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Effect of Fare and Travel Time on the Demand for Domestic Air Transportation

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LIST OF SYMBOLS

1.	AFT_i	adjusted flight time for any flight i
2.	Ai	local arrival time of flight i
3.	$b_0, b_1, b_2 \ldots b_k$	coefficients in regression function
4.	D_i	local departure time of flight i
5.	DT_{ji}	displacement time
6.	$\overline{DT}$	average displacement time
7.	ε_F	point elasticity of demand with respect to fare
8.	F	fare
9.	i	index used for flights i = 1,2,...m
10.	INC	personal income
11.	j	index used for time points j = 1, (start of traveling day), 2,....n (end of traveling day)
12.	LOS	level of service
13.	m	number of daily flights
14.	n	number of time points (equally separated) in the traveling day
15.	$\hat{Q}_D$	predicted demand in a given market
16.	R^2	coefficient of multiple determination
17.	SE	socio-economic activity
18.	SRVC	total labor and proprietors' income by place of work, by industry, service.
19.	SSE	sum of squared errors
20.	t_j, T(J)	time of day (time point j)
21.	$\bar{t}$, TBAR	average total trip time

22.	t_o , TNJ	nonstop jet time
23.	T	length of traveling day
24.	TT_j	total trip time
25.	$X_1, X_2 \ldots X_k$	explanatory variables in functional form of regression analysis
26.	Y	response variable in functional form of regression analysis
27.	$\hat{Y}$	the expected or predicted value for the particular value of explanatory variables
28.	$\overline{Y}$	observed average value
29.	Z	number of time zones crossed (positive if west to east, negative if east to west)
30.	π_j, PI(J)	proportion of daily passengers preferring to depart at time point j
31.	γ_i	connection adjustment = 0.0 for direct flights 0.5 for online flights 1.0 for interline flights

Introduction

One of the axioms in the air transportation industry is that advances in technology have led to a greater amount of passenger travel by air. Improvements in airframe and engine design have increased range, speed and payload and have decreased seat-mile costs (in constant dollars), while simultaneously introducing more comfortable and safer travel. The resultant lower ticket prices have made pleasure travel steadily more attractive in the competition for the consumer's disposable income, while the availability of comfortable, high speed travel has increased the air mode's share of business travel.

However, it has not been a trivial matter to determine the magnitude of travel that can be attributed to advanced aircraft technology. NASA, as the U.S. government agency responsible for research and technology in commercial aviation, has a natural interest in the applications of the technological improvements it has helped to create. Thus NASA has sponsored research analyzing the economic and operational impact of technological innovations; some of these studies have attempted to quantify the demand for air transportation that improvements in technology have brought about.

This report presents the final results of an econometric demand model developed by the MIT Flight Transportation Laboratory under NASA sponsorship over the course of the last three years.*

*NASA Contract NAS 1-15268, Langley Research Center, Technical Monitor Mr. Dal V. Maddalon; NASA Grant No. NSG-2129, Ames Research Center, Technical Monitors Mr. Mark H. Waters and Mr. Louis T. Williams.

During the first two years the conceptual framework for the model was developed and the initial calibration was undertaken.* Preliminary results were encouraging and validation and refinement of the model continued under Langley sponsorship during 1978. The model that was finally developed is useful for analyzing long haul domestic passenger markets in the United States. Specifically, it was used to show the sensitivities of passenger demand to changes in fares and speed reflecting technology through more efficient designs of aircraft; and to analyze, through the year 2000, the impact of selected changes in fares, speeds, and frequencies on passenger demand.

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* "An Analysis of Long and Medium Haul Air Passenger Demand", Steve E. Eriksen, NASA CR 152156, Volume 1, 1978.

1. Statistical Background: The Development of a Regression Model to Forecast Air Traffic

Regression analysis is a set of mathematical techniques used for the determination, based upon historical data, of the functional form of the causal relationship between a response variable, Y, and a set of explanatory variables, X_1, X_2,....,X_k. For example, one may hypothesize that a linear relationship exists between the price (X_1) and the amount of advertising (X_2) of a particular product and the sales volume of that product (Y).

$$Y = b_0 + b_1X_1 + b_2X_2 \tag{1}$$

The function of regression in this case would be to utilize historical data on sales, price, and advertising to estimate the numerical values of the constants b_0, b_1, and b_2.

The relationship between a response variable and a set of explanatory variables is generally not fully explained by the regression function. In the above example, sales volume would not be totally determined by the levels of price and advertising. Therefore, it is more appropriate to rewrite equation (1) as follows:

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 \tag{2}$$

where $\hat{Y}$ is the expected or predicted sales volume for the particular values of price (X_1) and advertising (X_2).

Suppose that in the above example the following estimates of the constants were obtained through regression analysis:

$b_0 = 21.3$ $\qquad$ $b_1 = -0.67$ $\qquad$ $b_2 = 1.21$

Furthermore, suppose that in one time period the price was 8.0 and the advertising expenditure was 3.3. The regression function predicts a sales volume for that particular time period of

$$\begin{aligned}\hat{Y} = b_0 + b_1X_1 + b_2X_2 &= 21.3 - 0.67X_1 + 1.21X_2 \\ &= 21.3 - 0.67\ (8.0) + 1.21\ (3.3) \\ &= 19.9 \text{ units}\end{aligned}$$

For this time period the sales volume was 19.3 units. Since the <u>observed</u> sales volume (Y) was 19.3 and the predicted sales ($\hat{Y}$) volume was 19.9, the prediction error or <u>residual</u> for this single observation is $Y - \hat{Y} = 19.3 - 19.9 = -0.6$ units.

For any given model and historical data base the "best" set of estimates of the coefficients or <u>model parameters</u> is a set that provides the best overall "fit" or the closest association between the resulting predicted values, $\hat{Y}$, and the observed values, Y of the response variable. Several "goodness of fit" statistics can be computed to gauge the accuracy of the model. These statistics will be discussed in subsequent sections of this report.

An accurate regression equation can be used for two distinct purposes: <u>forecasting</u> and <u>analysis</u>. For example, suppose that the marketing department for the product in the above example decided to price the product at 9.0 and spend 4.0 on advertising in the next time period. The sales forecast according to the model would be:

$$\hat{Y} = 21.3 - 0.67X_1 + 1.21X_2 = 21.3 - 0.67(9.0) + 1.21\ (4.0)$$
$$= 20.1 \text{ units}$$

When using a regression model, analysis refers to the impact upon the response variable of a change in a controllable input. For example, if management desired to increase the unit price of their product by 0.5, the model predicts a resulting decrease in sales of 0.67 x 0.5 = 0.335 units per time period.

1.1 Functional Form of the Model

The functional form of the air passenger demand model to be analyzed using regression analysis is:

$$\hat{Q}_D = a\ LOS^{b_1} F^{b_2} SE^{b_3} \qquad (3)$$

where

$\hat{Q}_D$ = predicted demand in a given market

LOS = level of service

F = fare

SE = socio-economic activity

The exponential form was chosen over a linear form, such as that of equation (2), because the exponential form is easily transformed into a linear equation and the parameter estimates are the expected elasticities.

1.2 Linearity

Taking the logarithms of both sides of equation (3) results in the following relationship:

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 \tag{4}$$

where

$\hat{Y} = \ln \hat{Q}_D$

$b_0 = \ln a$

$X_1 = \ln LOS$

$X_2 = \ln F$

and $X_3 = \ln SE$

Therefore, by performing a simple mathematical transformation the functional form becomes linear. Linearity is very desirable in regression analysis since the required estimation techniques are considerably less complex than the procedures for estimating the parameters of a nonlinear model. Furthermore, more suitable computer programs exist for linear regression analysis than for regression analysis of nonlinear models.

Since the basic model (3) is nonlinear in specification but can be easily transformed into a linear form (4) it is considered as an intrinsically linear model. A model which cannot be readily transformed into a linear form is intrinsically nonlinear. An example of an intrinsically nonlinear model is:

$$Y = b_0 + b_1(X_1X_2 + b_2X_3^2) \tag{5}$$

1.3 Elasticities

The elasticity of demand with respect to any given causal variable is a measure of the degree of responsiveness of demand to changes in that particular variable. Elasticity, a concept developed by economists, is very useful in the study of air transportation demand for the assessment of changes in fare, demographic, and technological variables upon air travel.

Conceptually the elasticity of demand with respect to fare, or the "fare elasticity", is the ratio of the percentage change in demand and the simultaneous percentage change in fare.

$$\text{Elasticity} = \frac{\frac{\Delta Q_D}{Q_D}}{\frac{\Delta F}{F}} = \frac{\Delta Q_D}{\Delta F} \cdot \frac{F}{Q_D} \tag{6}$$

The "point" elasticity of demand with respect to fare, ε_F, is the limit of the above expression as ΔF approaches zero.

$$\varepsilon_F = \lim_{\Delta F \to 0} \frac{\Delta Q_D}{\Delta F} \cdot \frac{F}{Q_D} = \frac{\partial Q_D}{\partial F} \cdot \frac{F}{Q_D} \tag{7}$$

If the absolute value of the elasticity of demand for air transportation or any other product is greater than one, the product is said to be price elastic. This implies that a cut in price will cause a sufficient response in demand so as to increase total revenue. If the price elasticity (in absolute terms) is less than one, the product is said to be inelastic. In this case a price reduction evokes such a small increase in demand that total revenue decreases.

Partially differentiating equation (3) with respect to fare (F) results in

$$\frac{\partial Q_D}{\partial F} = b_2 aLOS^{b_1} F^{b_2-1} SE^{b_3} \tag{8}$$

Substituting into equation (7)

$$\varepsilon_F = \frac{\partial Q_D}{\partial F} \cdot \frac{F}{Q_D} = b_2 aLOS^{b_1} F^{b_2-1} SE^{b_3} \cdot \frac{F}{aLOS^{b_1} F^{b_2} SE^{b_3}} = b_2 \tag{9}$$

Therefore, the parameters of the model, b_1, b_2, and b_3, are the elasticities with respect to service, fare, and socio-economic activity. The product form specification, equation (3), provides a capability for predicting these elasticities which will be very useful for subsequent policy analysis.

2. Definition of Variables

2.1 Demand (Q_D)

The variable selected for the measure of air passenger traffic activity in a region pair market is the number of passengers that originate in one region and fly to the other region for purposes other than to make a connection to a third region. This variable is the true origin to destination passenger traffic, using the passenger intent criterion. These data are tabulated in Table 8 of the Civil Aeronautics Board's Origin to Destination Survey.

2.2 Level of Service (LOS)

The level of service index is a dimensionless number scaled from zero to one which represents the ratio of the nonstop jet flight time to the average total passenger trip time.* The total trip time is the sum of the actual travel time (including stops and connections) and the amount of time the passenger is displaced from when he wishes to fly due to schedule inconveniences.

If "perfect" service were offered in a given region pair (by definition a nonstop jet departing at every instant of the day), there would be no such displacement. The total trip time would be merely the nonstop jet flight time and the ratio (LOS) would be unity. If poor service were

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*Hypothesizing aircraft whose flight time is faster than jets currently available (i.e., SSTs) produces a LOS index greater than 1.

offered (few flights, multistops, connections, slower aircraft, etc.), not only would travel time be substantially greater than non-stop jet flight time, but passengers would be forced to fly at inconvenient times. This inconvenience would be accounted for by the inclusion of significant "displacement" times, and the resulting level of service ratio would be substantially less than one.

2.2.1 Behavioral Assumptions

The basic assumption in the development of the level of service index is that a passenger, based on the purpose of his trip, will determine an optimal or preferred time of departure from the origin airport. Given that he is aware of his preferred departure time and is presented a schedule of available flights, he will then select that flight which minimizes the sum of the "displacement time" and the "adjusted flight time". The displacement time is the absolute value of the difference between the scheduled departure time and the preferred time of departure.* The adjusted flight time is defined as the scheduled flight time (departure time from original airport to arrival time at destination airport, including intermediate stops) for direct flights, the scheduled flight time plus one-half hour for online connections, and the scheduled flight time plus one hour for interline connections. (The adjusted flight time is also corrected for time zone changes).

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*If the passenger wishes to leave at 2 p.m. (or 4 p.m.) and the scheduled departure time is 3 p.m., then the displacement time is one hour.

The motivation for inclusion of the additional time assessment for connecting flights is that the consumer disutility of a connecting flight is greater than merely the increase in flight time. For an online connection, the passenger faces the chance of a broken connection due to a late arrival of the first leg or cancellation of the second. Also, the passenger is burdened with the inconvenience of having to change aircraft. For an interline connection, the passenger faces not only the possibility of a broken connection, but also a greater chance of having his baggage miss the connection. In addition, he not only has to change aircraft but may have to walk to a different terminal.

Table 1 defines four hierarchical types of service, based on the discussion above of travellers' preferences. An online connection without intermediate stops (i.e., one which requires only one stop) is assumed equivalent in consumer value to a two-stop direct flight. Hence, the presence of a connection within the same airline is equivalent to adding an additional intermediate stop. By the same argument, an interline connection has the equivalent disutility of two additional stops. Assessing an additional one-half hour of flight time for each equivalent stop yields the above-mentioned adjustments of one-half hour and one hour for online and interline connections, respectively.

Another assumption is that the loss function for arrival time displacement is linear and symmetric. Thus the disutility incurred by being displaced by a total of p hours is p times the disutility of being displaced by one hour. Furthermore, symmetry of the loss function assumes that the cost of departing late by p hours is equivalent to the cost of leaving p hours early.

Table 1. Four Levels of Equivalent Air Service

Level	Direct	Connecting
1	Nonstop	---
2	One-stop	---
3	Two-stop	Online Nonstop/Nonstop
4	Three-stop	Interline Nonstop/Nonstop

The definition of total trip time, as used in this report, is different from the term commonly noted in transportation analysis. Generally, total trip time includes access and egress times to and from the line haul terminals plus waiting (or displacement) and line haul travel time. These terms are important when an airport serves a large geographical region. Since this analysis measures the effect of airline scheduling, independent of access and egress time, these times are not considered.

A further assumption is that of infinite capacity. A passenger who elects (by the governing behavioral assumptions) to board a particular flight may do so without fear of its being full; therefore, load factor is not considered. This assumption is justified since usually, if a particular flight is consistently being overbooked, the airline(s) serving that market will increase capacity on that flight, or add more flights near that time of day. In most instances, overflow problems are corrected within a reasonable length of time.

2.2.2 Development of the Index

Given the behavioral assumptions described in the preceding section and a published flight schedule for one direction of a particular region pair, the total trip time, defined as the sum of the displacement time plus the adjusted flight time, for a passenger desiring to depart at any time of day can be determined. Then, given a distribution of passenger departure demand over the entire day, the average total trip time, weighted by this distribution, can be generated.*

In order to compute the average total trip time, clock time has been divided into a finite number of discrete time points which are separated by equal intervals throughout the traveling day. The time length of these intervals (and hence the number of time points) may be arbitrarily set (perhaps 15,30, or 60 minutes). The analysis is performed by considering passengers desiring to depart at only these time points rather than continuously. Therefore, the smaller these intervals (or the greater the number of time points) are, the less restricting is this approximation. However, as the number of time points increases, so does the computational complexity for LOS. Throughout this analysis the traveling day will be divided into thirty minute intervals starting at 4:00 a.m. and ending at midnight for a total of 41 time points.

