either strengthen or weaken behavior. The absence of a reinforcing stimulus leads to a variety of responses because there is no guidance as to the desirability of any one response.

The work described here was conducted by a behavioral psychologist in consultation with a research team that included an expert in transportation safety and a transportation specialist who is also a pilot. The following information sources and data were considered:

1. The interface between the airplane pilot and the air traffic controller, including the rules and regulations each is required to follow;
2. A significant number of National Transportation Safety Board (NTSB) reports on aircraft accidents and incidents;
3. Background visits to a control tower and an approach control facility; and
4. Tapes of conversations between pilots and air traffic controllers in a number of situations, including an accident and a near accident.

The tapes do not include all conversations of the parties involved, since the pilot could well be involved in cockpit conversations and the air traffic controller in conversations with people in the control room and neither is necessarily recorded on the channel being taped. In spite of these limitations and the small samples involved, a number of useful insights have been gained by doing a content analysis of the tapes, studying the speech rates of pilot and controller, and applying the principles of behavior theory to the results.

DESCRIPTION OF OPERATIONAL ENVIRONMENT

It is useful to consider the environment in which air traffic control operations take place. This can be divided into two parts: the general background and governing procedures.

General Background

At a given airport, the specific division of responsibility for air traffic control—when there is a division—varies with the size and complexity of the airport. On a given trip, pilots are "handed off" from en-route controller to en-route controller until they approach the vicinity of a terminal airport. At the more complex airports, they first come into contact with an approach controller. Once contact has been established, they proceed under radar control and are directed by the controller to a point at which they are ready for landing and they are handed off to a final approach controller. The final approach controller continues the operation, guiding the aircraft by radar until it is lined up with the runway and is approximately 8 km (5 miles) from the airport. At that point, the final approach controller turns the pilot over to the tower for the final landing clearance. It is the responsibility of the tower to ensure that the runway is available and that no other planes are in conflict in the immediate vicinity. Once clearance is given, however, the decision on whether to land is the specific responsibility of the pilot.

This is a general description of the sequence of control operations for commercial (and other) aircraft on arrival at a major airport. At smaller airports, the number of steps may be reduced. However, airports can easily have additional control functions (e.g., a slow-traffic controller) as well as sector coordination and hand-off personnel.

On departure, once an aircraft is airborne it is switched from the tower to a departure controller. The departure controller is responsible for keeping the aircraft climbing up and out of the area in a safe, orderly manner. This task is complex, requiring many steps and interrelating personnel. It is also performed in an environment that requires monitoring and decision making by each individual.

Governing Procedures

Because each individual involved in air traffic control is required to make continual and rapid decisions, the division of control and authority among the various parties involved is a central issue.

The pilot is governed by federal regulations that vary depending on the type of aircraft used (e.g., small reciprocating engine, turbojet, glider, or helicopter), the nature of the flight (i.e., personal or commercial), and weather conditions. In addition, professional pilots, whether airline or corporate, have their own company requirements and recommended procedures to follow.

Pilots and their flying techniques are further guided by various recommended, but not mandatory, Federal Aviation Administration (FAA) procedures. These are outlined in advisory circulars, the Airmen's Information Manual, and pilot "exam-o-grams". The FAA air traffic control manual assumes that the pilot complies with these recommended procedures.

The air traffic controller, on the other hand, is governed by FAA orders and the Manual of Operation for Air Traffic Control for his or her particular job classification. Both the orders and the manual are internal FAA publications.

A chilling example of the difficulties that can arise from such a diversity of regulations, procedures, and advisories is a 1974 air crash near Dulles International Airport outside Washington, D.C. The pilot, using an FAA approach procedure, was given a clearance by the air traffic controller. The pilot began his descent to the lowest permissible altitude as shown on the approach procedure chart—and hit the side of a mountain. This error was attributed to a misunderstanding of what the term "cleared for the approach" meant. The pilot assumed that since he was cleared for the approach he could begin his descent immediately. The controller assumed that the pilot would wait until he was over the mountain before beginning his descent. The FAA subsequently published a glossary of terms for pilots and air traffic controllers in an attempt to prevent a recurrence of this type of problem.

It is such problems in communication that are the subject of this paper. How many times had a pilot previously taken the phrase "cleared for the approach" to mean that any altitude within the permissible range, down to the minimum published altitude for the approach, was allowed, and survived only because no mountain happened to be in the way? In the terminology of behavior theory, the erroneous behavior (the incorrect response) was reinforced.

PRINCIPLES OF BEHAVIOR THEORY

Certain basic principles of human behavior can be applied to a wide variety of situations without much alteration. Behavior theory (1, 2) provides an excellent set of principles for use in analyzing behavior that is significant in transportation safety. The basic concepts of behavior theory that are relevant in the field of air traffic control are (a) the reinforcement contingency, (b) primary and conditioned reinforcement, (c) positive and negative reinforcers, (d) punishment, (e) extinction and reinforcement of undesirable responses, (f) intermittent reinforcement, and (g) discriminative stimulus control. Examples of these concepts are discussed below.

The Reinforcement Contingency

The most important aspect of behavior theory is the three-part reinforcement contingency. On particular occasions, in the presence of certain discriminative stimuli, a response or behavior is evoked. The behavior has consequences, or reinforcing stimuli. This relationship can be represented symbolically in the following way:

$$S^D \ldots R \rightarrow S^r \quad (1)$$

where

S^D = discriminative stimulus,
R = response, and
S^r = reinforcing stimulus.

S^r is the event that occurs after the response. Certain types of reinforcers (or, loosely speaking, rewards) strengthen behavior so that it occurs more frequently in the future. In some cases, however, there is no reinforcing stimulus and the behavior is weakened. In such cases, the discriminative stimulus evokes a wide variety of responses.

Primary and Conditioned Reinforcement

In the formula given above, the consequence is a conditioned reinforcer. This is most often the case. A conditioned reinforcer is, by definition, one that begins as a neutral stimulus and becomes reinforcing through experience, whereas a primary reinforcer is, by definition, one that is reinforcing from birth.

Examples of primary reinforcers are food (a primary positive reinforcer) and pain (a primary negative reinforcer). Although primary reinforcers play an important role in shaping the lives of every person, they are all modified by the conditioning history of the individual and are often not as important as conditioning reinforcers such as praise, job discipline, attention, and money.

Positive and Negative Reinforcers

A positive reinforcer is an event that strengthens the response that precedes it. For instance, a pilot might request clearance to land (the discriminative stimulus) and evoke the response or behavior from the controller of the desired permission given in a clear, crisp, and well-formatted way. The positive reinforcing stimulus from the pilot would be a "thank you" or a "well done" and a landing in the required time and place.

A negative reinforcer is an event that strengthens the desire to eliminate or avoid that event. For instance, the air traffic controller might give a clarification to a pilot that the controller judges to be adequate but the pilot (perhaps because of his own inadequacies) finds difficult to understand. In this case, the controller can receive a negative reinforcing stimulus—the burden of communicating with the pilot again—that evokes the response of cutting short or discouraging such communications.

In most situations, a multiplicity of factors are at work. For instance, the controller described above may also be subject to the positive reinforcer of the pilot's recognition of the controller's fine work.

Punishment

Punishment is an aversive event contingent on the occurrence of a particular behavior. It usually reduces the probability of that behavior occurring again under similar stimulus conditions but only for a period of time.

Unlike the effect of positive or negative reinforcement, the effect of punishment is temporary: In the absence of the punishing stimulus, behavior that was suppressed by the punishment regains its normal probability of occurrence. Punishment is not as desirable a form of control as positive or negative reinforcement, which affects behavior for a longer period of time and thus alters or shapes it in more lasting ways.

Extinction and Reinforcement of Undesirable Responses

It is often incorrectly assumed by the lay person that a desired response or behavior will continue when the reinforcement contingency is no longer in force. It is a basic observation in behavior theory, however, that, when reinforcement is discontinued (extinction), the conditioned behavior gradually decreases in strength until—if the process is continued long enough—the conditioned behavior returns to the preconditioning level.

