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CONSIDERATION OF INTERMODAL COMPETITION IN THE FORECASTING OF NATIONAL INTERCITY TRAVEL

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Forecasting of national travel demands has been performed to date separately for each mode, without giving consideration to changes in the transportation services and demands of other modes. A study was recently completed that had as its objectives the development of a prototype methodology for estimating future national passenger travel demands and the exercising of this methodology. This paper describes selected innovative aspects of an overall national intercity travel demand forecasting framework developed in this study. A method is described for transforming air trip tables, which are on an airport-to-airport basis as developed by the Civil Aeronautics Board into trip tables reflecting the "true" origins and destinations of the air trips. Also described is the development of a modal-split model that is based on a logistic function and that estimates the automobile and air market shares as a function of the travel impedances of each of the modes.

THE IMPORTANCE of considering the competition among modes has long been recognized in travel demand analyses conducted at the urban and corridor levels. Forecasting of national intercity travel has generally been performed separately for each mode, without giving consideration to changes in the transportation services and demands of other modes. Changes in the level of service of a mode, such as a highway, will affect the demands not just for that mode but for the other competing modes, such as rail or air. In this sense, it is important to develop demand forecasts for national intercity travel based on a methodology that explicitly considers the competition among modes of transportation.

A study (1) was recently completed that had 2 main objectives: (a) the development of a prototype methodology for forecasting national intercity travel such that the competition among modes is explicitly introduced into the analysis, and (b) the exercising of this methodology to prepare forecasts for 1975, 1980, and 1990. Although the results of this study are plausible, their interpretation and subsequent use should be considered within the context of the relatively limited resources with which they were developed. This paper focuses on selected innovative highlights of the forecasting framework. Specifically, it describes (a) a method for transforming airport-to-airport trip tables into trip tables reflecting the "true" origins and destinations of the air trips; and (b) a modal-split model that is based on a logistic curve and that estimates the automobile and air market shares as a function of the travel impedances of each of the modes.

Examination of the 1967 National Travel Survey strongly suggests that the predominant amount of intercity travel in the United States involves the automobile and air modes. On a national basis, the rail and bus modes account for approximately 4 percent of the total number of person trips. However, rail trips would tend to be concentrated in certain travel corridors, such as the Northeast Corridor, where they might capture a significant proportion of the trips, particularly if Metroliner types of services

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were introduced. For this reason, all potential transportation corridors in the country were identified, and separate demand analyses developed for the corridor and noncorridor trips.

For noncorridor trips, the analysis was restricted to the competition among the automobile, air, and bus modes. The analysis framework described in this paper was designed to predict travel demands, primarily by automobile and air modes, for noncorridor travel. Bus travel demands, not considered for modal-split calibration procedures because of insufficient data, were estimated by using factors obtained from the 1967 National Travel Survey. The reader is referred to the final report (1) for a discussion of the analysis process for corridor trips.

In this study, the areal system consists of 490 zones that are aggregates of counties. In this 490-zone structure, each standard metropolitan statistical area (SMSA) in the continental United States is represented by a single zone; the remainder of each state is divided into a geometrically suitable number of zones.

DEVELOPMENT OF TRUE AIR TRIP TABLES

The basic air travel data source of this study was the Civil Aeronautics Board (CAB) 1967 survey (2) that included a 10 percent sample of (a) all tickets sold by the certificated trunk and local carriers for domestic travel in scheduled services in the continental United States, and (b) all tickets lifted by these carriers for domestic travel and originally issued by airlines not reporting traffic for the CAB survey. Sample design and reliability and collection and reporting instructions are discussed elsewhere (2). However, it is of interest to note that 519 origins or destinations are identified by city codes at the air-hub level, which in many cases consists of more than 1 airport.

Several programs were written that processed the summary CAB tapes and developed a 490-zone origin and destination air trip table. A total of 88,074,230 expanded trips were contained in this table from which 338,910 trips were discarded because of invalid codes. This control total compares favorably with the CAB control total of 88,434,820 trips (2). However, detailed examination of this table revealed a major lacuna: 141 of the 490 zones were not associated with a city code, i.e., an air hub, thus implying that these zones did not attract or generate air trips. The procedure for solving this problem is described later.