The following notation is used:

n = number of time points (equally separated) in the traveling day

j = index used for time points $j = 1$ (start of traveling day), 2,....., n (end of traveling day)

t_j = time of day (time point j)

π_j = proportion of daily passengers preferring to depart at time point j

m = number of daily flights

i = index used for flights $i = i, 2, \ldots, m$

*"Average total trip time" is an estimate of the average travel time for any passenger in a city pair, given the diversity of schedules and preferred departure times of passengers.

D_i = local departure time of flight i

A_i = local arrival time of flight i

Z = number of time zones crossed (positive if west to east, negative if east to west)

γ_i = connection adjustment for flight i = 0.0 for direct flights; 0.5 for online flights; 1.0 for interline connections

Using this notation, the adjusted flight time for any flight i, AFT_i, is the difference between the arrival and departure times, $A_i - D_i$, minus the time zone change, Z, plus the connection adjustment γ_i.

$$AFT_i = A_i - D_i - Z + \gamma_i \tag{10}$$

The displacement time, DT_{ji}, for any passenger preferring to depart at time point j (t_j) and whose best option is flight i, is defined as the absolute value of the difference between the departure time of flight i, D_i, and the preferred time of day, t_j.

$$DT_{ji} = |D_i - t_j| \tag{11}$$

As described in the preceding section, a passenger preferring to depart at t_j will select that flight which will minimize the sum of displacement time plus adjusted flight time. This minimized sum is defined to be total trip time, TT_j.

$$\Pi_j = \min (DT_{ji} + AFT_i) = \min (|D_i - t_j| + A_i - D_i - Z + \gamma_i) \qquad (12)$$

The average total trip time, $\bar{t}$, is the weighted (by the π_j factors)* average of the total trip times of the passengers who prefer to depart at each of the n time points over the traveling day.

$$\bar{t} = \sum_{j=1}^{n} \pi_j \Pi_j = \sum_{j=1}^{n} \pi_j \min_i (|D_i - t_j| + A_i - D_i - Z + \gamma_i) \qquad (13)$$

The level of service index, LOS, is defined as the ratio of the nonstop jet time, t_o, to the average total trip time, $\bar{t}$.

$$LOS = \frac{t_o}{\bar{t}} = t_o \left[\sum_{j=1}^{n} \pi_j \min (|D_i - t_j| + A_i - D_i - Z + \gamma_i) \right]^{-1} \qquad (14)$$

2.2.3 Example

Boston to Washington is an example of a highly competitive medium haul (406 miles) market, involving two large urban centers which generate a substantial quantity of air passenger demand. Therefore, a high level of service is expected. Figure 1 shows that thirty-six flights are offered daily from Boston to Washington; all of these are direct flights, and most are nonstops.

The departure and arrival times are listed in the decimal equivalent of military time. For example, the departure time of the twenty-sixth flight, shown as 16.25, is 4:15 p.m., and the arrival time of the thirty-sixth

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* π_j is the time of time distribution of passenger demand in any given market pair. See Eriksen (1), p. 135-145.

Figure 1 Flight Schedule for Boston to Washington

FLIGHT SCHEDULE BOS WAS

FLIGHT	DEPART	ARRIVE	ADJUSTED FLIGHT TIME	STATUS	CARRIER(S)
1	7.00	8.17	1.17	DIRECT	AA
2	7.00	8.28	1.28	DIRECT	AA
3	7.17	8.35	1.18	DIRECT	DL
4	7.42	8.73	1.32	DIRECT	EA
5	8.00	9.15	1.15	DIRECT	DL
6	8.00	9.20	1.20	DIRECT	DL
7	8.25	9.58	1.33	DIRECT	EA
8	8.75	10.03	1.28	DIRECT	AA
9	9.17	10.80	1.63	DIRECT	AA
10	9.50	10.70	1.20	DIRECT	DL
11	9.92	11.03	1.12	DIRECT	AL
12	10.00	12.67	2.67	DIRECT	AL
13	10.67	11.95	1.28	DIRECT	AA
14	11.58	12.78	1.20	DIRECT	AL
15	12.17	13.45	1.28	DIRECT	EA
16	12.27	13.47	1.20	DIRECT	DL
17	12.30	13.45	1.15	DIRECT	DL
18	12.33	13.62	1.28	DIRECT	AA
19	13.33	16.08	2.75	DIRECT	AL
20	14.17	15.45	1.28	DIRECT	AA
21	14.58	15.78	1.20	DIRECT	DL
22	15.00	16.18	1.18	DIRECT	AL
23	15.62	16.92	1.30	DIRECT	EA
24	16.00	17.28	1.28	DIRECT	AA
25	16.17	17.30	1.13	DIRECT	DL
26	16.25	18.63	2.38	DIRECT	NA
27	16.92	18.27	1.35	DIRECT	EA
28	17.58	18.78	1.20	DIRECT	DL
29	18.17	19.45	1.28	DIRECT	AA
30	18.50	19.70	1.20	DIRECT	AL
31	19.33	21.98	2.65	DIRECT	AL
32	20.00	21.18	1.18	DIRECT	AL
33	20.25	21.48	1.23	DIRECT	AA
34	20.30	21.50	1.20	DIRECT	DL
35	21.00	22.67	1.67	DIRECT	AA
36	22.75	25.50	2.75	DIRECT	NQ

flight, shown as 25.50, is 1:30 a.m. of the following day. The adjusted flight time is merely the scheduled block time; since none of the flights are connections, no adjustments are involved in this particular schedule. (The status of a flight refers to its connection characteristics. Since each of the flights in this schedule is direct, the status is shown as such. In Figure 3, BOS-SFO, online connections are labeled "ONLINE" and interline connections are labeled "INTLIN".)

Figure 2 shows the results of the computation of the level of service related variables. The time of day demand distribution (π_j) is listed in the PI(J) column. For each of the forty-one time points, the computer program assigns the passengers preferring to depart at that time to one of the available flights in a manner dictated by the behavioral assumptions discussed in Section 2.2.1. For example, those passengers wishing to depart Boston for Washington at 7:00 p.m. (time point 31) are assigned to flight 30 which (referring back to Figure 1) departs at 6:30. Flight 30 is the flight that minimizes the sum of the displacement time (one-half hour) and the flight time. This sum is 1.70 hours as indicated in the TRIP TIME column of Figure 3.

The CONTRIBUTION TO TOTAL TRIP TIME is the product of the PI(J) and TRIP TIME figures, and the sum of this column is the average trip time weighted by the time of day demand distribution. This average, TBAR, is equivalent to the $\bar{t}$ defined in equation (13), and for this example is 1.532 hours.

The level of service index is the ratio of the nonstop jet time, t_o*

*t_o is not obtained from the city pair Official Airline Guide, but is computed from a general formula taking into account distance, longitude of airports (for winds), and time to reach cruise altitude. See Eriksen (1), pp.132-134. It is normally about the same as the non-stop trip time.

Figure 2. Level of Service Computations for Boston to Washington

COMPUTATION OF AVERAGE TOTAL TRIP TIME

J	T(J)	PI(J)	FLIGHT BOARDED	DISPLACEMENT TIME	ADJUSTED FLIGHT TIME	TRIP TIME	CONTRIBUTION TO TOTAL TRIP TIME
1	4.00	0.001	1	3.00	1.17	4.17	0.005
2	4.50	0.002	1	2.50	1.17	3.67	0.008
3	5.00	0.005	1	2.00	1.17	3.17	0.016
4	5.50	0.008	1	1.50	1.17	2.67	0.021
5	6.00	0.016	1	1.00	1.17	2.17	0.034
6	6.50	0.023	1	0.50	1.17	1.67	0.039
7	7.00	0.033	1	0.00	1.17	1.17	0.039
8	7.50	0.044	4	0.08	1.32	1.40	0.061
9	8.00	0.038	5	0.00	1.15	1.15	0.044
10	8.50	0.033	8	0.25	1.28	1.53	0.050
11	9.00	0.030	8	0.25	1.28	1.53	0.046
12	9.50	0.028	10	0.00	1.20	1.20	0.034
13	10.00	0.026	11	0.08	1.12	1.20	0.032
14	10.50	0.025	13	0.17	1.28	1.45	0.036
15	11.00	0.023	13	0.33	1.28	1.62	0.036
16	11.50	0.020	14	0.08	1.20	1.28	0.026
17	12.00	0.022	15	0.17	1.28	1.45	0.032
18	12.50	0.023	17	0.20	1.15	1.35	0.031
19	13.00	0.025	17	0.70	1.15	1.85	0.045
20	13.50	0.026	20	0.67	1.28	1.95	0.050

Figure 2 (continued)

J	T(J)	PI(J)	FLIGHT BOARDED	DISPLACE-MENT TIME	ADJUSTED FLIGHT TIME	TRIP TIME	CONTRIBUTION TO TOTAL TRIP TIME
21	14.00	0.026	20	0.17	1.28	1.45	0.038
22	14.50	0.027	21	0.08	1.20	1.28	0.035
23	15.00	0.035	22	0.00	1.18	1.18	0.041
24	15.50	0.043	23	0.12	1.30	1.42	0.060
25	16.00	0.045	24	0.00	1.28	1.28	0.057
26	16.50	0.047	25	0.33	1.13	1.47	0.068
27	17.00	0.045	27	0.08	1.35	1.43	0.064
28	17.50	0.043	28	0.08	1.20	1.28	0.055
29	18.00	0.036	29	0.17	1.28	1.45	0.052
30	18.50	0.029	30	0.00	1.20	1.20	0.034
31	19.00	0.025	30	0.50	1.20	1.70	0.042
32	19.50	0.021	32	0.50	1.18	1.68	0.035
33	20.00	0.023	32	0.00	1.18	1.18	0.027
34	20.50	0.023	34	0.20	1.20	1.40	0.033
35	21.00	0.022	35	0.00	1.67	1.67	0.036
36	21.50	0.020	35	0.50	1.67	2.17	0.044
37	22.00	0.015	35	1.00	1.67	2.67	0.041
38	22.50	0.010	36	0.25	2.75	3.00	0.030
39	23.00	0.008	36	0.25	2.75	3.00	0.023
40	23.50	0.005	36	0.75	2.75	3.50	0.019
41	24.00	0.003	36	1.25	2.75	4.00	0.011

TBAR = 1.532

LOS = TNJ/TBAR = 1.20/1.53 = 0.783

(listed as "TNJ" in the output), 1.20 hours, to the average total trip time, 1.532 hours, which equals 0.783. This number implies that if "perfect" service, a nonstop jet departing every instant of the day, were offered (LOS = 1.00), the average total trip time between Boston and Washington would decrease by 21.7%.

2.3 Fare (F)

The standard coach fare (Y) has been selected as the price variable and has been obtained from the Official Airline Guide. It can be argued that this fare is improper since it neglects the impact upon demand of discount fare plans. However, the results of a prototype study [2] indicate that further sophistication of the fare variable produces virtually identical results.*

In order to avoid having the fare variable measuring a time trend and to show fare levels as perceived by the consumer, the fare was deflated. Since air transportation is a service, the selected price deflator was the "implicit price deflator for personal consumption expenditures on services." The deflated fare variable is expressed in terms of constant dollars with 1972 as the base year.

* These results [2] may have been due to a limited impact of discount fares in the past. However, the proliferation of reduced fares (Super Savers, etc.) during the past few years may bias the results of predicted demand downwards when the model is applied to these years. See Section 7, Conclusions, for discussion of this point.

2.4 Socio-Economic Activity (SE)

It is postulated that the total potential demand for air passenger services in a region pair market is a function of the level of socio-economic activity in the two regions. Two aspects of socio-economic activity are considered in this research. The first is the ability of a region to generate air traffic and is represented by the total personal income of the region. The second is the region's ability to attract air traffic.

Generally, regions such as New York, Las Vegas, and Miami with predominantly service-oriented economies tend to draw more traffic relative to aggregate industry than the largely manufacturing-based economies such as Detroit's or Pittsburgh's. Thus, to represent the ability to attract traffic, a service industry measure, "total labor and proprietor's income by place of work by industry, service" was selected. These data are published annually by the Bureau of Economic Analysis (BEA) of the Department of Commerce.

The socio-economic attraction from region i to region j is defined as the product of the personal income of region i and the service income of region j. The average of the socio-economic attraction in both directions of a given region pair is computed, and the square root of this number is taken to convert the units to dollars. The socio-economic variable, SE, for a region pair ij is then defined as:

$$SE_{ij} = \sqrt{1/2(INC_i \cdot SRVC_j + SRVC_i \cdot INC_j)} \qquad (15)$$

where

INC = personal income, and

SRVC = total labor and proprietors' income by place of work, by industry, service

The socio-economic variable is also deflated by the implicit price deflator for personal consumption expenditures on services to be consistent with the fare variable adjustment.

3. Base Model Specification: Parameter Estimation and Base Forecasts

3.1 Ordinary Least Squares Estimates - Base Model

Many procedures exist for estimating the parameters of a regression equation. The most common is ordinary least squares. If the observed values of the response variable are denoted by Y and the predicted values are denoted by $\hat{Y}$ where

$$\hat{Y} = a + b_1X_1 + b_2X_2 + \ldots. \tag{16}$$

the differences between the Y and $\hat{Y}$ values are called the "residuals." The ordinary least squares estimates of a, b_1, b_2, ... are those values that minimize the sum of the squared residuals.

Using ordinary least squares and observed data from each of fifteen large long haul markets over a six year period (1969-1974), the parameters of equation (4) are as follows:

b_0 = 4.34 (1.37)*

b_1 = 2.91 (0.35) (service elasticity)

b_2 = -1.24 (0.14) (fare elasticity)

b_3 = 1.34 (0.09) (socio-economic elasticity)

Standard error of estimate = 0.26

Therefore, the regression equation is

---

* The numbers in the parentheses are the standard errors of the coefficients. For a basic discussion of most of the statistical techniques used in this report, see Taneja, N.K., Airline Traffic Forecasting (Lexington, Mass: Lexington Books, D.C.Heath, 1978).

$$\hat{Q}_D = \exp(4.34 + 2.91 \ln LOS - 1.24 \ln F + 1.34 \ln SE) \quad (17)$$

3.2 Goodness of Fit

After the parameters of any model have been estimated, the resulting equation must be validated. One step in the validation process is to measure the association between the observed values of the response variable, Y, and the values predicted by the regression model, Y. Recall that the objective of least squares estimation is to minimize the sum of squared errors, SSE.

$$\text{(min) } SSE = (Y - \hat{Y})^2 \quad (18)$$

The variance of Y is defined as the sum of squared differences between the observed values of Y and their average value, $\overline{Y}$.

$$\text{Var }(Y) = (Y - \overline{Y})^2 \quad (19)$$

The error sum of squares,SSE, is the part of the variance of Y that is not explained by the regression model.