It must be recognized that behavior varies when reinforcement is discontinued. When some of these variations in behavior are followed by positive reinforcement, the probability of the occurrence of those variants of the correct behavior is increased. It is therefore a major and critically important task to build into any communication process such as the one discussed here a set of positive reinforcers so that the various parties in the communication process can continually reinforce the desired behavior in the others. Because this is a two-way conversation, each party must have positive reinforcers for the other's behavior.

Rules that do not have a reinforcement contingency built into their application would fall into disuse. The use of punishment, which occurs only after the rules have not been followed, ensures that the rule book is followed only nominally, since only total disregard of the rule book elicits clear penalties, including dismissal. Under these conditions, blatant disregard of the rules will probably be avoided. However, variations in behavior occur that require the finer control achieved through positive reinforcement of appropriate behavior as it occurs. Explicit attention must be given to having the parties involved positively reinforce each other.

Intermittent Reinforcement

In real life, the same consequence does not always follow the same response. What happens when a response is only sometimes reinforced? Experience has revealed a somewhat startling answer: Behavior that is intermittently reinforced becomes stronger than behavior that is reinforced every time it occurs. Behavior reinforced only some of the time resists extinction to a greater extent than behavior reinforced on a continuous basis before the extinction procedure (i.e., the removal of all reinforcing stimuli) is instituted.

In the context of air traffic control operations, it is necessary to take into account not only behavior that is regularly reinforced but also—and especially—behavior that is only intermittently reinforced. From the point of view of the enforcement of regulations, it must be realized that, if undesirable behavior is permitted even some of the time, one should not be surprised if that undesirable behavior gains in strength. Indeed, according to the principle of intermittent reinforcement, it will be more difficult to extinguish such behavior than behavior that is continually reinforced. Reinforcing undesirable behavior, particularly in the face of countermanding regulations, makes those regulations lose their controlling strength in other areas as well.

Discriminative Stimulus Control

Discriminative stimuli control the behavior that is evoked only when there are appropriate consequences, or reinforcing stimuli. For example, consider that the relevant rules and regulations specify the following discriminative stimulus and behavior: The controller gives clearance instructions to the pilot (discriminative stimulus), and the pilot repeats the clearance message in the sequence given (behavior). But pilots repeat the message either in the order given or in the reverse order. Controllers provide no differential reinforcement for this; i.e., they accept the message in either order. A positive reinforcer—acknowledging the message only in its proper form—could bring the pilot's behavior under proper control. The negative reinforcer of not accepting the incorrect behavior could also con-

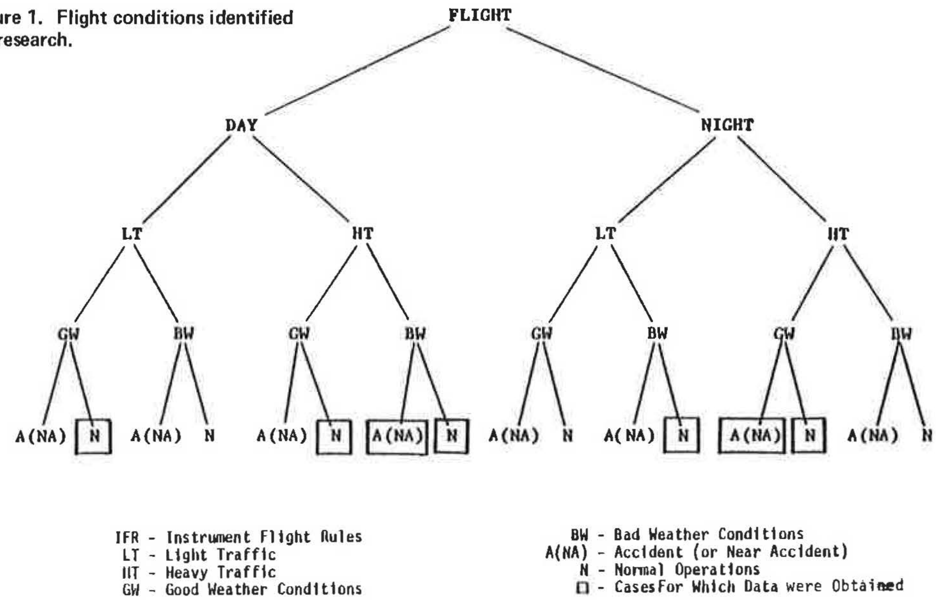


Figure 1. Flight conditions identified for research.

trol the behavior evoked by the discriminative stimulus. However, the discriminative stimulus (in the absence of reinforcement) does not control behavior.

DATA ACQUISITION

In pilot-controller interaction, each person's remarks constitute both the discriminative stimuli and the reinforcing stimuli for the other. In addition to the discriminative stimuli and the reinforcers provided by the participants, discriminative stimuli and reinforcers are also produced by external conditions, such as the air traffic control rules and regulations; weather, time of day, and amount of traffic; and special situations, such as another plane having trouble at the same time.

Four external factors were identified as being of primary interest in this study: (a) day versus night, (b) heavy versus light traffic, (c) good versus bad weather, and (d) "incident" versus normal operations (incident includes both accidents and near accidents). The 16 cases that illustrate these four external conditions are shown in Figure 1.

A total of eight episodes were analyzed; these represented the seven boxed cases shown in Figure 1. To obtain even the seven distinct cases, it was necessary to tape some pilot-controller conversations by using the research organization's own equipment. These tapes, unlike FAA tapes, do not have time marks. Thus, it was not possible to conduct time analyses of all of the tapes.

The duration of the pilot-controller interactions that were taped varied from 9 min to approximately 60 min and totaled about 3 h of interaction. The combinations of external conditions covered by these interactions can be summarized as follows:

1. Four day and four night interactions;
2. One accident, one near accident, and six normal-operation interactions;
3. Four heavy-traffic and four light-traffic interactions; and
4. Five bad-weather and three good-weather interactions.

For purposes of definition, good weather is considered to be a condition that allows operation by visual flight rules, and bad weather is considered to be a condition that requires operation by instrument flight rules.

Transcripts were made of all tapes. Each transcript was checked for accuracy at least once by the typist and then by the pilot and safety inspector members of the research team. Finally, the psychologist on the research team listened to portions of the tapes to further verify their accuracy.

DATA ANALYSIS AND RESULTS

Speech Rate

Analysis

One of the two formal, quantitative methods of analysis used was an analysis of pilot-controller interactions by means of graphs of the cumulative word rate. This analysis consisted of plotting the cumulative number of words as a function of time. The graphic presentation makes apparent the interrelations between the two participants as well as their speech rates.

The following rules were used to count words:

1. Speech emitted by the pilot constitutes the "pilot word rate".
2. Speech emitted by the controllers (occasionally the speech of more than one controller is on a tape) constitutes the "controller word rate".
3. The designation of an aircraft—for example, "Global 168"—is counted as one word because the complete set of symbols, words and numbers, is necessary to name the aircraft.
4. Designations of altitude, heading, speed, and the name of a destination such as "New York" are treated as single words although they are written as more than one word.

Word frequencies were calculated for periods of 5 s unless the time announcer's voice on the original tape was masked by the speech of one of the interlocutors (controller or pilot), in which case longer intervals were used. The frequencies were then cumulated over time, and the graphs were drawn. Finally, at least some examples of communication problems are written in on the graphs to point out some of the trouble spots with respect to various rates of speech by controller or pilot. Note that these illustrative communications do not include all conversations even for the accident or near-accident situation.

Results

Figure 2 shows a graph of the cumulative word rates for an interaction at night, in light traffic, in bad weather, and preceding an accident. The curves for pilot and controller speech are plotted separately as a function of time. Note that the controller has not yet heard from the plane that ultimately had the accident. The interaction recorded immediately preceded the time in which the accident occurred.

The most obvious fact is that the controller(s) speak(s) much more than the pilot. This is to be expected because the pilot is asking for, and the controller is furnishing, information. The horizontal portions of the lines indicate periods of no radio contact between controller and pilot. These periods do not necessarily mean that controllers are silent. They may be talking to other controllers or having conversations that are not recorded on the channel represented by the tape.