The trip tables developed from the CAB sample are at the air-hub level; hence, they do not necessarily represent the "true" origins or destinations of the air trips. Although 141 zones do not contain CAB air hubs, there are clearly intercity air trips that have these zones as their origins or destinations. Furthermore, passengers, whose origins and destinations are in a given zone, will not always use the airport closest to that zone but may often use a more distant airport offering more convenient services. Various empirical studies (3) support this concept, namely, that the traveler is concerned with the door-to-door service provided by the transportation system and not just with the service on 1 segment of his trip. Therefore, an analysis was developed and carried out to convert the airport-to-airport trip tables into trip tables representing "true" origins and destinations. If A and B represent 2 air hubs, and if $\{i\}$ and $\{j\}$ denote the sets of tributary zones to these hubs, then the problem to be solved was twofold: (a) identify those zones that belong to $\{i\}$ and $\{j\}$, and (b) determine the feasible routes between a given i and a given j that pass through A and B.

The gravity model was used to distribute the users of each air hub to their "true" origins or destinations. Note that, in all likelihood, the sets $\{i\}$ and $\{j\}$ would contain the zone in which A and B were located. The trip-attraction input to the gravity model consisted of the population of each zone. The trip-production input consisted of the total number of trips at each air hub, i.e., the row sums of the airport-to-airport trip tables. As noted earlier, 141 of the 490 zones contained no air hub, and their trip-production factors were set equal to zero. The airport access friction factor curve was based on the results of a recent NCHRP report (4) that investigated airport-access trip production as a function of travel time from and to the airport. A composite curve was developed that incorporated data from airports in Atlanta, Buffalo, Philadelphia, Pittsburgh, Providence, and Washington, D.C. This curve showed no significant change in trip production for access times ranging from 15 to 60 min.

Examination of the output of the gravity model revealed that about 62,855,000 out of the total of 88,410,000 air trips had a final or true origin and destination that was the same as the zone in which the airport city was located. The remaining 25,555,000 air trips, or about 29 percent, had a final origin and destination that was other than the zone in which the airport city was located. In other words, approximately 29 percent of the total airport access travel in the country crossed a zonal boundary in the 490-zone structure. These results are plausible, despite a tendency for the gravity model to distribute trips to points more distant than might be desired.

After the gravity model had been run, it can be seen that 2 trip tables were created: (a) an airport-to-airport trip table, and (b) an airport-to-true-origin-and-destination-zone trip table. In other words, information was available on the trips from i to A, from A to B, and from B to j. The next step was to develop a trip table for the true origins and destinations of the air trips, that is, to develop an i-to-j trip table. The number of trips from i to j was defined as

$$T_{ij} = \sum_{A,B \in r} \left(\frac{T_{iA}}{\sum_i T_{iA}} \frac{T_{jB}}{\sum_j T_{jB}} T_{AB} \right)$$

where T_{AB} is an entry in the airport-to-airport trip table, T_{iA} and T_{jB} are entries in the airport-to-true-origin-and-destination-zone trip table, and r is the set of all feasible routes between i and j.

Because of the large number of combinations that had to be considered, application of the preceding relationship resulted in high computer costs. To reduce running times to more acceptable levels required that conditions be formulated so that only the more significant entries from each trip table were introduced into the analysis. The first condition, relating to the airport-to-zone trip table, restricted the number of trips on a given interchange to those greater than or equal to 15 percent of the total trips at the given airport. All zone-to-airport interchanges that did not meet this criterion were discarded, and those interchanges that satisfied the criterion were factored so that the total number of trips at the airport remained unchanged. Imposing this condition counteracted the tendency of the gravity model to distribute trips too widely. This criterion also implied that no more than 6 zones could be the true origin and destination for a given airport, which was acceptable in view of the relatively large size of the zones.

The second condition, relating to the airport-to-airport trip table, was that a given interchange had to pass one of the following tests to be considered feasible: (a) It had to be greater than 0.1 percent of the total airport use at both airports, or (b) it had to be greater than or equal to 10 trips. All possible routes between a given i and a given j were checked for feasibility; in particular, for each i-j, the following were checked: i-A-B-j and i-B-A-j. Unlike the application of the former condition, the application of the latter did not make it possible to estimate total trips and to appropriately factor the feasible interchanges to a control total prior to the completion of the analysis.