A common measure of goodness of fit is the coefficient of multiple determination, R^2.

$$R^2 = 1 - \frac{SSE}{\text{Var }(Y)} \quad (20)$$

It follows from the above discussion that R^2 is the portion of the variance of Y that is explained by the regression model. The range of R^2 is between zero and one. A value of R^2 near zero implies that the model explains a very small portion of the variance of the response variable and that the fit is poor. A value of R^2 near one indicates that a large portion of the variance is explained by the model and that the fit is good.

The model of equation (17) has an R^2 value of 0.945. The three explanatory variables account for 94.5% of the variance of the log of demand. This statistic is sufficiently close to one to warrant a preliminary conclusion that the model provides a reasonably good fit.

3.3 Base Forecasts

Base forecasts for four selected long haul markets were generated using equation (17) to observe how well the predicted traffic volumes compare with the actual traffic.

Forecasts are provided for the years 1950, 1955, 1960, and 1967-1978. These time series include the years 1969-1974 which were used for parameter estimation (see Section 3.1), the two years prior (1967 and 1968) and the four years (1975-1978) after the estimation period. Included were three distant time periods (1950, 1955, and 1960) when aircraft technology was radically different from that of the years 1969-1974.

Base forecasts have also been generated for the future years 1980, 1985, 1900, 1995, and 2000. Input variables include computed levels of service based upon schedule scenarios, constant fare (in real terms), and socio-economic forecasts provided by the Bureau of Economic Analysis of the Department of Commerce.

A detailed description of the forecasting process is provided in the example of the Boston-San Francisco market in Section 5. The results for the other markets are given in Section 7. The computer program (written in Fortran IV G) used for forecasting is found in the Appendix. The program used to compute level of service, written in PL1, is also included in the the Appendix.

4. Analysis Model Specification: Demand Sensitivity

The sole objective of the parameter estimation procedure for equation (17) was a model that predicted well. There was no explicit concern for the precision of the estimates of the individual parameters per se; if the model in total provided a good fit it was acceptable as a forecasting instrument.

Demand sensitivity, however, is predicated upon accurate estimates of individual parameters, which in this particular model are elasticities (see Section 1.3). For example, to assess the impact upon demand of a five percent decrease in fare, with all other variables held constant, an accurate fare elasticity would be required.

Two requirements for accurate individual parameter estimates are violated when the ordinary least squares procedure is used to estimate the parameters of equation (4). These requirements were of no concern in the forecasting process, but render equation (17) inappropriate for demand sensitivity analysis. The two problems are simultaneity and collinearity.

4.1 Simultaneity

Simultaneity or "two-way causality" is said to exist when a random change in the response variable, Y, causes a change in one or more of the explanatory variables, X_i.

It seems reasonable to believe that while interregional demand is a function of socio-economic activity in the two regions (as stated in equation (4)), a change in demand will not precipitate a change in regional income. Furthermore, while demand is sensitive to fare, fares have not changed as a result of demand, but have been based on distance. For example, the distance between New York and Chicago is 721 miles and the distance between Bangor and

Akron is 694 miles. The former market experiences a demand of roughly 1.5 million passengers per year, the latter attracts fewer than 100 passengers per year, while the fares in these two markets are virtually identical. Thus no problems with simultaneity can be seen with demand and fare and socio-economic variables.

A simultaneity problem does exist between demand and level of service. While it is hypothesized that demand is stimulated by improved service, it can also be reasonably argued that the airlines will react to an increase in traffic in a market by improving the quality of service. The consequence of this simultaneity is a bias, a type of statistical inaccuracy, in the estimation of b_1 when ordinary least squares is employed.

This problem was rectified by using a statistical technique known as instrumental variable regression. A discussion of the instrumental variable approach is contained in Pindyck and Rubenfeld (4), and the details of how this procedure was applied to this particular model is found in Eriksen (1). Discussion of the results of this procedure is deferred to Section 4.3.

4.2 Collinearity

The second statistical malady inherent in this model is collinearity, the condition where two of the explanatory variables are correlated. Since fare is a function only of interregional distance there is no concern about it being related to level of service or socio-economic activity. However, level of service and socio-economic activity are correlated. Since the airlines have not competed by varying fares, the larger socio-economic markets, like New York-Chicago, receive higher service levels than the smaller markets, like Bangor-Akron.

The consequence of collinearity is that between markets both service and socio-economic activity change simultaneously in the same direction. It is therefore difficult to determine the degree to which each of the two variables is affecting demand. Therefore, the precision of the estimates of b_1 and b_3 is in question. If b_1 is predicted too high then b_3 will surely be too low and vice versa. It is important to re-emphasize that this problem is of no concern for a forecasting model; all that is required is a good fit. However, for policy analysis accurate coefficients are the primary objective, and collinearity is a definite pitfall.

The procedure employed to combat the collinearity between level of service and socio-economic activity is principal components regression. This technique is described in Tukey and Mosteller (3) and in Eriksen (1), and its direct application to this problem is detailed in Eriksen (1).

4.3 Analysis Model

The result of the estimation process using the procedures described above is:

b_0 = -0.0859 (0.003)*

b_1 = 0.429 (0.002) (service elasticity)

b_2 = -1.26 (0.033) (fare elasticity)

b_3 = 1.73 (0.0186) (socio-economic elasticity)

standard error of estimate = 0.386

R^2 = 0.877

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* The numbers in the parentheses are the standard errors of the coefficients.

Note that the value of R^2 has dropped from 0.945, using ordinary least squares, to 0.877. This is to be expected since the ordinary least squares estimates assure that the sum of squares of residuals is minimized. Therefore, since the ordinary least squares model maximizes R^2, any other set of estimates will result in a lower value of R^2.

As can be seen, the use of principal component analysis produced higher precision for the elasticities, i.e., the standard errors of the coefficients were substantially lower than the values produced by the ordinary least squares procedure. Statistically speaking, lower standard deviation should provide higher confidence in the value of these parameters. The elasticities produced by the use of principal component analysis were also more in line with estimates available in industry. However, while these coefficients are more useful for analyzing sensitivity of changes in the explanatory variables such as fare and service, they are likely to produce less precise forecasts.

It can be concluded that the ordinary least squares model, in spite of simultaneity and collinearity, is the preferred forecasting model. The highest R^2 implies the best fit. However, it can further be concluded that the parameter estimates shown immediately above are more accurate reflections of the true elasticities, since certain problems related to their precisions have been rectified. Consequently throughout this study base forecasts will be generated using the model given in Section 3.1, and sensitivity analyses will be conducted using the elasticities listed above in this section.

5. The Boston-San Francisco Market: A Case Study

The forecasting and analysis techniques developed in the preceding sections will be applied to a selected market, Boston-San Francisco, to (a) validate the accuracy of the forecasting model over the past and to generate forecasts, and (b) to illustrate how the analysis model can be used for sensitivity analyses for future time periods.

5.1 Base Forecasts

Forecasts are made using equation (17). Equation (21) is equation (17) multiplied by a factor of ten since the demand figures used in the estimation procedure were from the 10% CAB sample and are therefore one order of magnitude small.

$$\hat{Q}_D = 10.0 \exp (4.34 + 2.91 \ln LOS - 1.24 \ln F + 1.34 \ln SE) \qquad (21)$$

For the past, the predicted demand is obtained by substituting the observed values of LOS, F, and SE into the model and solving for Q_D. For future years the values of the explanatory variables must first be predicted and then substituted into equation (17) to obtain the base forecasts.

5.1.1 The Year 1975

An example of the generation of a forecast for 1975 follows. Each of the explanatory variables will be obtained and substituted into equation (21). The resultant demand can be compared to the actual value.

Figure 3 is a reproduction of the flight schedule from Boston to San Francisco from the Official Airline Guide of September 1, 1975. Figure 4

Fig. 3

FLIGHT SCHEDULE BOS SFO 1975

FLIGHT	DEPART	ARRIVE	ADJUSTED FLIGHT TIME	STATUS	CARRIER(S)
1	7.00	11.02	7.52	ONLINE	AA/AA
2	7.00	11.97	7.97	DIRECT	AA
3	7.17	13.62	9.95	ONLINE	AA/AA
4	7.25	12.07	7.82	DIRECT	TW
5	7.58	11.80	7.72	ONLINE	AA/AA
6	7.67	12.50	8.33	ONLINE	UA/UA
7	8.50	15.42	10.42	ONLINE	AA/AA
8	9.50	12.42	5.92	DIRECT	UA
9	10.33	15.30	8.47	ONLINE	AA/AA
10	11.17	15.28	7.62	ONLINE	UA/UA
11	12.00	14.85	5.85	DIRECT	TW
12	12.50	19.72	10.22	DIRECT	TW
13	13.42	18.87	8.95	ONLINE	NW/NW
14	13.50	19.27	8.77	DIRECT	AA
15	13.50	19.63	9.63	ONLINE	AA/AA
16	13.58	18.00	7.92	ONLINE	UA/UA
17	14.92	19.43	8.02	ONLINE	AA/AA
18	15.25	19.35	7.10	DIRECT	AA
19	15.50	19.97	7.97	ONLINE	TW/TW
20	16.00	20.52	8.52	INTLIN	TW/UA
21	16.08	20.67	8.08	ONLINE	UA/UA
22	16.25	20.23	6.98	DIRECT	TW
23	16.50	21.22	8.22	ONLINE	UA/UA
24	16.50	21.48	7.98	DIRECT	UA
25	17.50	22.42	8.42	ONLINE	AA/AA
26	17.50	22.48	8.98	INTLIN	TW/AA
27	17.50	22.53	8.53	ONLINE	AA/AA
28	17.50	24.17	9.67	DIRECT	TW
29	18.83	24.30	8.97	ONLINE	UA/UA
30	18.83	24.90	9.07	DIRECT	AA
31	21.00	25.28	7.78	ONLINE	TW/TW
32	21.00	27.53	10.03	ONLINE	AA/AA

Fig. 4

COMPUTATION OF LEVEL OF SERVICE INDEX BOS SFO 1975

J	T(J)	PI(J)	FLIGHT BOARDED	DISPLACE-MENT TIME	ADJUSTED FLIGHT TIME	TRIP TIME	CONTRIBUTION TO TOTAL TRIP TIME
1	4.00	0.005	1	3.00	7.52	10.52	0.049
2	4.50	0.008	1	2.50	7.52	10.02	0.079
3	5.00	0.014	1	2.00	7.52	9.52	0.133
4	5.50	0.020	1	1.50	7.52	9.02	0.178
5	6.00	0.026	1	1.00	7.52	8.52	0.222
6	6.50	0.030	1	0.50	7.52	8.02	0.237
7	7.00	0.034	1	0.00	7.52	7.52	0.257
8	7.50	0.037	5	0.08	7.72	7.80	0.292
9	8.00	0.034	8	1.50	5.92	7.42	0.252
10	8.50	0.031	8	1.00	5.92	6.92	0.211
11	9.00	0.028	8	0.50	5.92	6.42	0.180
12	9.50	0.026	8	0.00	5.92	5.92	0.151
13	10.00	0.026	8	0.50	5.92	6.42	0.165
14	10.50	0.026	8	1.00	5.92	6.92	0.179
15	11.00	0.025	11	1.00	5.85	6.85	0.173
16	11.50	0.024	11	0.50	5.85	6.35	0.155
17	12.00	0.026	11	0.00	5.85	5.85	0.151
18	12.50	0.027	11	0.50	5.85	6.35	0.172
19	13.00	0.031	11	1.00	5.85	6.85	0.215
20	13.50	0.035	11	1.50	5.85	7.35	0.261
21	14.00	0.037	11	2.00	5.85	7.85	0.289
22	14.50	0.038	18	0.75	7.10	7.85	0.300
23	15.00	0.042	18	0.25	7.10	7.35	0.312
24	15.50	0.046	18	0.25	7.10	7.35	0.337
25	16.00	0.043	22	0.25	6.98	7.23	0.310
26	16.50	0.039	22	0.25	6.98	7.23	0.284
27	17.00	0.036	22	0.75	6.98	7.73	0.277
28	17.50	0.032	22	1.25	6.98	8.23	0.265
29	18.00	0.031	22	1.75	6.98	8.73	0.268
30	18.50	0.028	22	2.25	6.98	9.23	0.256
31	19.00	0.025	29	0.17	8.97	9.13	0.228
32	19.50	0.022	31	1.50	7.78	9.28	0.205
33	20.00	0.020	31	1.00	7.78	8.78	0.176
34	20.50	0.016	31	0.50	7.78	8.28	0.136
35	21.00	0.014	31	0.00	7.78	7.78	0.109
36	21.50	0.011	31	0.50	7.78	8.28	0.093
37	22.00	0.007	31	1.00	7.78	8.78	0.060
38	22.50	0.000	31	1.50	7.78	9.28	0.000
39	23.00	0.000	31	2.00	7.78	9.78	0.000
40	23.50	0.000	31	2.50	7.78	10.28	0.000
41	24.00	0.000	31	3.00	7.78	10.78	0.000

TBAR = 7.617

LOS = TNJ/TBAR = 6.16/7.62 = 0.809

shows the output from the level of service computational program. (For a detailed explanation of the output see Section 2.2.3.) The bottom line of Figure 4 shows the level of service variable, LOS, at 0.809. A similar analysis of the San Francisco to Boston schedule provides a value of 0.750 for LOS. The market value of LOS is defined as the geometric mean of the two directional values.*

$$LOS = \sqrt{0.809 \times 0.750} = 0.779 \qquad (22)$$

The one-way coach fare (tax included) in the Boston-San Francisco market on September 1, 1975 was \$190. The implicit price deflator for personal consumption expenditures on services (1972 base) for 1975 is 123.5. The deflated fare is therefore

$$F = \$190 \times \frac{100}{123.5} = \$153.85 \qquad (23)$$

The 1975 levels of personal income for the Boston and San Francisco Bureau of Economic Analysis (BEA) areas were 39,300 and 39,000, respectively. The service industry income levels for the two regions were 5,800 and 5,480 respectively. The deflated value for SE is therefore

$$SE = \sqrt{\frac{1}{2}(39{,}300 \times 5{,}480 + 39{,}000 \times 5{,}800)} \times \frac{100}{123.5} = 12{,}000 \qquad (24)$$

---

* The directional LOS are multiplied to guard against asymmetrical markets; if service in one direction were substantially smaller, the geometric mean would be more representative than an arithmetical mean.

Substituting the computed values of LOS, F, and SE into equation (21), the forecast for the year 1975 is

$$\hat{Q}_D = 10.0 \exp(4.34 + 2.91 \ln 0.779 - 1.24 \ln 153.85 + 1.34 \ln 12{,}000)$$
$$= 211{,}350 \qquad (25)$$

5.1.2 Other Years

The years over which the model was tested include 1950, 1955, 1960, three time periods during which the aircraft were radically different from those of the years over which the model was calibrated. Also included are 1967-1968, the two years before, and 1975-1978, the four years after the calibration years, 1969-1974. For each of these years, forecasts were computed using the procedure of section 5.1.1. The results are listed in Table 2 along with the observed traffic figures.