Figure 3 shows a graph for an interaction that occurred at night, in light traffic, and in bad weather and that included an accident. The tape illustrates a characteristic also found in the preceding case (Figure 2): The speech rate for both controllers and pilots is frequently rather high although the situation includes apparent idle time of some significant length. In general,

Figure 2. Tape of pilot-controller interaction before an accident.

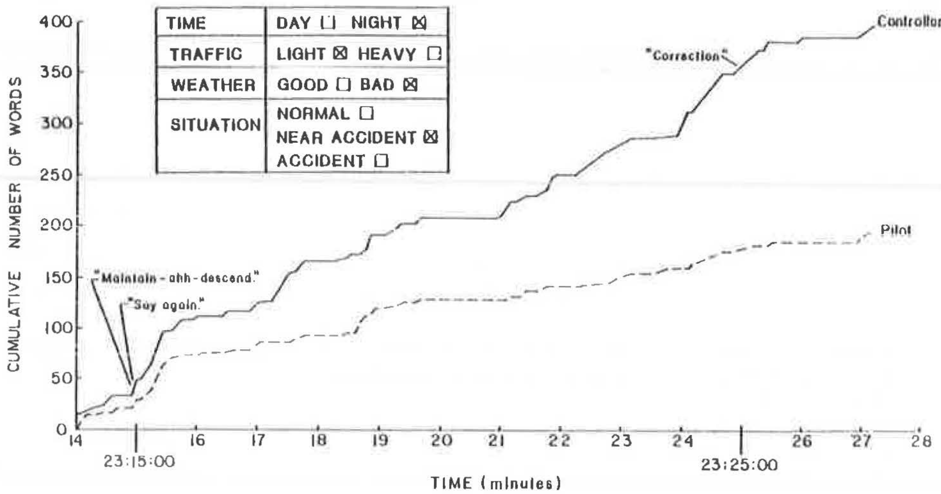
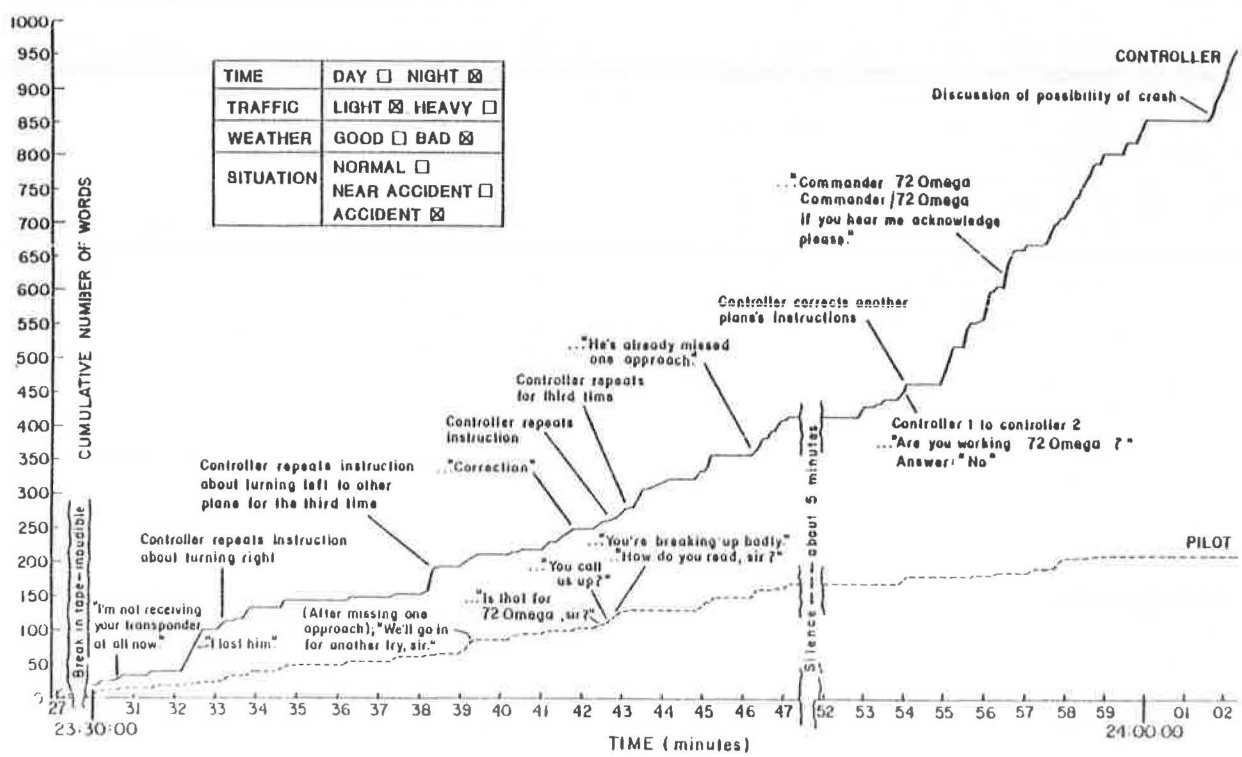


Figure 3. Tape of pilot-controller interaction including an accident.



pilots have periods in which the speech rate is slower, but the controllers tend not to have significantly slower speech rates. It is interesting to note that the traffic condition cited is light traffic, so that the controller ought not to be under pressure to go on to the next pilot, and yet the speech rate is very high. In terms of behavior theory, this nonadaptive response can be ascribed to generalization; that is, the controller generalizes from the heavy-traffic to the light-traffic condition, using a response mode that is adaptive and necessary in one condition (the high speech rate) for the other condition as well.

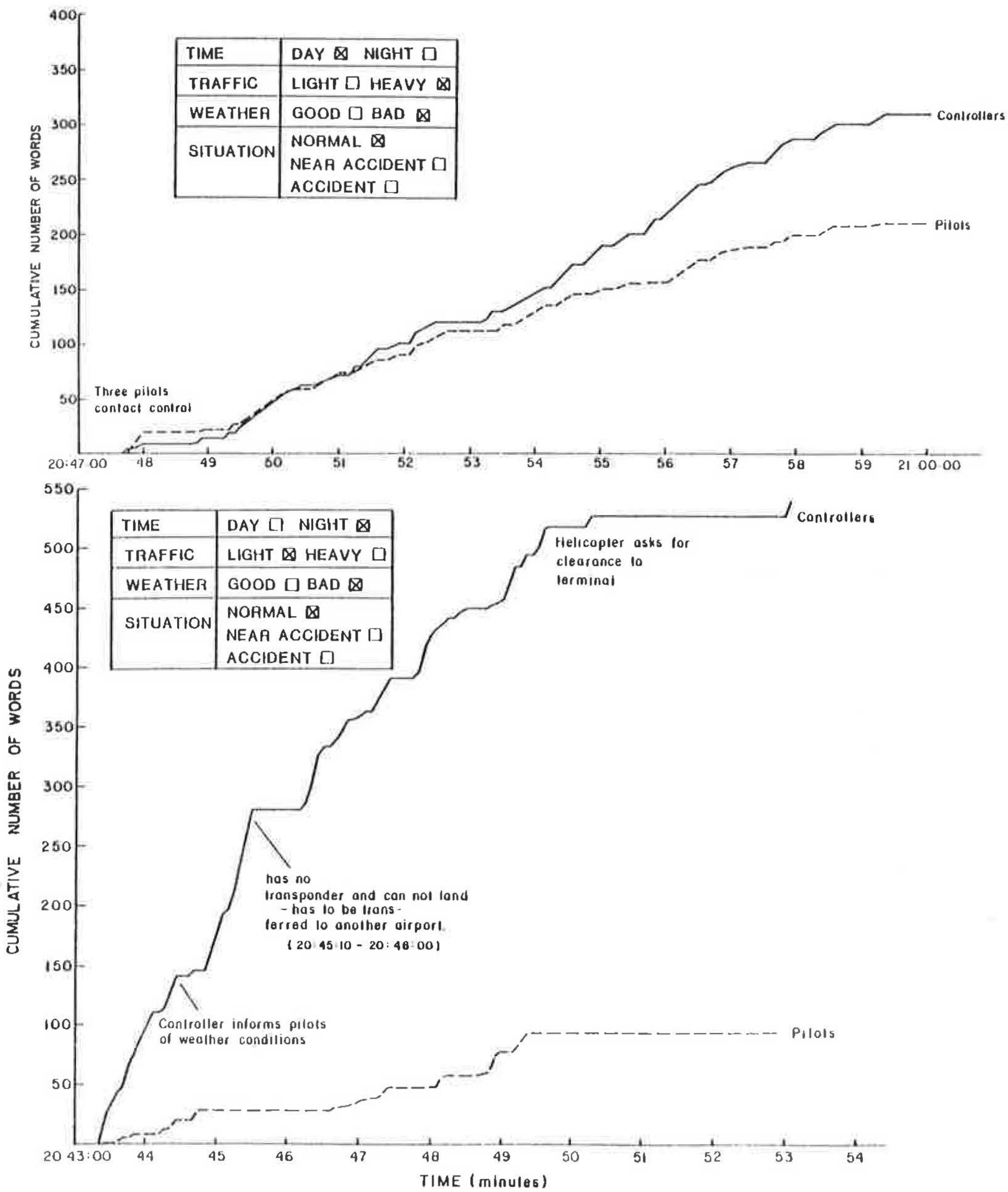
It is important to note that, although the speech rate is high, it is normally intelligible, particularly considering the limited vocabulary that is used in such communications. But a high speech rate can easily become unintelligible and can certainly put an additional burden on the participants. Cases in which this occurred were noted on other tapes; in one such case, the pilot heard incorrect information, missed the immediate correction by the controller, and became confused about what action to take.

It is testimony to the limited but critical nature of this type of communication that in many situations the controller has no direct or observational knowledge of the plane. In this particular case, the accident occurred in the gap indicated by "silence—about 5 minutes". The controller(s) continued to attempt to contact the plane well after it was lost. This is not said to imply criticism but simply to note and emphasize that the pilot and controller depend critically on the oral communication channel.

Figure 3 shows a speech rate well beyond even that found in Figure 2 as the controller(s) seek(s) information on the plane, which the weight of evidence now indicates had crashed. However, it is not this rate but the high speech rate that routinely occurs (and for which there is evidence preceding the accident) that is cited as significant.

Figure 4 shows graphs for two additional cases.

Figure 4. Rate of speech of controllers and pilots as a function of time.



More information can be extracted from these tapes with regard to specific communication problems and content, but the speed rates are generally consistent with the remarks made for the other cases.

Speech Content

Analysis

The other major category of formal, quantitative analysis is content analysis. Two major categories of speech content were used: self-correction and requests for clarifications and repetitions. Both of these categories were used to individually classify pilot speech and controller speech, which produced four categories of classification. After these frequencies were determined, each of the scores was transformed into the number of occurrences per hour in each category, for easy comparison and further analysis.

Self-Correction

Inspection of the transcripts indicated that controllers occasionally correct themselves in their communications. For example, they might say, "Maintain—ahh—descend". Sometimes the correction is preceded by the word "correction". The point of this is not to note that controllers make mistakes but rather to determine what number of such occurrences or difference in pattern from one time to another would indicate a communication problem.

Requests for Clarification and Repetition

Inspection of the transcripts showed that, in the course of information exchanges between controllers and pilots, one party occasionally did not understand or did not hear what the other party said. Examples of such requests are fairly obvious. They sometimes consist of phrases such as, "What'd ya say?" At other times, the pilot might hear only the first part of a message to which the controller appended a correction and might request clarification because the information seemed inaccurate or confusing.

Results

Figures 5 and 6 show the results of the analysis of speech content. The factors considered were good versus bad weather, light versus heavy traffic, day versus night, and normal operations versus accident or near-accident condition.

In general, the results are what one would logically expect: more corrections or clarifications in bad weather than good, at night than during the day, and before accidents than not (although for the data at hand this could be explained by other factors, since the accident and near-accident situations were both at night and in bad weather). Results for light versus heavy traffic appear anomalous: The controller produces more corrections and requires more clarifications in light than in heavy traffic.

IMPLICATIONS OF RESULTS

Word Rate

One of the most important observations extracted from the data analysis is that controllers generally speak at a high rate regardless of the traffic condition. Although there may be some justification for a high speech rate under heavy-traffic conditions, there is little justification for it in lighter-traffic conditions.

The fact that the air traffic controller is being "trained" to the higher speech rate in the heavy-traffic conditions and is transferring it (generalizing) to all conditions must be viewed with concern. In behavior theory terms, the high speech rate is apparently reinforced by the rewards of meeting the heavy-traffic situation.

Reversing Information

Some pilots respond to controller instructions by repeating the information as given, whereas others respond by repeating the information in reverse order. This introduces a degree of uncertainty under tense circumstances. Is a controller to assume that the pilot is using the reverse-order practice, or that he has perhaps misunderstood his instructions? When certain number combinations are involved, this would become critical.

The fact that this difficulty exists means that the aberrant pilot behavior is not properly reinforced and that the controller should require responses in a consistent format to avoid confusion and hazard. The controller has the opportunity—and should have the responsibility—to encourage uniform responses by questioning or challenging variants (i.e., withholding positive reinforcement for the variants and reinforcing appropriate responses).

Requests for Clarification

The speech-content analysis of the tapes included an analysis of the number of clarifications or corrections requested by pilots or given by controllers. In general, the pattern was the expected one: more clarifications and corrections in bad weather than in good, more at night than during the day, etc. One pattern, however, was the reverse of that expected: more clarifications and corrections in light traffic than in heavy traffic.

One explanation might be that the information in the light-traffic situation is "extra" or even "idle chatter"; that is, the controller has the time, or knows that the pilot has the time, to check and double-check the instructions. Another possible explanation in the same vein is that, because of the low-pressure situation, one party or the other is too casual and more prone to error.

There is, however, another, more disturbing possibility—that the controller feels that this information is needed but does not ask for it in heavy traffic because of the pressures of the situation. The controller might be responding to the more overpowering positive reinforcement of moving on to other pilots who need information and thus forego obtaining or correcting some information for each pilot. A more detailed study of this problem is certainly in order.

Number of Controllers

One possible solution to some of the problems cited here would appear to be increasing the number of controllers and thus lessening the burden on each individual controller. But it must be recognized that, under the existing air traffic control system, this would mean that each controller would be responsible for a smaller air space, and this would imply not only greater coordination problems but also a greater number of controllers and more hand-off situations per flight. An alternate solution might lie in enhanced technology that allows the controller to reduce hurried, verbal com-

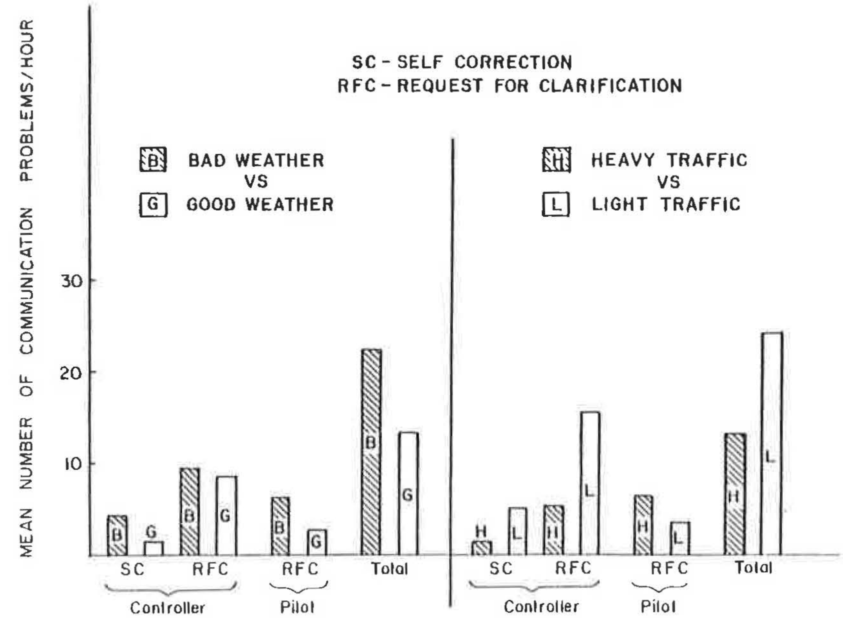


Figure 5. Analysis of speech content for good versus bad weather and heavy versus light traffic.