A comparison of the predicted and the actual traffic indicates that reasonably good agreement (less than 12% error, and in most years less than 5% error) exists for the years 1967-1978. Substantial divergence exists for the years 1950-1955-1960, for which a number of reasons can be advanced.

The 1950-1960 fare and schedule data were extracted from copies of the OAG on file at the CAB library. The old editions of the OAG had been tabulated by carrier (rather than by market), and the schedules were similar in format to the old railroad timetables. This format rendered the identification of online connections very difficult and the identification of interline connections nearly impossible. Thus LOS calculations may be inaccurate for these years.

The historical traffic flow data were extracted from the CAB Origin to

Table 2. Prediction Accuracy, Boston-San Francisco, General Long Haul Model

Year	Predicted	Actual
1950	4,650	8,390
1955	13,050	31,630
1960	28,930	48,600
1967	136,650	154,460
1968	157,640	163,710
1969	174,760	179,320
1970	171,980	171,650
1971	177,390	173,330
1972	197,770	191,430
1973	215,520	205,840
1974	191,090	199,360
1975	211,350	200,130
1976	203,280	220,310
1977	239,820	215,660
1978	258,980	265,510

Destination (O-D) Surveys. Three rather severe problems related to the tabulation of time series of O-D statistics were discovered during the collection and processing of these data:

1. The survey period had been changed at least twice from 1950 to 1965. Currently a systematic 10% sample of flight coupons is drawn. Previous procedures included a census during the last two weeks of September and a census during the entire month of September.
2. The early samples consisted of tickets sold rather than flight coupons lifted. Therefore a person who purchased four tickets and used only one could conceivably be counted four times.
3. Domestic O-D traffic was redefined in 1968 to include travel from within the continental states to Hawaii and Alaska (and vice versa). Prior to this time a traveler flying from Chicago to Honolulu via San Francisco would have been recorded as an O-D passenger from Chicago to San Francisco. Therefore, the pre-1968 traffic counts for gateway cities are inconsistent (greater) with the counts for the year 1968 and later.

The socio-economic time series for the historical years were also tabulated in an inconvenient format. The income figures are tabulated for years 1950, 1959 and 1962 by county rather than by BEA area. Therefore, summing over all counties within each BEA area to obtain aggregate figures for each of the above years was necessary. A log-linear interpolation was then used to estimate these figures for the years 1955 and 1960. For 1976-1978 the 1970-1975 growth rate in the SE variables was linearly extrapolated, which may also cause some prediction errors.

Due to the problems with the 1950-1960 traffic, schedule and socio-economic numbers, it is impossible to determine whether these divergences are due to inherent model specification errors or to inconsistent data.

In another attempt to establish the validity of the formulation of the model, i.e., the use of the explanatory variables as being the appropriate ones to use in the demand model, the Boston-San Francisco city pair market was calibrated using data for the years 1967-1975. Since the general model was calibrated using 15 large long haul city-pairs and data for six years, extremely accurate predictions in any specific market pair would not normally be expected. However, if the general formulation was adequate, a specific city-pair model, calibrated on data pertaining to that city-pair only, would be expected to be more accurate. Conversely, since fewer data are available for calibration, although the predictive ability was expected to improve, the accuracy of the individual coefficients was likely to decrease. For Boston-San Francisco the calibration yielded the following formula:

$$\hat{Q}_D = 10 \exp(-1.27 + 1.52 \ln LOS - 0.18 \ln F + 1.32 \ln SE)$$
$$R^2 = 0.951$$

with standard errors of the coefficients: 5.53; 0.72; 0.45; 0.37

The results for 1950-1978 using the city-pair model are shown in Table 2a and Figure 5. As expected, the predicted demand more closely matches the actual demand over the calibration years;* however, the standard deviations for the individual coefficients have increased due either to the existence of multicollinearity or the reduction in noise resulting from the disaggregation of the long haul markets. Yet, despite the increase in standard deviation

* The inaccuracy of 1978 may be explained in part by the proliferation of discount fares during that year which were not taken into account, and the simple extrapolation of the SE variables.

Table 2a. Prediction Accuracy, Boston-San Francisco, City-Pair Model

TRAFFIC

Year	Predicted	Actual
1950	15,640	8,390
1955	27,340	31,630
1960	49,760	48,600
1967	150,840	154,560
1968	166,320	163,710
1969	175,240	179,320
1970	176,510	171,650
1971	179,700	173,330
1972	190,640	191,430
1973	203,220	205,840
1974	196,160	199,360
1975	200,330	200,130
1976	196,910	220,310
1977	213,470	215,660
1978	224,410	265,510

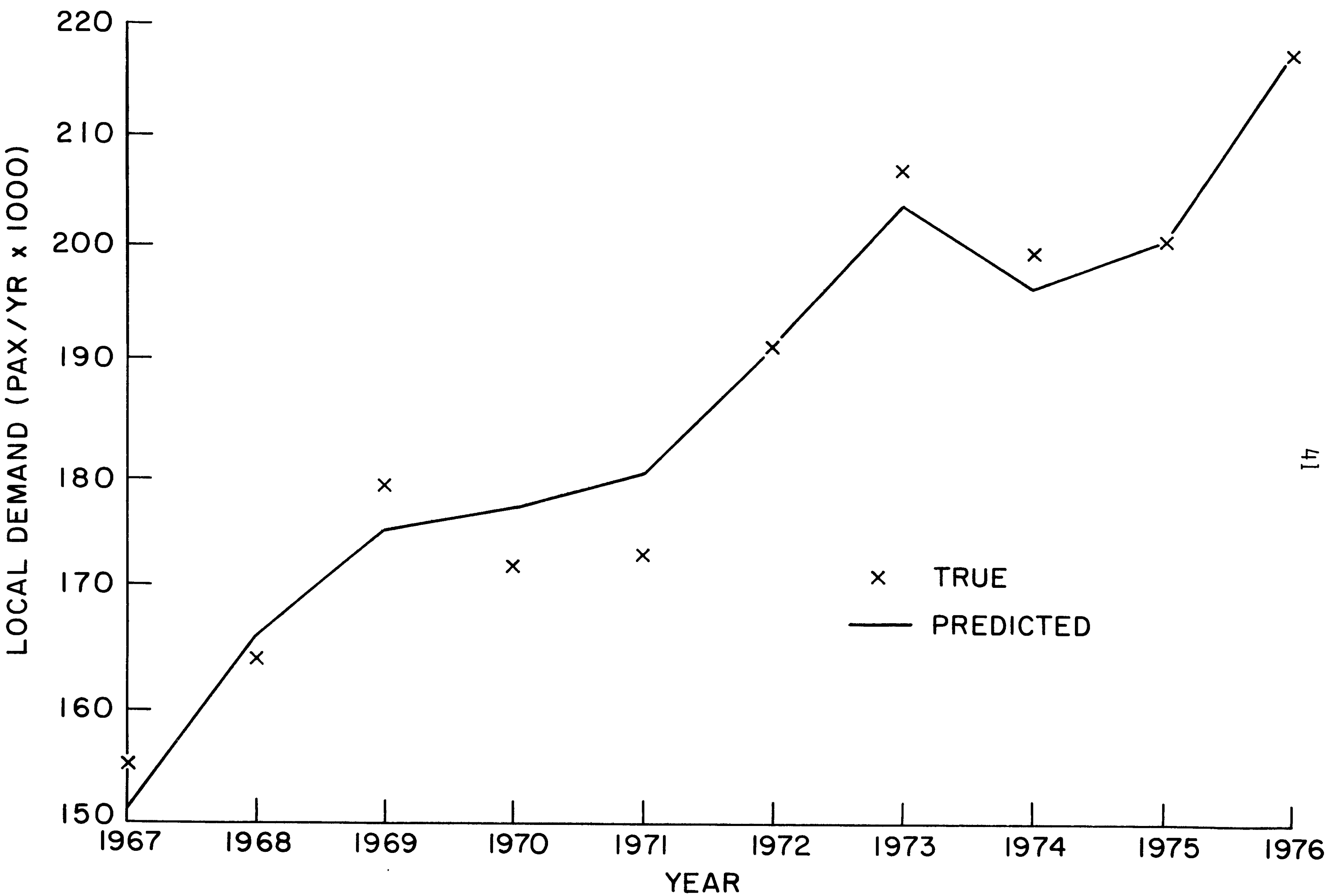


FIGURE 5 TIME SERIES PLOTS OF PREDICTED AND TRUE LOCAL DEMAND BOSTON TO SAN FRANCISCO 1967 TO 1976

of the individual coefficients, this equation produces forecasts with higher precision. The imprecision of the constant term does not invalidate the overall goodness of fit for the equation since the constant term is normally outside the range of calibration.

5.1.3 Forecast Years

Forecasts using equation (21) were made for the years 1980, 1985, 1990, 1995, and 2000. Several assumptions about the explanatory variables were made. Sensitivity analyses pertinent to these assumptions were performed and are described in subsequent sections.

The predicted values for level of service were the result of schedule scenarios based upon growth rate and technology assumptions. The assumed growth rates in seating capacity from 1975 to 1985, 1986 to 1990, and 1991 to 2000 were 8%, 7%, and 10% respectively. The differences between predicted capacity and the actual capacity of the 1975 scheduled flights were extrapolated by various types of aircraft. The capacity of each type of aircraft is given in Table 3.

Other assumptions include:

1. Stretched 747, 767, and regular 757 will be initiated into service by the end of 1985.
2. L1011 will be replaced by 767 stretch in the years 1985 and beyond.
3. DC10 will be replaced by 767 stretch in the years 1990 and beyond.
4. 707 will be phased out by 757 in the years 1985 and beyond.
5. Each type of aircraft is replaced in the schedule of the next forecast year by the aircraft of one grade larger. For example, 747 in 1975 is replaced by 747 stretch in 1980, etc.

Based upon the flight schedules of future years derived with the above assumptions, values of LOS were computed.

Table 3 Assumed Capacities

Aircraft	Capacity
747 stretch	500
747	350
L1011	235
DC10	235
767 stretch	235
707	145
DC8	145
757	145
727	110

Fares, in constant dollars, were assumed to remain the same throughout the forecast period. This assumption is based on a scenario in which standard coach fares increase at the same rate as the implicit price deflator for consumer expenditures on services.

The projections of the socio-economic variables have been provided by the Bureau of Economic Analysis. The most current series are found in Volume 2 of the OBERS Projections (5).

The resultant forecasts are shown in Table 4. They reflect the expected traffic growth in the Boston-San Francisco market for the next twenty years assuming no radical changes in fare and technology.

5.2 Sensitivity Analyses

In this section the elasticities of demand with respect to the explanatory variables, which were estimated in Section 4.3 during the development of the analysis model, will be used to examine the response of demand to changes in fares, aircraft speed, frequency of service, and socio-economic activity.

5.2.1 Predicted Demand for Various Fare Levels

Figure 6 is a time series plot of predicted local demand in the Boston-San Francisco market for five different fare levels. The middle plot (fare = F) assumes no constant dollar change in fare, and therefore is the base forecast series from Table 4. (For the years 1950-1975 the fare = F plot is the actual demand.)

Table 4. Base Forecasts, Boston-San Francisco, General Market Model

Year	Predicted Traffic
1980	320,000
1985	472,000
1990	648,000
1995	1,044,000
2000	1,681,000

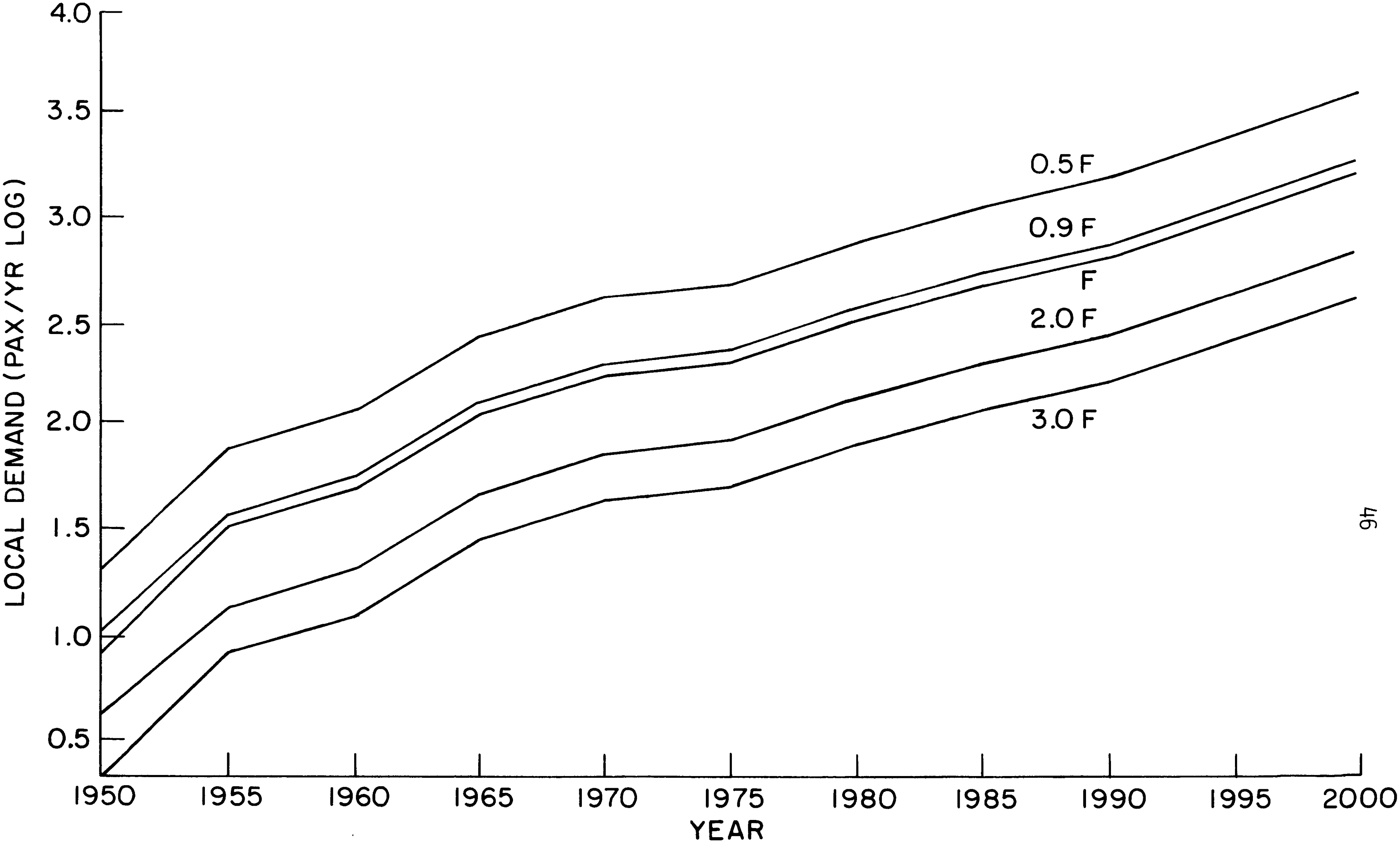


FIGURE 6 TIME SERIES PLOT OF HISTORICAL AND PREDICTED LOCAL DEMAND FOR VARIOUS FARE LEVELS: BOSTON TO SAN-FRANCISCO 1950 TO 2000 ; SUBSONIC TRAVEL TIME; $\epsilon_{FARE} = -1.26$

5.2.2 Predicted Demand for Propeller, Subsonic Jet and Supersonic Aircraft

Figure 7 is a time series plot of predicted local demand in the Boston-San Francisco market for three different types of aircraft having different travel times. The middle plot is the predicted demand for subsonic jet travel time and therefore represents the base forecasts for future years. The remaining two curves are the result of level of service values coming about as a result of propeller and supersonic travel times. (Propeller technology is that of the 1950's.)