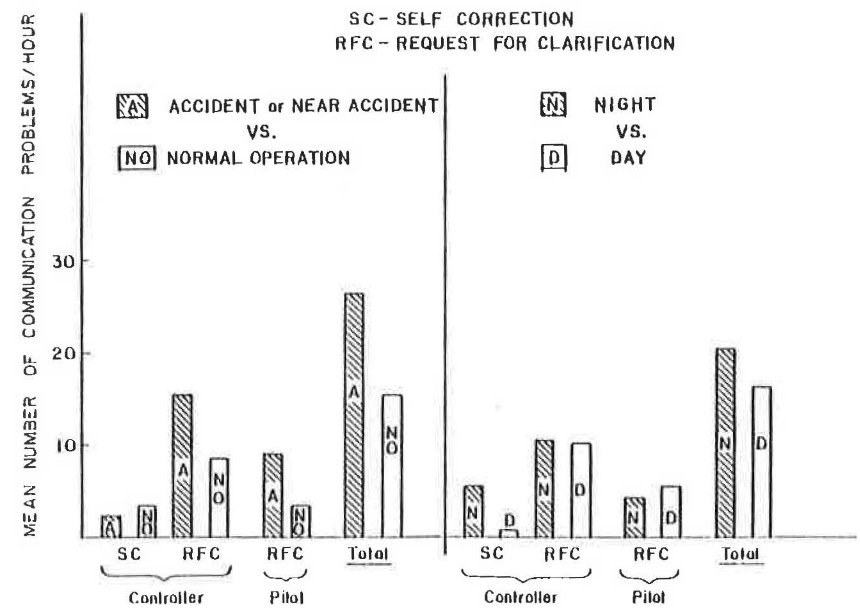


Figure 6. Analysis of speech content for accident or near-accident situation versus normal operations and night versus day.

munications and to provide unequivocal, documented instructions to each pilot.

Speech-Content Analysis

In this study, speech-content analysis has been used to good effect in documenting the difference in clarifications and corrections per unit of time under various conditions. It is recommended that such a tool be considered for use in a random-sampling monitoring procedure to discern patterns or variations that might identify potential problems. One possible flaw must be noted: Such monitoring or sampling might itself become a negative reinforcer and actually increase aberrant behavior or suppress good behavior. For instance, pilots and controllers can quickly learn that clarifications and corrections lead to a "bad score" and create artificially "good scores" by suppressing, even subconsciously, otherwise necessary clarifications and corrections.

APPLICATION OF BEHAVIORAL PRINCIPLES

A number of basic principles can be extracted from behavior theory and applied to the pilot-controller interface. Several of these principles are noted in this paper. A more extensive study might identify a number of such guiding principles and specify their applications.

As one example from the study of memory, consider the following: It is well known that saying another number after saying a number that is supposed to be remembered creates the classic condition for confusing the numbers. Yet this is precisely what happens when a pilot states an understood numeric command (such as assigned altitude) and then states the flight identification, which is itself a number.

OTHER OBSERVATIONS

Based on the limited observation of a trained observer, the following conditions or situations are worthy of note:

1. The problem of formatting the acknowledgment of a received message is troublesome because of the possible confusion of numbers and possible word clipping in transmission.
2. Similar, or possibly even identical, flight identification numbers can occur in the same air space.
3. The windowless character of some ground facilities may have subtle, adverse psychological effects on workers.

CONCLUSIONS AND RECOMMENDATIONS

Although the data base for this research was limited, the conclusions are consistent with what one would expect based on the general principles of behavior theory. A number of basic principles can be extracted from behavior theory and applied to the interface between pilots and air traffic controllers. Certainly, the opportunity to apply behavior theory to enhancing the safety of the pilot-controller interface has not been exhausted by this work. Indeed, if anything, this work has indicated the usefulness of these techniques for identifying underlying problems in such human behavior, particularly in communications. Further work along these lines is strongly recommended.

ACKNOWLEDGMENT

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Analysis of Dynamic Response of Aircraft to Profiles of Unloaded and Loaded Pavements

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A study conducted to determine whether there is a significant difference in the simulated dynamic response of an F-4C aircraft as it traverses unloaded (undeflected) or loaded (deflected) pavement is described. The U.S. Air Force computer code TAXI, which calculates vertical accelerations at three points on an aircraft as it traverses a pavement profile, was used to simulate aircraft response. An unloaded-pavement profile was obtained on a 640.5-m (2100-ft) test section. Deflections caused by a load cart equipped with an F-4C aircraft tire were measured on the same test section, and these deflections were subtracted from the unloaded-pavement profile to obtain a loaded-pavement profile. A statistical analysis was performed that consisted of two parts: (a) a test of the mean of a sample composed of the differences between acceleration responses to unloaded- and loaded-pavement profiles and (b) a test of the distribution of the acceleration responses to both types of profiles. The analyses were performed for six aircraft speeds. There was no significant difference in the responses to unloaded- and loaded-pavement profiles at speeds up to 640.5 m/s (40.7 ft/s), although at higher speeds some rejections of the mean occurred. Based on the results, it appears that the present U.S. Air Force practice of using unloaded-pavement profiles to simulate the dynamic response of aircraft is acceptable and that loaded-pavement profiles need not be obtained for this purpose.

A major problem encountered by aircraft during takeoff, landing, and taxiing operations is the high level of vertical acceleration produced by a rough runway. This response can affect the readability of on-board instruments during ground operations. This and other factors influence the overall safety of an aircraft and indicate that pavement roughness is a factor that cannot be ignored in evaluation of airfield pavements.

It has been recommended that, when the acceleration response experienced in an aircraft exceeds 0.3 *g*, remedial measures be taken (1). The Port Authority of New York and New Jersey found that the maximum level of aircraft vibration before passenger discomfort was noted was 0.12 *g* in the normal operation area and 0.3 *g* in infrequently trafficked areas (2). Hall and Kopelson (3) also used a roughness criterion based on accelerations and indicated that a runway was undesirable when the acceleration at either the pilot's station or the aircraft's center of gravity exceeded 0.5 *g*.

To control the adverse effects of a rough runway, the areas in question must be located and corrected. A subjective qualitative assessment of pavement roughness can be obtained from flight crews, but the specific area of the runway that needs repairs cannot be located in this way.

One way to effectively locate rough areas of runway pavement is to equip an aircraft with low-frequency servo accelerometers, which record the accelerations encountered while the aircraft traverses the runway. This method, however, is costly, both in time and personnel. Furthermore, since different aircraft respond to identical pavements differently and the responses generated are a function of aircraft speed, such tests are not very useful.

To determine the response of an aircraft to pavement roughness quickly and inexpensively, the Civil and Environmental Engineering Development Office of the U.S. Air Force has developed the computer code TAXI (4), which simulates the response of an aircraft to pavement roughness by using aircraft characteristics and the pavement profile as input. Output includes landing-strut forces and displacements and vertical accelerations at three points on the aircraft frame.

The pavement profile used as input to the TAXI program is currently obtained by using either laser or inertial profilometers. These devices record a series of elevations taken with respect to a local datum to define the pavement profile. This profile, however, is for an unloaded pavement that is not deflected by the weight of an aircraft. The pavement actually traversed by an aircraft is loaded and therefore deflected. Consequently, the profile of a pavement that is traversed by an aircraft at different speeds is different from those used as input to the TAXI program.

It has not been determined whether there is a significant difference in the simulated response of an aircraft to profiles of unloaded and loaded pavements. The purpose of this study was to make such a determination. If it were found that the response of an aircraft to an unloaded-pavement profile was essentially the same as that to a loaded-pavement profile, then the methods currently used to evaluate pavement roughness would be acceptable. If, however, a significant difference existed, it would then be necessary to develop a rapid and accurate means for the determination of a loaded-pavement profile to be used as input to TAXI.

The objectives of this research were

1. To develop a method of statistically comparing aircraft response to profiles of unloaded and loaded pavements that would determine whether or not a significant difference existed and
2. To perform the comparison while varying aircraft speed, direction of travel, and level of significance.

TAXI PROGRAM

The TAXI computer program (4) simulates the dynamic response of an aircraft as it traverses a rigid surface. The program does not take into account any deflection of the runway pavement that is attributable to aircraft weight. The input to TAXI consists of aircraft data and a series of elevations at 0.6-m (2-ft) intervals, which make up a pavement profile. The programmer has the option of specifying either a constant-speed taxi or a takeoff simulation. The output of the program includes a listing of 10 aircraft parameters at specified time (or distance) intervals and plots of vertical accelerations and the pavement profile as viewed from the aircraft nose gear. Included in the output parameters are vertical accelerations at the pilot station, the center of gravity, and the tail section, as well as landing-strut forces and displacements.

The profile used as input to TAXI is modified by the program. The length of the profile is increased by adding 30.5 m (100 ft) to the starting end of the pavement so that the nose gear of the aircraft traverses the entire input profile. This modified profile is then normalized with respect to the first input elevation point. In the resulting profile, the first 31.1 m (102 ft) of pavement is at zero elevation. The rest of the points are arrived at by taking the difference between the input elevation at the point in question and the first input elevation. Finally, the elevations are normalized with respect to a straight line drawn from the first input elevation to a point 85.4 m (280 ft) from the end of the pavement profile. The profile is normalized to facilitate output plotting.

The resulting normalized profile is that which the program simulates as being traversed by the aircraft. Although it is different from the profile that is used as input, studies have shown that there is little difference in aircraft response to normalized and nonnormalized profiles (5).

Figures 1-3 show example plots of the output of TAXI in the general form of the vertical-acceleration response of an aircraft to a pavement profile. These vertical accelerations are shown for the tail section, the center of gravity, and the pilot station of an F-4C aircraft as it traverses an unloaded-pavement profile at a constant taxi speed of 30.5 m/s (100 ft/s).

DETERMINATION OF UNLOADED- AND LOADED-PAVEMENT PROFILES

To obtain a profile of an unloaded pavement, elevation points along a 640.5-m (2100-ft) test section of taxiway at Eglin Air Force Base, Florida, were obtained at 0.6-m (2-ft) intervals. These points describe the unloaded-pavement profile that would normally be used as input to the TAXI program should the simulated response of an aircraft to this section of taxiway be desired.

At each of 23 stations along the taxiway test section, deflections were measured at six points along a line perpendicular to the direction of travel of a load cart. The load cart was a truck on which the rear axle was modified and mounted with an F-4C aircraft tire to apply a 111-kN (25 000-lbf) single-wheel load to the pavement. The applied load simulated the load that would be applied by the main gear of an F-4C loaded almost to its maximum takeoff weight.

These deflections, measured by linear variable differential transformers, were assumed to be the same as those produced by an F-4C aircraft traversing the taxiway. Deflections were also obtained by using light-emitting diodes. These deflections were measured parallel to the direction of travel of the load cart at points 0.6 m (2 ft) apart in the same positions as the points that define the unloaded profile. The deflections measured by the two methods were used to compute the deflections beneath the center of the aircraft tire at 0.6-m intervals along the test section. These computed deflections were then subtracted from the elevations of the unloaded-pavement profile to yield the loaded-pavement profile.

Although the deflection measurements were made at creep speeds and it is known that deflections decrease with increasing vehicle speeds, the loaded-pavement profile obtained by the procedure described above was assumed to be the same as that of a pavement actually traversed by a loaded aircraft moving at high speeds. For the purposes of this research, this assumption is conservative because it results in maximum differences in profiles of unloaded and loaded pavements.

A detailed description of the procedure and the equipment used in determining the unloaded- and loaded-pavement profiles is contained in a report by Highter and Snyder (6).

STATISTICAL ANALYSIS

In determining whether or not the acceleration responses for the unloaded- and loaded-pavement profiles were significantly different, it was decided that the analysis would be performed on short subsections of the pavement as well as on the whole test section. By breaking

Figure 1. Vertical-acceleration responses to unloaded-pavement profile at constant taxi speed of 30.5 m/s: tail section.

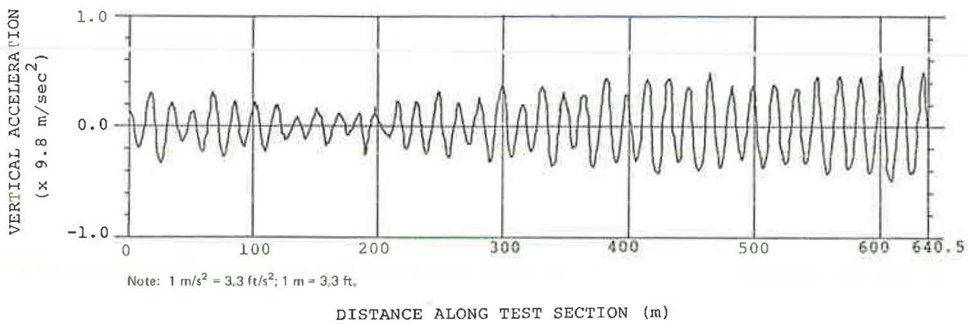


Figure 2. Vertical-acceleration responses to unloaded-pavement profile at constant taxi speed of 30.5 m/s: center of gravity.

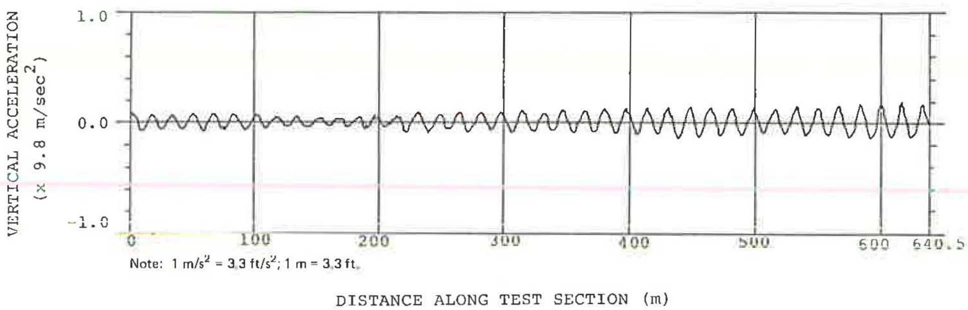
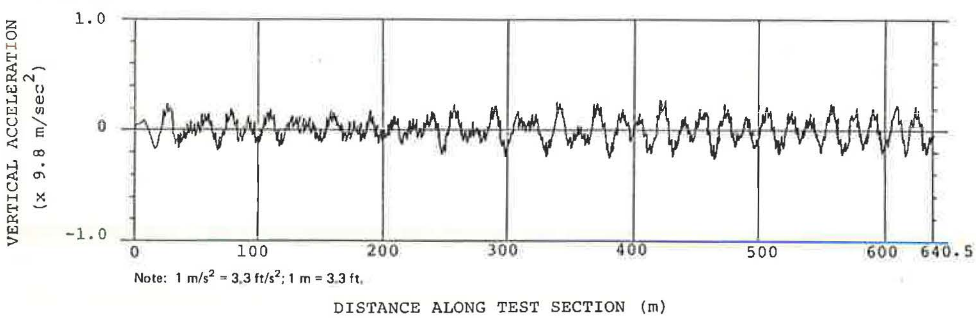


Figure 3. Vertical-acceleration responses to unloaded-pavement profile at constant taxi speed of 30.5 m/s: pilot station.



the test section up into smaller subsections, localized areas over which the acceleration responses either were or were not significantly different could be identified.