5.2.3 Demand vs. Fare

The four curves superimposed in Figure 8 represent the predicted demand vs. fare relationships for selected travel times in the Boston-San Francisco market in the year 1980. The fare values are expressed in 1972 dollars, with a base fare of $156.10, and a base travel time of six hours. Starting with the base forecast from Table 3 the curves in Figure 8 were constructed using the fare and level of service elasticities (-1.26 and 0.429) developed in section 4.3.

5.2.4 Demand vs. Travel Time

The five curves in Figure 9 represent the estimated demand vs. travel time relationships for selected fare levels in the Boston to San Francisco market in the year 1980. Again, a base forecast was projected using the forecasting model of equation (21), and the fare and level of service elasticities determined in Section 4.3 were used to generate the curves.

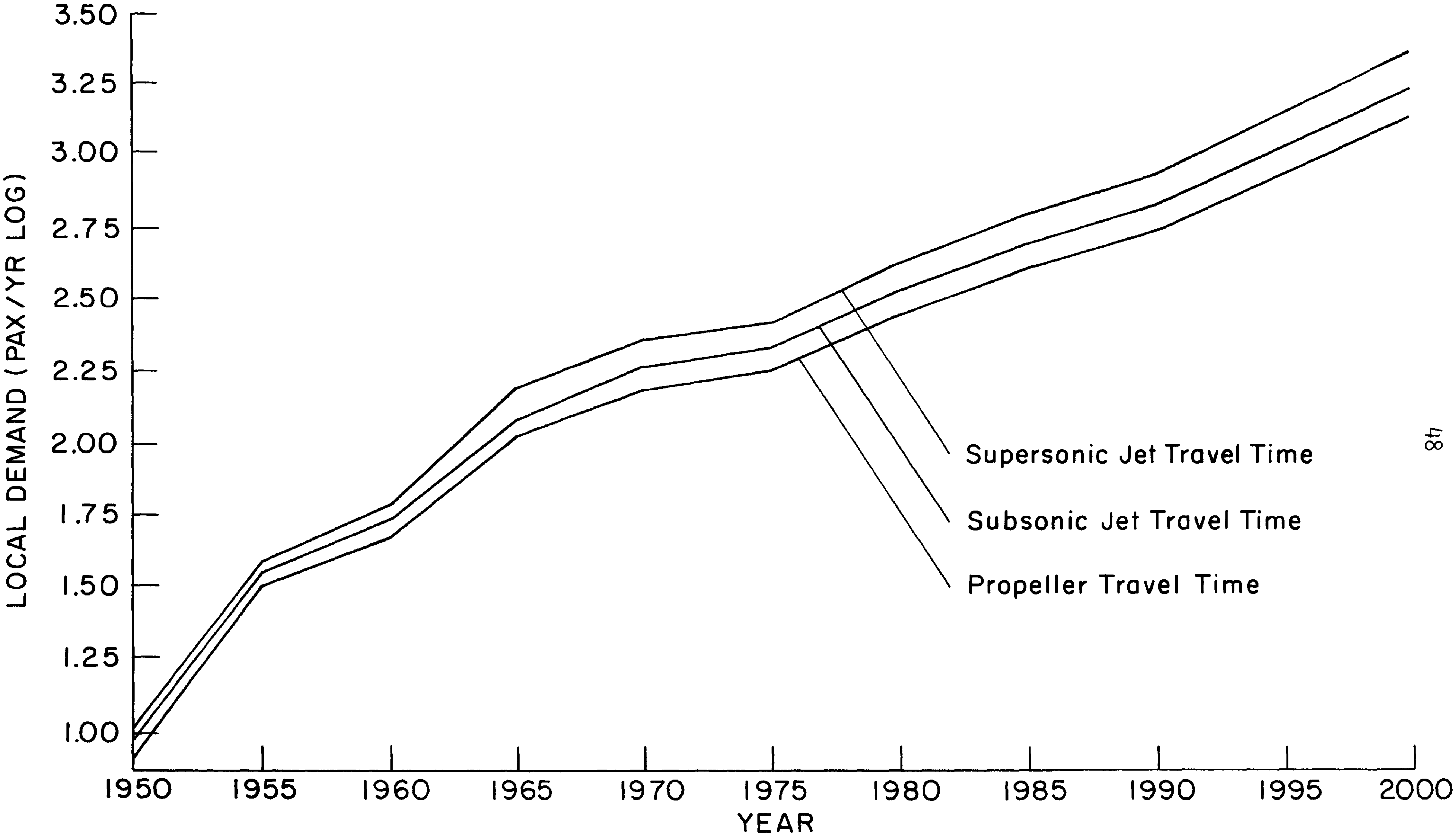


FIGURE 7 TIME SERIES PLOT OF HISTORICAL AND PREDICTED LOCAL DEMAND FOR VARIOUS TRAVEL TIMES BOSTON TO SAN FRANCISCO 1950 TO 2000 FARE LEVEL = 1F $\epsilon_{LOS} = 0.429$