The 640.5-m (2100-ft) test section was divided into 25 subsections, each of which was 25.6 m (84 ft) long. Since TAXI outputs aircraft acceleration responses at 0.6-m (2-ft) intervals, the comparison would be based on 43 points/subsection; when it was performed on the entire test section, the comparison would be based on 1051 points.

Once the acceleration responses were obtained from TAXI by using unloaded- and loaded-pavement profiles, it was necessary to compare the responses and determine whether or not they were significantly different. Because no standard method was available to statistically compare two sets of data in the manner required in this study, a method of comparison had to be developed. We wanted to compare the two sets of responses to see if they were significantly different and at the same time to take into account the position of the aircraft on the test section when the response occurred.

If the test used were an ordinary comparison of the means of the two sets of acceleration responses, the position of the responses along the test section would be lost, because the mean is the algebraic average of all accelerations along the section and does not account for position of occurrence. A test of the distribution would also be inadequate, because such a test would only compare the number of accelerations that are within the same range of magnitude and, again, would not account for position of occurrence along the section.

For these reasons, the comparison of acceleration responses consisted of two parts. The first part was a test of the mean of a sample constructed by taking the difference between acceleration responses to the unloaded- and loaded-pavement profiles point for point along the section tested. Each element in this sample was therefore a comparison of the two acceleration responses generated at that point on the test section. The hypothesis that the mean of this sample is significantly close to zero was then tested to determine the similarity of the two responses.

Table 1. Statistical comparison of acceleration responses to unloaded- and loaded-pavement profiles for forward run, α = 0.05, and speeds of 10.2, 20.3, and 30.5 m/s.

Length of Subsection (m)	Test	Speed = 10.2 m/s			Speed = 20.3 m/s			Speed = 30.5 m/s		
		Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station
0-25.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
25.6-51.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
51.2-76.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
76.9-102.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
102.5-128.1	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
128.1-153.7	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
153.7-179.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
179.3-205.0	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
205.0-230.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
230.6-256.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
256.2-281.8	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
281.8-307.4	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
307.4-333.1	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
333.1-358.7	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
358.7-384.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
384.3-409.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
409.9-435.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
435.5-461.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
461.2-486.8	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
486.8-512.4	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
512.4-538.0	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
538.0-563.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
563.6-589.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
589.3-614.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
614.9-640.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
0-640.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A

Note: 1 m = 3.3 ft.
A = accepted.

The second part of the comparison was a chi-square test of the distribution of the two acceleration responses. The hypothesis that the unloaded acceleration responses could have come from the loaded acceleration responses was then tested to determine whether or not there existed any difference between the two.

The differences between the acceleration responses for the unloaded and loaded pavements were obtained on a point-for-point basis along the test section. This was done for each of the three locations on the aircraft for which vertical accelerations were available—the tail section, the center of gravity, and the pilot station. The test of the mean was then performed on these acceleration differences. In performing this test it was assumed that the number of elements (n) in each section tested was large enough so that the distribution could be approximated by that of a normally distributed population. In this study, the test was performed on either 43 elements (for each subsection) or 1051 elements (for the entire test section)—more than enough to satisfy the assumption.

A two-tailed test was then performed on the mean of the acceleration differences. The null hypothesis was that the mean u_o is equal to zero. The test of this hypothesis was achieved by using the statistic

$$Z = (\bar{X} - u_o)/(S/\sqrt{n}) \quad (1)$$

where

$\bar{X}$ = sample mean,
u_o = hypothesized sample mean, and
S = standard deviation.

The null hypothesis that the mean is equal to zero was accepted if the value of the computed statistic fell within the range $\pm Z_\alpha$, which can be obtained from standard statistical references (7, 8) for the specified level of significance α. An acceptance of the null hypothesis indicates that there is no reason to reject the assumption that the mean of the sample equals zero.

Testing the mean is not in itself a sufficient method for testing the significance of the differences between

Table 2. Statistical comparison of acceleration responses to unloaded- and loaded-pavement profiles for forward run, α = 0.05, and speeds of 40.7, 50.8, and 61 m/s.

Length of Subsection (m)	Test	Speed = 40.7 m/s			Speed = 50.8 m/s			Speed = 61 m/s		
		Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station
0-25.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
25.6-51.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
51.2-76.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
76.9-102.5	Mean	A	A	A	A	A	A	A	A	R
	Distribution	A	A	A	A	A	A	A	A	A
102.5-128.1	Mean	A	A	A	A	A	A	R	R	R
	Distribution	A	A	A	A	A	A	A	A	A
128.1-153.7	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
153.7-179.3	Mean	A	A	A	R	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
179.3-205.0	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
205.0-230.6	Mean	A	A	A	A	A	R	A	R	R
	Distribution	A	A	A	A	A	A	A	A	A
230.6-256.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
256.2-281.8	Mean	A	A	A	A	A	A	R	R	R
	Distribution	A	A	A	A	A	A	A	A	A
281.8-307.4	Mean	A	A	A	R	A	R	R	R	R
	Distribution	A	A	A	A	A	A	A	A	A
307.4-333.1	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
333.1-358.7	Mean	A	A	A	A	A	R	R	R	R
	Distribution	A	A	A	A	A	A	A	A	A
358.7-384.3	Mean	A	A	A	A	A	R	R	R	R
	Distribution	A	A	A	A	A	A	A	A	A
384.3-409.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
409.9-435.5	Mean	A	A	A	A	A	A	R	A	R
	Distribution	A	A	A	A	A	A	A	A	A
435.5-461.2	Mean	A	A	A	A	A	A	R	R	R
	Distribution	A	A	A	A	A	A	A	A	A
461.2-486.8	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
486.8-512.4	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
512.4-538.0	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
538.0-563.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
563.6-589.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
589.3-614.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
614.9-640.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
0-640.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A

Note: 1 m = 3.3 ft.
A = accepted; R = rejected.

the acceleration responses because the differences obtained from the responses will not be entirely positive or entirely negative. When the mean is computed by using these values, positive and negative elements will cancel, so the mean can be expected to be close to zero. It would also be possible to arrive at identical values of the mean from two entirely different sets of acceleration differences as long as the elements canceled each other in the appropriate way. These undesirable characteristics prevent the test of the mean from accounting for the magnitude of the differences between corresponding values of acceleration response.

The test of the mean, however, is an excellent first step in a two-step analysis that forms a screening method to determine the significance of the differences in the two sets of acceleration responses. If this first test is rejected—that is, if the null hypothesis $u_o = 0$ is not accepted—there is no need to further test the section. If, however, the null hypothesis is accepted, a method of testing the differences between the sets of acceleration responses that will compensate for the shortcomings of the test of the mean should be conducted. In this study, the next test was a chi-square test of the sample distribution.

To perform a chi-square test of the distribution, a theoretical distribution must be available that can be used as a basis for comparing the sample that is being tested. It was assumed that the responses to the loaded profile could be treated as if they were a theoretical distribution. Since the loaded-pavement profile is that which is actually traversed, this is reasonable. In this way the test of the distribution would then become a test to see whether or not the acceleration responses to the unloaded-pavement profile could have come from the theoretical distribution defined by the responses to the loaded-pavement profile.

To perform the chi-square test, the number of occurrences within certain ranges of magnitude—referred to as cells—must be established. The first step in finding these values is to construct the cells. The highest and lowest values of acceleration obtained over each subsection for either the unloaded- or the loaded-pavement

Table 3. Statistical comparison of acceleration responses to unloaded- and loaded-pavement profiles for reverse run, $\alpha = 0.05$, and speeds of 10.2, 20.3, and 30.5 m/s.

Length of Subsection (m)	Test	Speed = 10.2 m/s			Speed = 20.3 m/s			Speed = 30.5 m/s		
		Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station
0-25.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
25.6-51.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
51.2-76.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
76.9-102.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
102.5-128.1	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
128.1-153.7	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
153.7-179.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
179.3-205.0	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
205.0-230.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
230.6-256.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
256.2-281.8	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
281.8-307.4	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
307.4-333.1	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
333.1-358.7	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
358.7-384.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
384.3-409.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
409.9-435.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
435.5-461.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
461.2-486.8	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
486.8-512.4	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
512.4-538.0	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
538.0-563.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
563.6-589.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
589.3-614.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
614.9-640.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
0-640.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	R	R	A	A	A	A	A	A	A

Note: 1 m = 3.3 ft.
A = accepted; R = rejected.

profile were recorded for each of the three positions on the aircraft frame at which acceleration responses were available. These values would become the upper and lower limits of the cells used in the test. The cells were obtained by dividing the region between the upper and lower limits into six equal subregions. We then determined how many of the accelerations generated out of a total of 43 for a subsection 25.6 m (84 ft) long fell within the boundaries of each cell. This was done by using first the responses to the loaded-pavement profile and then those to the unloaded-pavement profile.

For the chi-square test to be valid, the lowest number of responses generated by the loaded profile that could occur in any cell was five. If there were not at least five in a cell, the deficient cell was combined with whichever of the two adjacent cells (either above or below) contained the smaller number of occurrences.

The chi-square test was performed by using frequencies of occurrence obtained in this manner and the following statistic:

$$\chi^2 = \sum_{i=1}^{n} [(f_i - F_i)^2 / F_i] \qquad (2)$$

where f_i is the number of observed (unloaded) accelerations in cell i, F_i is the number of theoretical (loaded) accelerations in cell i, and n is the number of cells. The null hypothesis that the unloaded responses came from a population defined by the loaded responses was accepted if the value of the computed statistic was less than χ^2_α. The value of χ^2_α can be obtained from standard statistical references (7, 8) for the specified level of significance α.

One drawback in using a chi-square test on a pavement section in this way is that accelerations generated by more than one area along the section may fall in the same cell. This would tend to decrease the validity of the test, since the position along the test section at which the acceleration was generated is lost. By using short [25.6-m (84-ft) long] subsections of the test section, this error was minimized because the number of areas

Table 4. Statistical comparison of acceleration responses to unloaded- and loaded-pavement profiles for reverse run, $\alpha = 0.05$, and speeds of 40.7, 50.8, and 61 m/s.

Length of Subsection (m)	Test	Speed = 40.7 m/s			Speed = 50.8 m/s			Speed = 61 m/s		
		Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station	Tail Section	Center of Gravity	Pilot Station
0-25.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
25.6-51.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
51.2-76.9	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
76.9-102.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
102.5-128.1	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
128.1-153.7	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
153.7-179.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
179.3-205.0	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
205.0-230.6	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
230.6-256.2	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
256.2-281.8	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
281.8-307.4	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
307.4-333.1	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
333.1-358.7	Mean	A	A	A	A	A	A	R	A	R
	Distribution	A	A	A	A	A	A	A	A	A
358.7-384.3	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
384.3-409.9	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
409.9-435.5	Mean	A	A	A	A	A	A	R	A	A
	Distribution	A	A	A	A	A	A	A	A	A
435.5-461.2	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
461.2-486.8	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
486.8-512.4	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
512.4-538.0	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
538.0-563.6	Mean	A	A	A	A	A	A	R	R	A
	Distribution	A	A	A	A	A	A	A	A	A
563.6-589.3	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A
589.3-614.9	Mean	A	A	A	A	A	A	A	R	A
	Distribution	A	A	A	A	A	A	A	A	A
614.9-640.5	Mean	A	A	A	A	A	A	R	R	A
	Distribution	A	A	A	A	A	A	A	A	A
0-640.5	Mean	A	A	A	A	A	A	A	A	A
	Distribution	A	A	A	A	A	A	A	A	A

Note: 1 m = 3.3 ft.
A = accepted; R = rejected.

within the section that generated accelerations that fell in the same cell was reduced. Furthermore, if the test of the mean had been accepted for the subsection being tested, the probability of this error would be reduced even more, since it has been determined that there is probably little difference between the responses on a point-for-point basis.

PRESENTATION AND DISCUSSION OF RESULTS

Some results of the statistical analysis are given in Tables 1-4, which indicate whether the null hypothesis for the test of the mean or the distribution was accepted or rejected for each of the subsections tested.

Tables 1 and 2 give results for an aircraft traversing the pavement profile in a forward direction, and Tables 3 and 4 give results for a reverse direction of travel. The results are tabulated for constant taxi speeds of 10.2, 20.3, 30.5, 40.7, 50.8, and 61 m/s (33.3, 66.7, 100.0, 133.3, 166.7, and 200.0 ft/s). Since aircraft response to one section of a pavement is dependent on the preceding pavement sections (3), the effect of carrying out the analysis on both forward and reverse runs is to double the data on which the analysis was performed.

During the forward runs, no rejections of the test of the mean occurred until the higher speeds were reached—namely, 50.8 and 61 m/s (166.7 and 200.0 ft/s). No rejections occurred until a speed of 61 m/s was reached during reversed runs.

At these speeds, it was observed that the number of rejections at the center of gravity was usually smaller than at the pilot station or the tail section. Since it was observed that the extremities of the aircraft experienced greater accelerations than the center of gravity (Figures 1-3), this was to be expected. Therefore, it would seem to follow that the tail section and pilot station would experience even greater accelerations than the center of gravity as a result of pavement roughness at high speeds. The differences in accelerations caused by deflection of the loaded pavement would also increase as the speed increased, causing more rejections at the pilot station and tail section than at the center of gravity. Yet, in the extreme case—61 m/s (200.0 ft/s)—only about one-third of the tests performed resulted in rejections.

The chi-square test of the distribution produced no rejections for any subsection tested under any of the specified conditions for speed or direction. It was observed, however, that rejections of the entire test section occurred at the tail section and the center of gravity when the aircraft traversed the profile in the reverse direction at a speed of 10.2 m/s (33.3 ft/s). It is felt that these rejections occurred because these two comparisons consisted of 1051 acceleration responses each. Short sections of pavement profile were not used, and as a result the acceleration values in each cell were generated from many different positions along the test section. As we stated earlier, this can cause a loss in reliability in the test of the distribution. This loss in reliability is felt to be the cause of these rejections. Since the test of the distribution was accepted under the same conditions when subsections 25.6 m (84 ft) long were used, it seems reasonable to conclude that these rejections are not significant.

Analyses were also performed by using a level of significance $\alpha = 0.02$, and some changes in the results were observed. No changes occurred in the results of the test of the distribution for all conditions tested; about 40 percent fewer rejections of the test of the mean occurred for $\alpha = 0.02$ than for $\alpha = 0.05$. The total number of rejections for $\alpha = 0.02$ was 27, and that for $\alpha = 0.05$ was 46.

SUMMARY AND CONCLUSIONS

The acceleration responses simulated in this study by using the U.S. Air Force computer code TAXI are considered to be typical of the response of an F-4C aircraft to profiles of unloaded and loaded pavements.

A statistical analysis was prepared that consisted of two parts: (a) a test of the mean of a sample made up of the differences between the responses to the two profiles on a point-for-point basis and (b) a test of the distribution of the responses to the two profiles. This analysis was used to determine whether or not significant differences existed in the response of an aircraft to unloaded- and loaded-pavement profiles. It was found that in a comparison of this type it is necessary to divide the test section into a number of smaller subsections to achieve reliability.

Based on the results of the statistical analysis, the following statements can be made:

1. Throughout the range of speeds analyzed, the distributions of acceleration responses to unloaded- and loaded-pavement profiles are virtually the same.
2. Some significant differences in the responses to unloaded- and loaded-pavement profiles do occur at speeds in excess of 40.7 m/s (133.3 ft/s). The observed differences in responses were not a major part of the total number of comparisons made at these speeds; less than 33 percent of the total number of comparisons made were rejected at the highest speed of 61 m/s (200 ft/s).
3. No major differences in the results were seen when the level of significance of the statistical analysis was varied from 0.05 to 0.02.

It was concluded that there were no significant differences in the simulated dynamic response of an F-4C aircraft to unloaded- and loaded-pavement profiles during taxiing operations at speeds up to 61 m/s at the test section under study.

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