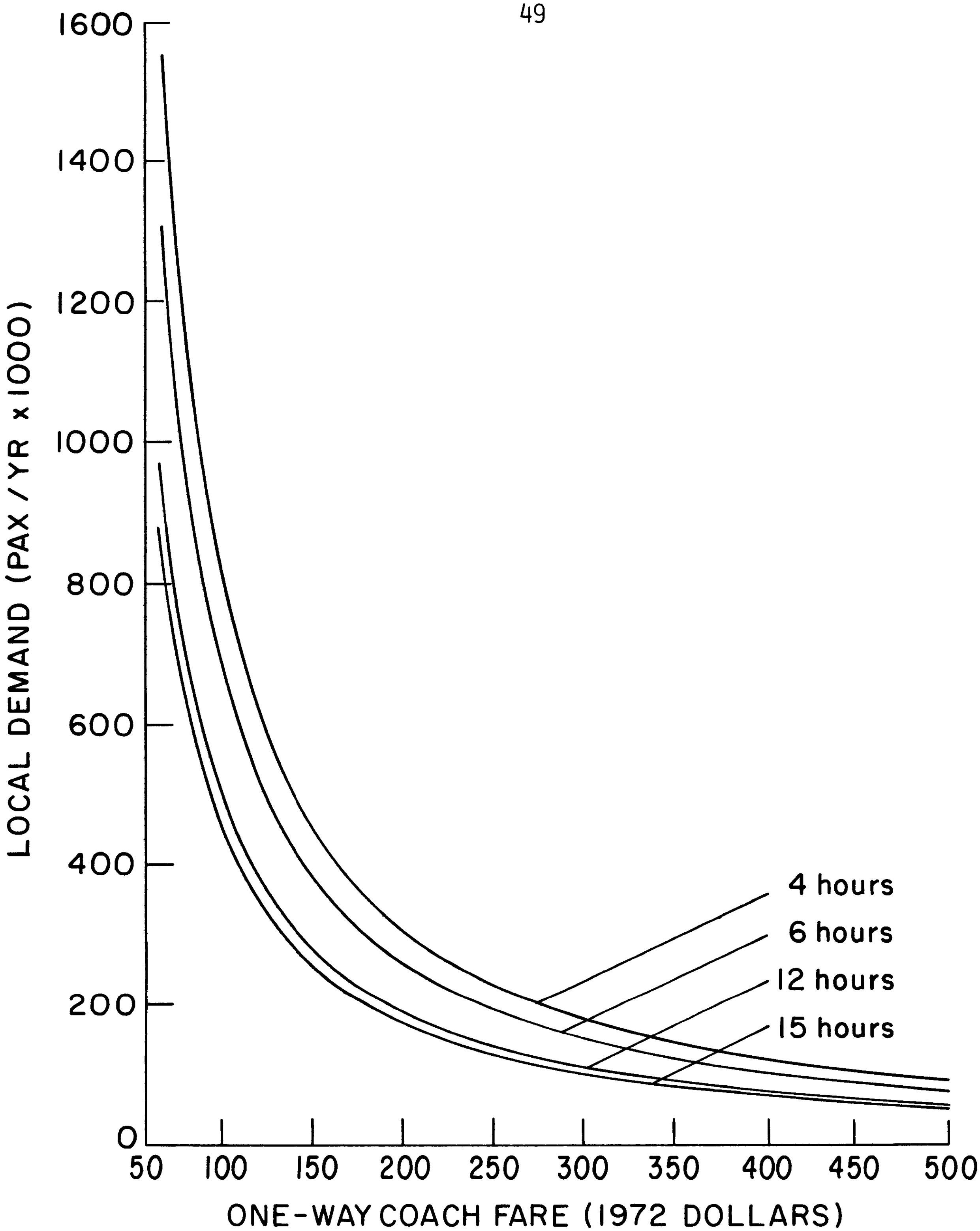


FIGURE 8 DEMAND VS. FARE FOR SELECTED TRAVEL TIMES BOSTON TO SAN FRANCISCO 1980

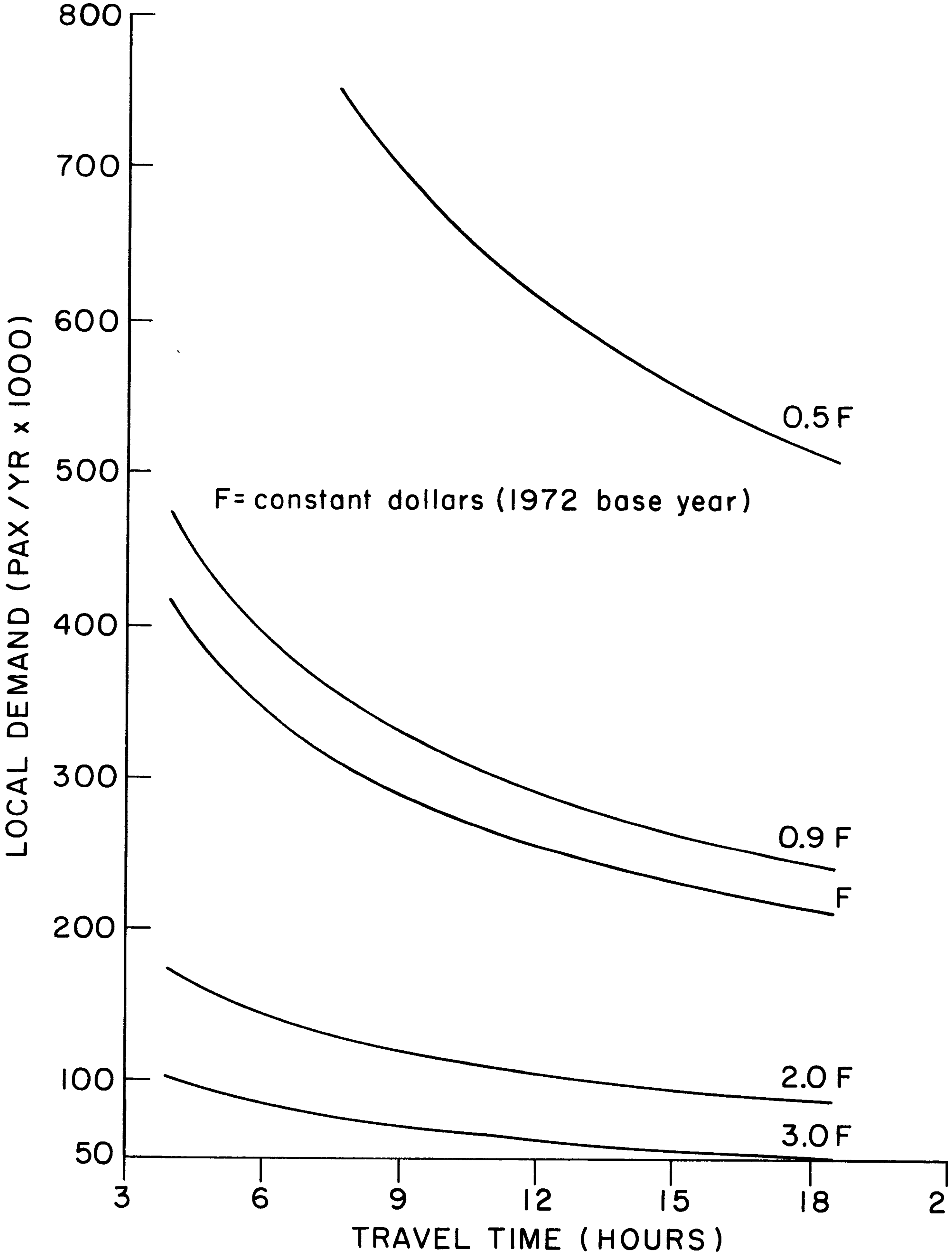


FIGURE 9 DEMAND VS. TRAVEL TIME FOR SELECTED FARES BOSTON TO SAN FRANCISCO 1980

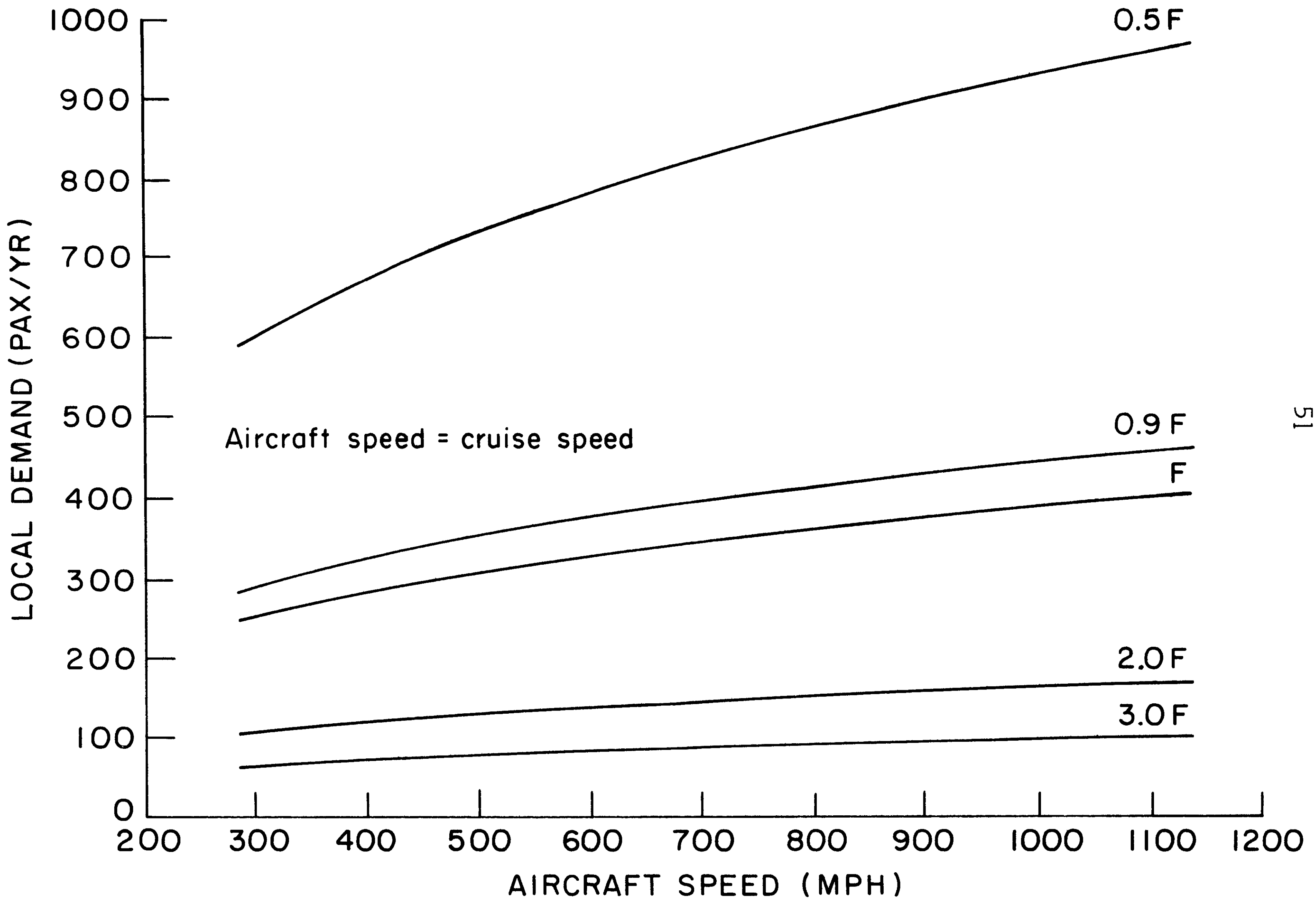


FIGURE 10 DEMAND VS. AIRCRAFT SPEED FOR SELECTED FARES
BOSTON TO SAN FRANCISCO 1980

5.2.5 Demand vs. Aircraft Speed

Figure 10 contains a set of curves which relate passenger demand level in the Boston-San Francisco market to aircraft speed at various fare levels for the year 1980. The base case is fare = F and aircraft speed = 560 mph. The demand vs. speed relationship for any given fare was determined by recomputing the level of service variable, LOS, using the same departure times as the base schedule but adjusting the block speeds according to alternations in aircraft cruise speed. These computations were performed for decreases in aircraft speed of 30% and 15% and increases of 15% and 30%. Using these four points and the base case, each curve was fitted.

5.2.6 Demand vs. Frequency

Figure 11 is a demand vs. frequency curve for Boston to San Francisco in the year 1980. The frequency variable is the number of optimally scheduled daily nonstop jet departures. Optimal scheduling implies that the departure times are selected so that average displacement time is minimized. For example, if only two flights are scheduled, the departure times that will minimize the unweighted average displacement time are at one-third and two-thirds of the way through the traveling day. If three flights are to be scheduled then the optimal departure times are 1/6, 1/2, and 5/6 through the traveling day. This optimal scheduling concept can be generalized into the following equation which gives the departure time, D_i, of each of n scheduled flights as a fraction of the traveling day:

$$D_i = \frac{2i - 1}{2n} \qquad i = 1, 2, \ldots, n \qquad (26)$$

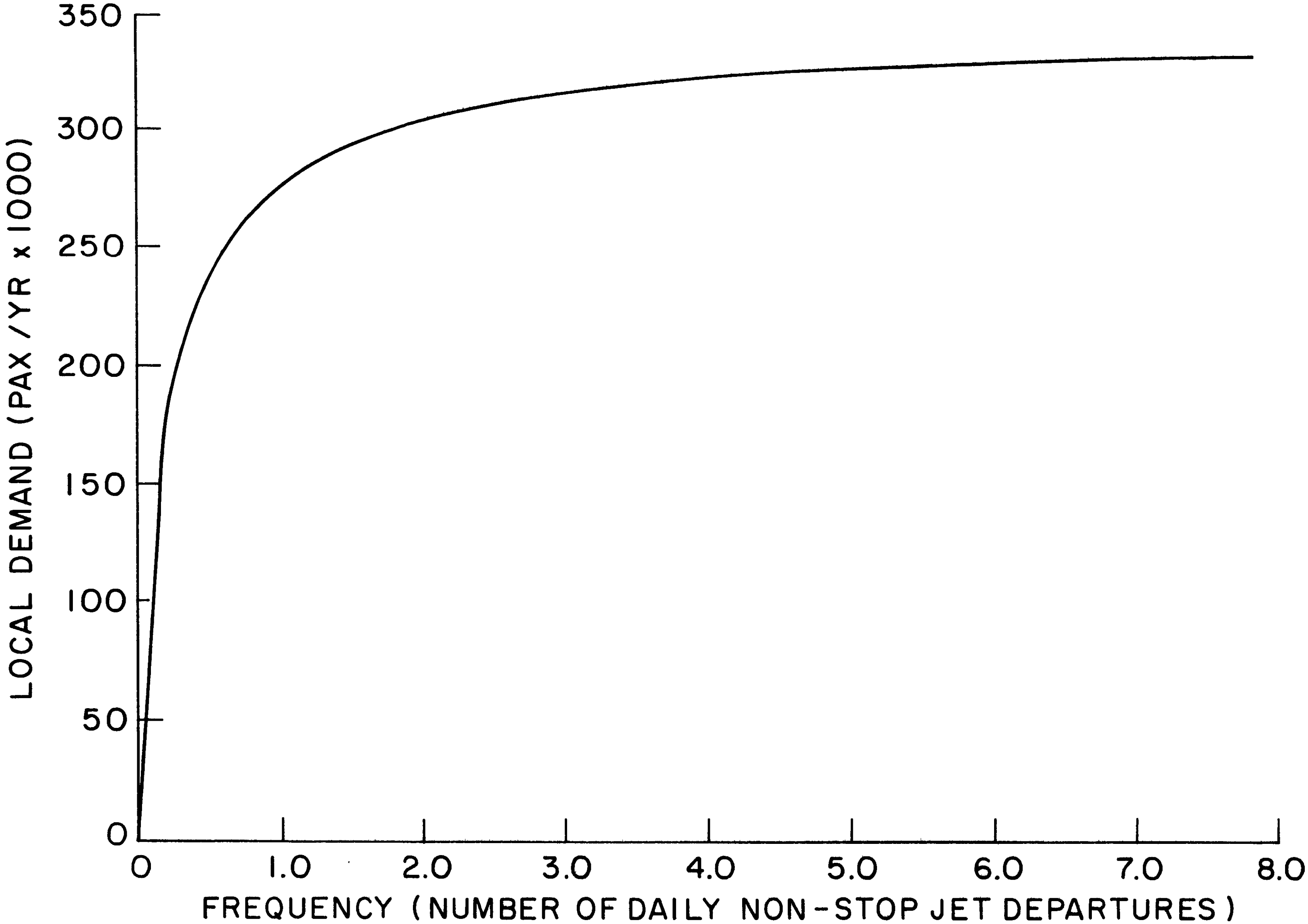


FIGURE 11 DEMAND VS. FREQUENCY BOSTON TO SAN FRANCISCO 1980

For example, the departure time of the fifth of seven optimally scheduled nonstop flights is 9/14 through the traveling day.

$$D_5 = \frac{2(5) - 1}{2(7)} = \frac{9}{14}$$

If T is the length of the traveling day, then the average displacement time, given an optimal schedule, can be shown to be (assuming the passenger behavior pattern postulated in Section 2.2.1):

$$\overline{DT} = \frac{T}{4n} \tag{27}$$

Since the level of service variable, LOS, is defined in equation (14) as the ratio of nonstop jet time, t_0, to the average of the flight and displacement times, therefore, for n optimally scheduled nonstop jets, the level of service is:

$$LOS = \frac{t_o}{t_o + \frac{T}{4n}} = \frac{n}{n + \frac{T}{4\,t_o}} \tag{28}$$

The standard value of the length of the travelling day used for development of demand vs. frequency relationships for long haul markets is D = 16 hours. The nonstop jet time for a flight from Boston to San Francisco is roughly t_o = 6.0 hours. Substituting these values into the above LOS equation yields the relationship between level of service and number of flights (assuming optimal scheduling) for the Boston to San Francisco segment.

$$LOS(BOS\text{-}SFO) = \frac{n}{n + \frac{16}{4(6.0)}} = \frac{n}{n + 0.667} \qquad (29)$$

Based upon the schedule generated by the assumptions of Section 5.1.3, the level of service value, LOS, for the Boston - San Francisco market for the year 1980 is 0.844. The base forecast from Table 4 is 320,000 passengers. Since the elasticity with respect to LOS is 0.429 (Section 4.3) then the demand sensitivity relationship as a function of perturbations in LOS is shown below:

$$Q_D(LOS) = 320{,}000 \left(\frac{LOS}{0.844}\right)^{0.429}$$

$$= 344{,}000\ LOS^{0.429} \qquad (30)$$

For optimal schedules of n daily flights equations (29) and (30) can be combined to form the demand vs. frequency relationship:

$$Q_D = 344{,}000\left(\frac{n}{n + 0.667}\right)^{0.429} \qquad (31)$$

This function is plotted in Figure 11.

5.2.7 Demand vs. Fare for Various Levels of Socio-Economic Activity

Figure 12 contains three hypothetical demand vs. fare curves for the Boston - San Francisco market for the year 1980. The middle curve was

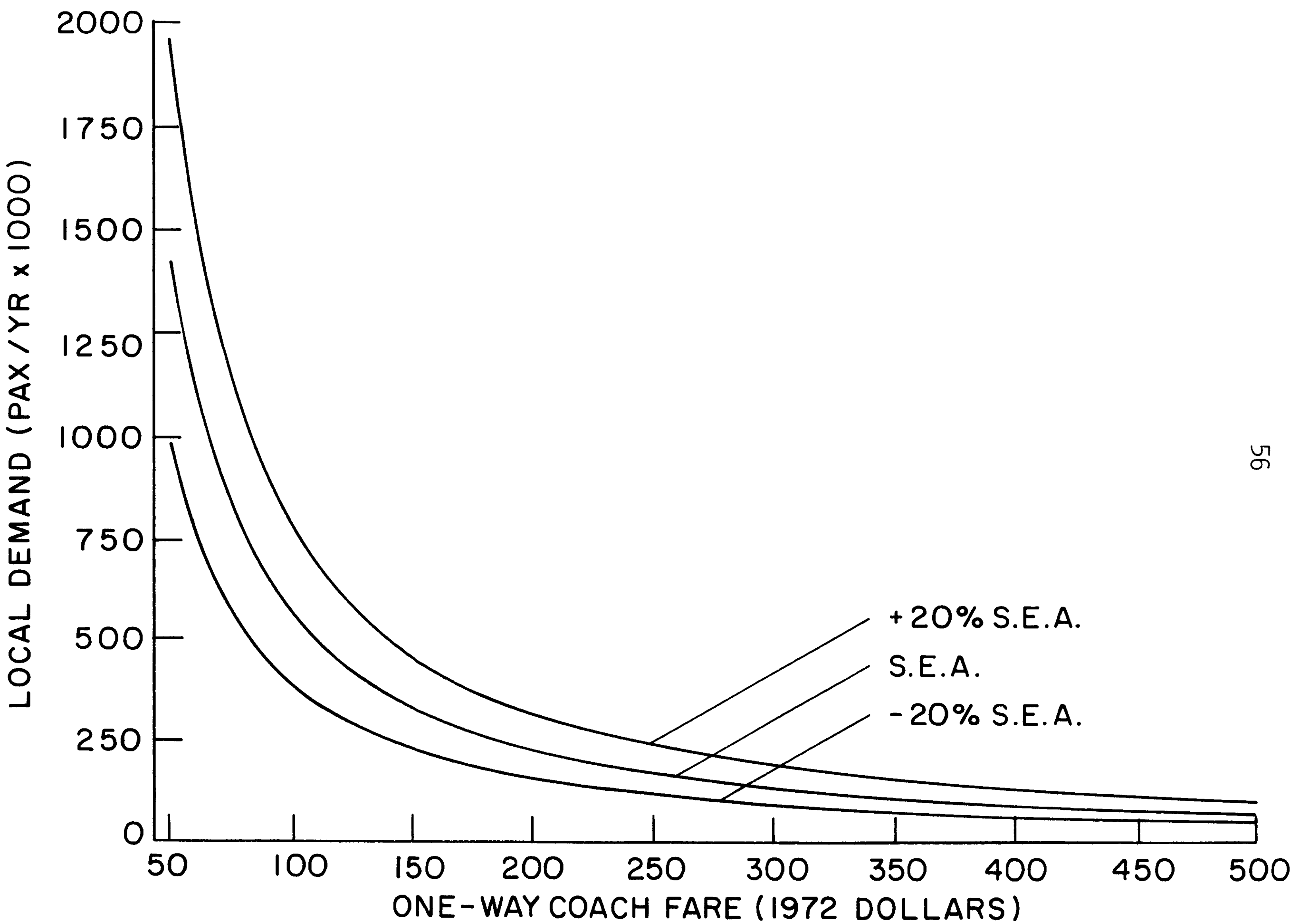


FIGURE 12 DEMAND VS. FARE FOR SELECTED LEVELS OF SOCIOECONOMIC ACTIVITY: BOSTON TO SAN FRANCISCO, 1980

from the base forecast of 320,000 passengers (Section 5.1.3) and the fare elasticity of -1.26 (Section 4.3). The remaining two curves are the results of perturbations of plus and minus 20% of the socio-economic projections provided by the Department of Commerce. The purpose of this set of curves is to measure the effect of inaccuracy of these projections.

6. Implications for NASA Research

The purpose of this research was to develop a set of demand models which can measure the impact upon market demand of policy decisions. These decisions may be the introduction of new aircraft technology or the implementation of new managerial strategies within the framework of existing technology. This section provides examples of how the demand models developed in this research may be applied to policy analysis.

This section is divided into two subsections. Within these subsections are the analyses of impact on demand of the introduction into long haul market of a supersonic transport aircraft and the introduction of a fuel efficient aircraft.

6.1 The Introduction of a Supersonic Transport

Figure 3 shows that in 1975 there were two daily nonstop departures from Boston - San Francisco. Flight number "8" is United 97, an early morning 747, and flight number "11" is TWA 33, a noontime L-1011 departure. The resulting value of the level of service variable for this schedule is 0.809, as shown in Figure 4. In this section the equipment used for these two flights will be "replaced" by supersonic transports and the impact upon demand will be predicted.

Assuming a total of one half hour for taxiway occupancy and acceleration to and deceleration from cruise speed, and a cruise speed of 1800 miles per hour, the block time of a supersonic transport flight from Boston to San Francisco, approximately 2700 miles, is estimated as

$$t_o = 0.5 \text{ hours} + \frac{2700 \text{ miles}}{1800 \text{ mph}} = 2.0 \text{ hours}$$

Figure 13 shows the Boston to San Francisco flight schedule with the two nonstop subsonic flights replaced with supersonic transports. The resulting level of service value is computed in figure 14 to be 1.204, which represents an increase of 48.8%. Since the elasticity of demand with respect to service was predicted in Section 4.3 to be 0.429, the estimated increase in demand due to the introduction of supersonic service is 0.429 x 48.8% = 20.9%. Therefore, had this service been in effect (at the standard coach fare), the model suggests that the total traffic volume in this market would have been 242,000 passengers for the year 1975 as opposed to the observed volume of 200,000 passengers.

6.2 The Introduction of A Fuel Efficient Subsonic Aircraft

The next generation of subsonic aircraft will be a medium range two engine plane with a capacity of about 200 people. It will bridge the gap between the shorter range and smaller capacity narrow-bodies (DC-9, 727, 737) and the longer range and greater capacity wide-bodies (DC-10, L-1011, 747). It will be substantially cheaper to operate in medium and medium to long haul markets (in terms of direct operating cost per available seat-mile) than the existing four-engine narrow-bodied planes (DC-8, 707).

If the new generation aircraft were introduced, it is reasonable to believe that the cost savings of the airlines would be passed on to the

FIGURE 13

FLIGHT SCHEDULE BOS SFO 1975

FLIGHT	DEPART	ARRIVE	ADJUSTED FLIGHT TIME	STATUS	CARRIER(S)	
1	7.00	11.02	7.52	ONLINE	AA/AA	
2	7.00	11.97	7.97	DIRECT	AA	
3	7.17	13.62	9.95	ONLINE	AA/AA	
4	7.25	12.07	7.82	DIRECT	TW	
5	7.58	11.80	7.72	ONLINE	AA/AA	
6	7.67	12.50	8.33	ONLINE	UA/UA	
7	8.50	15.42	10.42	ONLINE	AA/AA	
8	9.50	8.50	2.00	DIRECT	UA	FLAG
9	10.33	15.30	9.47	ONLINE	AA/AA	
10	11.17	15.28	7.62	ONLINE	UA/UA	
11	12.00	11.00	2.00	DIRECT	TW	FLAG
12	12.50	19.72	10.22	DIRECT	TW	
13	13.42	18.87	8.95	ONLINE	NW/NW	
14	13.50	19.27	8.77	DIRECT	AA	
15	13.50	19.63	9.63	ONLINE	AA/AA	
16	13.58	18.00	7.92	ONLINE	UA/UA	
17	14.92	19.43	8.02	ONLINE	AA/AA	
18	15.25	19.35	7.10	DIRECT	AA	
19	15.50	19.97	7.97	ONLINE	TW/TW	
20	16.00	20.52	8.52	INTLIN	TW/UA	
21	16.08	20.67	8.08	ONLINE	UA/UA	
22	16.25	20.23	6.98	DIRECT	TW	
23	16.50	21.22	8.22	ONLINE	UA/UA	
24	16.50	21.48	7.98	DIRECT	UA	
25	17.50	22.42	8.42	ONLINE	AA/AA	
26	17.50	22.48	8.98	INTLIN	TW/AA	
27	17.50	22.53	8.53	ONLINE	AA/AA	
28	17.50	24.17	9.67	DIRECT	TW	
29	18.83	24.30	8.97	ONLINE	UA/UA	
30	18.83	24.90	9.07	DIRECT	AA	
31	21.00	25.28	7.78	ONLINE	TW/TW	
32	21.00	27.53	10.03	ONLINE	AA/AA	

FIGURE 14

COMPUTATION OF LEVEL OF SERVICE INDEX   POS SFO 1975

J	T(J)	PI(J)	FLIGHT BOARDED	DISPLACE- MENT TIME	ADJUSTED FLIGHT TIME	TRIP TIME	CONTRIBUTION TO TOTAL TRIP TIME
1	4.00	0.005	8	5.50	2.00	7.50	0.035
2	4.50	0.008	8	5.00	2.00	7.00	0.055
3	5.00	0.014	8	4.50	2.00	6.50	0.091
4	5.50	0.020	8	4.00	2.00	6.00	0.119
5	6.00	0.026	8	3.50	2.00	5.50	0.143
6	6.50	0.030	8	3.00	2.00	5.00	0.148
7	7.00	0.034	8	2.50	2.00	4.50	0.154
8	7.50	0.037	8	2.00	2.00	4.00	0.150
9	8.00	0.034	8	1.50	2.00	3.50	0.119
10	8.50	0.031	8	1.00	2.00	3.00	0.092
11	9.00	0.028	8	0.50	2.00	2.50	0.070
12	9.50	0.026	8	0.00	2.00	2.00	0.051
13	10.00	0.026	8	0.50	2.00	2.50	0.064
14	10.50	0.026	8	1.00	2.00	3.00	0.078
15	11.00	0.025	11	1.00	2.00	3.00	0.076
16	11.50	0.024	11	0.50	2.00	2.50	0.061
17	12.00	0.026	11	0.00	2.00	2.00	0.051
18	12.50	0.027	11	0.50	2.00	2.50	0.068
19	13.00	0.031	11	1.00	2.00	3.00	0.094
20	13.50	0.035	11	1.50	2.00	3.50	0.124
21	14.00	0.037	11	2.00	2.00	4.00	0.147
22	14.50	0.038	11	2.50	2.00	4.50	0.172
23	15.00	0.042	11	3.00	2.00	5.00	0.212
24	15.50	0.046	11	3.50	2.00	5.50	0.252
25	16.00	0.043	11	4.00	2.00	6.00	0.257
26	16.50	0.039	11	4.50	2.00	6.50	0.255
27	17.00	0.036	11	5.00	2.00	7.00	0.251
28	17.50	0.032	11	5.50	2.00	7.50	0.241
29	18.00	0.031	11	6.00	2.00	8.00	0.245
30	18.50	0.028	11	6.50	2.00	8.50	0.236
31	19.00	0.025	11	7.00	2.00	9.00	0.225
32	19.50	0.022	31	1.50	7.78	9.28	0.205
33	20.00	0.020	31	1.00	7.78	8.78	0.176
34	20.50	0.016	31	0.50	7.78	8.28	0.136
35	21.00	0.014	31	0.00	7.78	7.78	0.109
36	21.50	0.011	31	0.50	7.78	8.28	0.093
37	22.00	0.007	31	1.00	7.78	8.78	0.060
38	22.50	0.000	31	1.50	7.78	9.28	0.000
39	23.00	0.000	31	2.00	7.78	9.78	0.000
40	23.50	0.000	31	2.50	7.78	10.28	0.000
41	24.00	0.000	31	3.00	7.78	10.78	0.000

TBAR = 5.115

LOS = TNJ/TBAR = 6.16/5.12 = 1.204

consumer in terms of lower fare levels. Level of service could also be affected, but this is more uncertain since many factors are involved, such as the number of planes purchased by the airlines, expected utilization, etc.

If the new technology aircraft were introduced without a change in the level of service, but with a decrease (in constant dollars) of between 5% and 30% in fares in markets roughly the length of the Boston - San Francisco market, given a price elasticity of -1.26, the model would predict the traffic volumes shown in Table 5.

Table 5. Effect Upon Demand of Fuel Efficient Aircraft Assuming A 5% - 30% Decrease in Fare

Percentage Decrease in Fare	Percentage Increase in Demand
5	6.3
10	12.6
15	18.9
20	25.2
25	31.5
30	37.8

7. Conclusions

A general econometric long haul market demand model was defined and calibrated. The determinants of demand were assumed to be the level of service (speed and frequency of aircraft) between the markets; the socio-economic characteristics (income and level of service activity) of the origin-destination market regions; and the fare. The demand model was conceived as a tool which could be used by NASA and other governmental and private organizations for assessing various policy options in the air transportation industry. Thus the primary requirement of the model was that it should provide reasonably accurate answers to questions about changes in the determinants in demand; i.e., for sensitivity analyses.

The model parameters with the smallest standard errors that should be used for policy analyses were estimated to be:

Coefficient	Value	Standard Error
b_0 (constant)	-0.0859	0.00343
b_1 (level of service)	0.429	0.00197
b_2 (fare)	-1.26	0.0333
b_3 (socioeconomic level)	1.73	0.0186

A secondary requirement of the long haul demand model was that it should produce reasonably accurate forecasts about the level of traffic. To this end, a different statistical technique was used to estimate the parameters of the model which would have as its primary requirement the minimization of the error on the total demand. Given this goal, two approaches to forecasting traffic in city pairs were possible: one, using the demand model calibrated using data from 15 city-pairs and 6 years (i.e., Eq. 17); or, two, using the demand model with the parameters estimated from data of the individual city-pair market (as for Table 2a1). Since the intent of the forecasting procedure was to assess the validity of the model in general, i.e., how the determinants of demand chosen for the model really explain the traffic flow, both approaches were used. The results are shown in Table 6 for three other long haul markets and compared with the actual demand.

As in the Boston-San Francisco case, the individual market pair estimates are somewhat better than those of the general market demand model. The predictive ability of both estimates in the early non-jet years is poor, for reasons explained in Section 6; the downward bias in 1978 may be due to the reduced-fare plans offered in these markets (particularly New York-Los Angeles and Chicago-Los Angeles) and perhaps poor estimates of the socio-economic variables.

The underlying derivations of the components of the model are sufficiently sophisticated to capture the important characteristics of the complex passenger market environment. Furthermore, the models developed are adaptive in that they can be updated without too much difficulty as additional data become available.

From the results shown above, it appears that air transportation demand is elastic with respect to price and socio-economic activity and inelastic with respect to level of service as defined in this study. This information can provide useful input regarding future technological and economic scenario

Table 6 NYC-LAX

Year	Actual Demand	General Demand Parameter Estimation	Individual City Pair Parameter Estimation
1950	134,440	42,610	158,400
1955	358,340	118,310	295,470
1960	473,690	419,300	575,930
1967	926,140	735,650	922,180
1968	992,820	817,880	1,001,107
1969	1,081,300	898,750	1,075,040
1970	1,055,070	835,710	1,047,370
1971	1,034,290	841,970	1,046,110
1972	1,092,300	869,830	1,087,980
1973	1,117,480	869,680	1,118,420
1974	1,131,300	876,560	1,130,018
1975	1,169,160	918,830	1,170,080
1976	1,248,690	962,770	1,197,290
1977	1,312,770	1,977,780	1,273,570
1978	1,643,890	1,211,690	1,359,200
		R^2 = 0.945	R^2 = 0.992

* The R^2 values are 0.945 for the general market model parameter specification (see Section 3.1); the individual city pair R^2 terms are based on data from 1967-1975 as in the Boston-San Francisco case (see Section 5.1.2).

Table 6 (continued): CHI-LAX

Year	Actual Demand	General Demand Parameter Estimation	Individual City Pair Parameter Estimation
1950	79,740	13,470	204,080
1955	169,340	92,530	308,960
1960	274,620	272,980	431,500
1967	597,140	592,140	610,900
1968	631,540	653,440	628,890
1969	665,190	711,480	647,300
1970	653,870	609,650	639,620
1971	628,430	579,820	632,230
1972	652,610	692,230	657,220
1973	669,260	746,130	685,480
1974	702,670	710,550	694,280
1975	694,130	801,030	698,170
1976	724,990	815,620	705,740
1977	722,810	848,470	718,460
1978	1,053,460	961,970	731,200
		$R^2 = 0.945$	$R^2 = 0.874$

Table 6 (continued) HOU-WAS

Year	Actual Demand	General Demand Parameter Estimation	Individual City Pair Parameter Estimation
1950	12,710	2,340	3,920
1955	16,560	5,880	6,640
1960	18,830	7,540	12,040
1967	41,810	49,410	45,730
1968	50,110	48,990	45,380
1969	49,020	41,260	49,640
1970	56,160	48,000	56,660
1971	57,100	45,720	57,770
1972	74,820	74,690	73,240
1973	82,610	78,270	82,600
1974	96,040	77,560	90,380
1975	93,970	96,070	99,550
1976	98,570	105,020	107,620
1977	120,033	126,830	119,540
1978	141,960	146,460	130,380
		R^2 = .945	R^2 = 0.965

development; for example, a means to assess two types of service, one faster and more expensive and one slower but cheaper.

Overall, the model appears to satisfactorily track traffic demand in the long haul markets. Given the new regulatory environment, a fare variable adjustment in the general market model appears warranted for future research. In addition, it may be possible to improve the specification of the model through the incorporation of a sophsticated route structure variable. Finally, it is recommended that further research in this area should include market segmentation by business versus pleasure travel.

APPENDIX

```
FORTRAN IV G1  RELEASE 2.0          MAIN            DATE = 79108          17/43/47          PAGE 000

      C
      C     E. W. LIU     M.I.T. FLIGHT TRANSPORTATION LABORATORY
      C
      C*****FORECASTING MODEL FOR PASSENGER DEMAND----------PREDICTED****************C
      C
            DIMENSION IRDEFT(12),DEFLT(12)
            REAL*8 CP
      C     INPUT IMPLICIT PRICE DEFLATORS OF EACH YEAR
            READ(5,2) (IRDEFT(I),DEFLT(I),I=1,3)
      2     FORMAT(I4,F5.1)
      C     INPUT CITY-PAIRS
      87    READ(5,88) CP
      88    FORMAT(A7)
      C     INPUT COEFFICIENTS OF DEMAND EQUATION
            READ1,BTL10,BTL11,BTL12,BTL13,ERRL
      1     FORMAT(5(F10.5,3X))
            WRITE(6,10) CP
      10    FORMAT(' ',38X,A7,//,23X,'FARE',10X,'SOCIO-ECONOMICS',6X,'LEVEL',1
           X0X,'DEMAND',/,5X,'YEAR',6X,'CONSTANT',2X,'CURRENT',3X,'CONSTANT',3
           XX,'CURRENT',2X,'OF SERVICE',2X,'PREDICTED   ACTUAL',/)
            DO 30 J=1,4
      C     INPUT LEVEL OF SERVICE, CURRENT DEMAND, CURRENT SOCIO-ECONOMIC ACTIVITY,
      C     AND CURRENT FARE
      C     10% SAMPLE OF CURRENT DEMAND
      C     SOCIO-ECONOMIC ACTIVITY IN THOUSANDS OF $
            READ(5,3) IR,ALOS,QD,SEA,FARE,LSTC
      3     FORMAT(7X,I4,F5.3,F7.0,F9.0,F6.2,I1)
            IF(LSTC.EQ.9) GO TO 70
            IF(LSTC.EQ.4) GO TO 87
            CSEA=SEA/DEFLT(J)*100.
            CFARE=FARE/DEFLT(J)*100.
            GALOS=ALOG(ALOS)
            GCFARE=ALOG(CFARE)
            GCSEA=ALOG(CSEA)
            GQD=ALOG(QD)
      40    GPQD=BTL10+BTL11*ALOG(ALOS)+BTL12*ALOG(CFARE)+BTL13*ALOG(CSEA)
            PQD=2.71828**GPQD
            WRITE(6,50) IR,CFARE,FARE,CSEA,SEA,ALOS,PQD,QD
      50    FORMAT(5X,I4,6X,F6.2,4X,F6.2,3X,F9.0,2X,F9.0,4X,F5.3,4X,F9.0,2X,F7
           X.0,//)
            WRITE(6,98) GCFARE,GCSEA,GALOS,GPQD,GQD
      98    FORMAT(15X,F9.5,1X,F9.5,1X,F9.5,1X,F9.5,1X,F9.5,////)
      30    CONTINUE
            GO TO 87
      70    STOP
            END
```

Input Data for Demand Forecasting Program

I. Input Statement of Implicit Price Deflators:

```
        READ(5,2) (IRDEFT(I),DEFLT(I),I=1,12)
2       FORMAT(I4,F5.1)
```

Data Deck Arrangement: (Column 1-4: Year; Column 5-9: Deflator)

```
1950 47.4
1955 58.5
1960 68.0
1967 78.8
1968 82.0
1969 86.1
1970 90.5
1971 95.8
  .
  .
  .
```

II. Input Statement of City Pair:

```
        READ(5,88) CP
88      FORMAT(A7)
```

Data Deck Arrangement: (Column 1-7: The Name of City Pair)

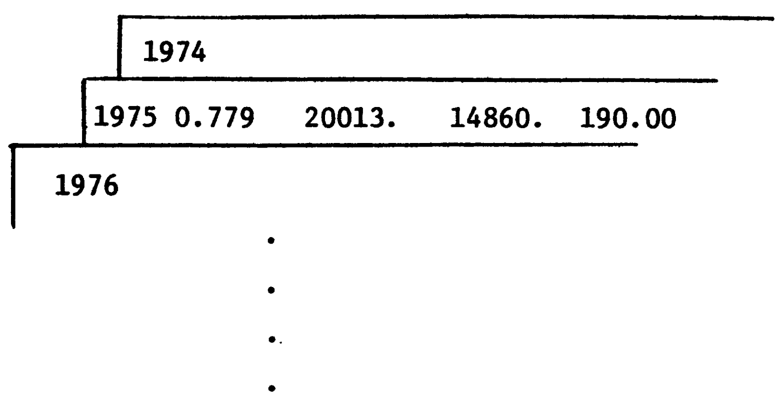
Example: Boston-San Francisco

```
BOS-SFO
```

III. Input Statement of Year, Level of Service, Actual Demand, Socio-economic Index, Standard One-way Coach Fare, and Last Card Index:

```
      READ(5,3) IR,ALOS,QD,SEA,FARE,LSTC
3     FORMAT(7X,I4,F5.3,F7.0,F9.0,F6.2,I1)
```

Data Deck Arrangement: (Column 8-11: Year; Column12-16: Level of Service; Column 17-23: Actual Demand; Column 24-32: Socio-economic Index; Column 33-38: Standard One-way Coach Fare; Column 39: "4" of the last card for each city pair card deck, "9" of the last card at the end of program.)



SOURCE LISTING

```
STMT LEV NT

   1        0  LOS_CMP:      PROCEDURE OPTIONS(MAIN);
               /*
                    S. E. ERIKSEN      M.I.T. FLIGHT TRANSPORTATION LABORATORY

                    PL/I PROGRAM TO COMPUTE THE LEVEL OF SERVICE INDEX FOR AIR TRANSPORTATION
                    SERVICE IN A REGION PAIR USING THE "PREFERRED DEPARTURE TIME" MODEL

                    REF:  MAY 3, 1976 PROGRESS REPORT TO NASA, APPENDIX A
               */
   2    1   0  DECLARE (PI(41),P(60),T(41),SUMPI,DHR,DMIN,AHR,AMIN,DPT(100),ART(100),
                    BFT(100),IT,TRIPTIME(41),CONTRIBUTION(41),TNJ,TBAR,LOS,ZONE,
                    SHARE(12),COMP1,COMP2,RECIP2,SUP,ESHARE(12)) FLOAT;
   3    1   0  DECLARE (DELTA,BIGI(41),IJ,KEY(2)) FIXED BINARY;
   4    1   0  DECLARE CITY_PAIR CHARACTER(12),(LEG1(100),LEG2(100)) CHARACTER(2),
                    SLASH(100) CHARACTER(1),STATUS(100) CHARACTER(6),
                      CARRIER(9) CHARACTER(2),FLAG CHARACTER(4),
                        (EQUIP1(100),EQUIP2(100)) CHARACTER(3),
                         EQUIPMENT(12) CHARACTER(3);
               /*
                    ASSIGN CLOCK TIMES (T(J)) TO TIME POINTS (J)
               */
   5    1   0  DO J=1 TO 41;
   6    1   1   T(J)=3.5+J/2;
   7    1   1   END;
               /*
                    INPUT ORIGINAL TIME OF DAY DISTRIBUTION
               */
   8    1   0  GET EDIT ((P(J) DO J= 1 TO 18))(COLUMN(1),18(F(4,4)));
   9    1   0  GET EDIT ((P(J) DO J=19 TO 36))(COLUMN(1),18(F(4,4)));
  10    1   0  GET EDIT ((P(J) DO J=37 TO 41))(COLUMN(1), 5(F(4,4)));
  11    1   0  DO J=42 TO 60;
  12    1   1   JM48=J-48;
  13    1   1   IF J<49 THEN P(J)=0.0;
  14    1   1        ELSE P(J)=P(JM48);
  15    1   1   END;
               /*
```

```
                    INPUT COVER CARD
                 */
 16    1   0     RESTART:
                 GET EDIT(TO,TNJ,ZONE,CITY_PAIR) (COL(7),2(F(5,2)),F(3),X(1),A(12));
                 /*
                     DELTA IS THE EXTENT (HALF HOURS) BY WHICH THE TIME AXIS IS SHIFTED
                 */
 17    1   0     IF TO=0.0 THEN TO=TNJ;
 18    1   0     DELTA=ROUND(2.0*(TNJ+ZONE)-2.0,0);
 19    1   0      SUMPI=0.0;


                 /*
                     SHIFT AXES AND MULTIPLY P(J)'S
                 */
 20    1   0      DO J=1 TO 41;
 21    1   1       JA=J+DELTA;
 22    1   1       IF JA<1 THEN PI(J)=0.0;
 23    1   1           ELSE PI(J)=SQRT(P(J)*P(JA));
 24    1   1       SUMPI=SUMPI+PI(J);
 25    1   1       END;
                 /*
                     NORMALIZE TO SUM TO ONE

                 */
 26    1   0     DO J=1 TO 41;
 27    1   1       PI(J)=PI(J)/SUMPI;
 28    1   1       END;
                 /*
                     INPUT FLIGHT DATA AND COMPUTE BLOCK FLIGHT TIMES
                 */
 29    1   0     NC=0;
 30    1   0     DO N=1 TO 9;
 31    1   1      SHARE(N)=0.0;
 32    1   1     END;
 33    1   0     I=1;
 34    1   0     FLIGHT_INFO:
                 GET EDIT(DHR) (COL(1),F(2));
 35    1   0     IF DHR<2 THEN GO TO PRINCIPLE;
 36    1   0     GET EDIT(DMIN,AHR,AMIN,LEG1(I),SLASH(I))
                     (F(2),F(4),F(2),X(2),A(2),A(1));
```

```
37    1  0    DPT(I)=DHR+DMIN/60.0;
38    1  0    ART(I)=AHR+AMIN/60.0;
39    1  0    BFT(I)=ART(I)-DPT(I)-ZONE;
40    1  0    IF SLASH(I) ¬='/' THEN
               DO;
41    1  1      STATUS(I)='DIRECT';
42    1  1      LEG2(I)='  ';
43    1  1       GET EDIT(EQUIP1(I)) (A(3));
44    1  1      END;
45    1  0     ELSE DO;
46    1  1       GET EDIT (LEG2(I),EQUIP1(I),EQUIP2(I))  (A(2),X(1),A(3),X(1),A(3));
47    1  1      IF LEG1(I)=LEG2(I) THEN
                 STATUS(I)='ONLINE';
48    1  1       ELSE DO;
49    1  2        STATUS(I)='INTLIN';
50    1  2        BFT(I)=BFT(I)+0.5;
51    1  2        END;
52    1  1       BFT(I)=BFT(I)+0.5;
53    1  1      END;
54    1  0   I=I+1;
55    1  0   GO TO FLIGHT_INFO;

56    1  0   PRINCIPLE:
             M=I-1;
57    1  0   PUT PAGE;
58    1  0   PUT SKIP(2)EDIT ('FLIGHT SCHEDULE',CITY_PAIR)(COLUMN(11),A,X(3),A(12));
59    1  0   PUT SKIP(4)EDIT ('ADJUSTED')(COLUMN(28),A);
60    1  0   PUT EDIT ('FLIGHT  DEPART  ARRIVE  FLIGHT TIME  STATUS  CARRIER(S)')
                  (COLUMN(2),A);
61    1  0   PUT SKIP(2);
62    1  0   DO I=1 TO M;
63    1  1    FLAG='FLAG';
64    1  1    IF BFT(I)>0.80*TNJ THEN IF BFT(I)<5.0*TNJ THEN FLAG='    ';
65    1  1    PUT EDIT(I,DPT(I),ART(I),BFT(I),STATUS(I),LEG1(I),SLASH(I),LEG2(I),
                 FLAG)
                 (COLUMN(4),F(2),F(9,2),F(8,2),F(11,2),X(5),A(6),X(5),A(2),A(1),
                  A(2),X(4),A(4));
66    1  1    END;
             /*
```

```
            COMPUTATION OF AVERAGE TOTAL TRIP TIME
         */
1  0     TBAR=0.0;
1  0     ASSIGNMENT:   DO J=1 TO 41;
1  1      TRIPTIME(J)=100.0;
1  1      DO I=1 TO M;
1  2       TT=ABS(DPT(I)-T(J))+BFT(I);
1  2       IF TT>=TRIPTIME(J)
              THEN GO TO NEXT_FLIGHT;
1  2       BIGI(J)=I;
1  2       TRIPTIME(J)=TT;
1  2     NEXT_FLIGHT:  END;
1  1      CONTRIBUTION(J)=PI(J)*TRIPTIME(J);
1  1      TBAR=TBAR+CONTRIBUTION(J);
1  1      END;
1  0     LOS=TO/TBAR;
         /*
             OUTPUT
         */
1  0     PUT PAGE;
1  0     PUT SKIP EDIT('COMPUTATION OF LEVEL OF SERVICE INDEX',CITY_PAIR)
              (COLUMN(15),A,X(4),A(12));
1  0     PUT SKIP(4)EDIT('FLIGHT  DISPLACE-    ADJUSTED','CONTRIBUTION TO')
              (COLUMN(18),A,COLUMN(61),A);
1  0     PUT EDIT('J  T(J) PI(J) BOARDED  MENT TIME  FLIGHT TIME  TRIP TIME',
              'TOTAL TRIP TIME')(COLUMN(3),A,COLUMN(61),A);
1  0     PUT SKIP(2);
1  0     DO J=1 TO 41;
1  1       IJ=BIGI(J);
1  1      DT=ABS(DPT(IJ)-T(J));
1  1      PUT EDIT(J,T(J),PI(J),IJ,DT,BFT(IJ),TRIPTIME(J),CONTRIBUTION(J))
              (COLUMN(2),F(2),F(6,2),F(6,3),F(7),COLUMN(29),F(4,2),COLUMN(39),

              F(5,2),COLUMN(51),F(5,2),COLUMN(64),F(6,3));
1  1      END;
1  0     PUT SKIP(2)EDIT('TBAR = ',TBAR)(COLUMN(57),A,F(6,3));
1  0     PUT SKIP(3)EDIT('LOS = TNJ/TBAR = ',TNJ,'/',TBAR,' = ',LOS)
              (COLUMN(23),A,F(4,2),A,F(4,2),A,F(5,3));
1  0     IF DHR>-1 THEN GO TO RESTART;
1  C     FINISH:  END LOS_CMP;
```

Input Data for Level of Service Program

I. Input Original Time of Day Distribution

The following distribution data are input from column 1 to 72; continued on the next data card. (18 number per card)

0012 0023 0051 0078 0155 0233 0334 0435 0381 0326 0303
0280 0264 0249 0225 0202 0218 0233 0245 0256 0264 0272
0350 0427 0447 0466 0447 0427 0357 0287 0249 0210 0229
0233 0218 0202 0152 0101 0078 0054 0027

II. Input Cover Card and Schedules of Service for Each City Pair:

a. Cover Card for Each City Pair:

Column 13-16: Block Time, Column 18-19: Zone, Column 21-23:Departure Airport, Column 25-27: Arrival Airport, Column 29-32: Year

```
6.16 -3 BOS SFO 1975
```

b. Schedule Data:

1. Nonstop Flights:

Column 1-4: Departure Time (0700) Column 7-10: Arrival Time (1158)

Column 13-14: Carrier (AA) Column 16-18: Type of Aircraft (727)

Column 20: No. of Intermediate Stop (2)

```
0600 --------------------
0700  1158 AA 727  2
0715  -------------
```

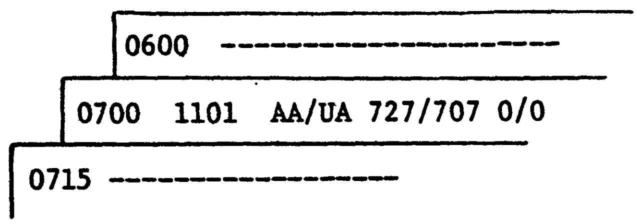
2. Connection Flights:

Column 1-4: Departure Time (0700) Column 7-10: Arrival Time (1101)

Column 13-17: Carriers (AA/UA)

Column 19-25: Type of Aircraft (727/707)

Column 27-29: No. of Intermediate Stop (0/0)



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15. Supplementary Notes

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16. Abstract

The results of an econometric travel demand model are presented. The model is useful for analyzing long haul domestic passenger markets in the United States. In particular, it shows the sensitivities of demand to changes in fares and speeds reflecting technology through more efficient aircraft designs.

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