With the imposition of the conditions identified in the preceding, it was possible to develop the true origin-to-destination air trip tables. A total of approximately 85,823,000 air trips were contained in this table, as compared to a CAB control total of about 88,435,000. Thus, about 2.9 percent of the total air trips were lost through the application of the second condition. Approximately 116 of the 490 zones did not have any air trips originating in or destined to the zones, as compared to a total of 141 zones in the same category prior to the application of the gravity model, which was a reduction of about 18 percent in the number of zones in this category.

DEVELOPMENT OF INTERCITY MODAL-SPLIT MODEL

For noncorridor movements, competition was assumed to be limited to the automobile, air, and bus modes. Bus travel, which could not be modeled because of insufficient data, was estimated based on factors obtained from the 1967 National Travel Survey. The analysis described in this section was designed to evaluate competition between the automobile and air modes. In the following, W, w, t, and c respectively identify numbers of trips, modal splits, travel times, and travel costs, with the subscripts 1 and 2 referring to air and automobile modes respectively; thus, w_1 denotes number of air trips between 2 zones, whereas w_2 denotes number of automobile trips between 2 zones.

Model Development

It is assumed that a traveler selects a mode by comparing the travel times and the travel costs of both modes. It is suggested that this process be described by using the differences between travel times and travel costs. As may be expected, these variables are highly collinear, primarily because both time and cost are estimated as functions of distance. Collinearity problems are avoided by using a single independent variable that is defined as a linear combination of the differences between automobile time and air time on the one hand and automobile cost and air cost on the other. Mathematically, this may be expressed as

$$x = \alpha \Delta t + \beta \Delta c$$

$$\Delta t = t_2 - t_1$$

$$\Delta c = c_2 - c_1$$

where α and β are 2 specified coefficients.

The 2-mode model is based on the hypothesis that a differential change in the share of one mode, such as air, is proportional to the share of each mode and the differential change in the independent variable x. Mathematically, this can be written as

$$dw_1 = pw_1 w_2 dx \tag{1}$$

where p is the proportionality coefficient to be determined by calibration. Between w_1 and w_2, the following relationship $w_1 + w_2 = 1$ must hold. If $1 - w_1$ is substituted for w_2, Eq. 1 becomes

$$\frac{dw_1}{w_1(1 - w_1)} = pdx \tag{2}$$

The integration of this differential equation yields

$$w_1 = \frac{1}{1 + \exp(-px - a)} \tag{3}$$

where a is a constant of integration to be determined by calibration. This function is represented graphically by a logistic curve.

Conversely, considering the differential change in the share of the automobile mode leads to

$$w_2 = \frac{1}{1 + \exp(-qx - b)} \tag{4}$$

where q and b are parameters corresponding to p and a respectively. These 4 parameters must satisfy the following identity:

$$w_1 + w_2 = \frac{1}{1 + \exp(-px - a)} + \frac{1}{1 + \exp(-qx - b)} = 1$$

which implies $\exp[-(p+q)x-(a+b)] = 1$ which holds if $(p+q)x+(a+b) = 0$ for any value of x; that is, if $q = -p$ and $b = -a$. Hence, for calibration purposes, it is sufficient to calibrate either Eq. 3 or Eq. 4.

The variable x measures the difference between automobile and air; hence, an increase in x implies an increase in air trips and a corresponding decrease in automobile trips. This relationship holds only if p is positive, which implies that negative calibrated values of p must be rejected even if other elements of the calibration are satisfactory.

Sensitivity

Sensitivity is defined as the change in modal split due to a unit change in x. If "small" changes are assumed, the differential expression given by Eq. 1 can be used; i.e., in the case of air modal split

$$dw_1 = pw_1(1 - w_1)\,dx$$

The rate of change in modal split is, therefore,

$$\frac{dw_1}{dx} = pw_1(1 - w_1)$$

The graph of this function varying between 0 and p/4 is represented by a parabola as shown in Figure 1.

The relative change in modal split for a change dx in x is given by

$$\frac{1}{w_1}\frac{dw_1}{dx} = p(1 - w_1)$$

The graph of this function is shown in Figure 1 for the same values of p as used in the preceding graph.

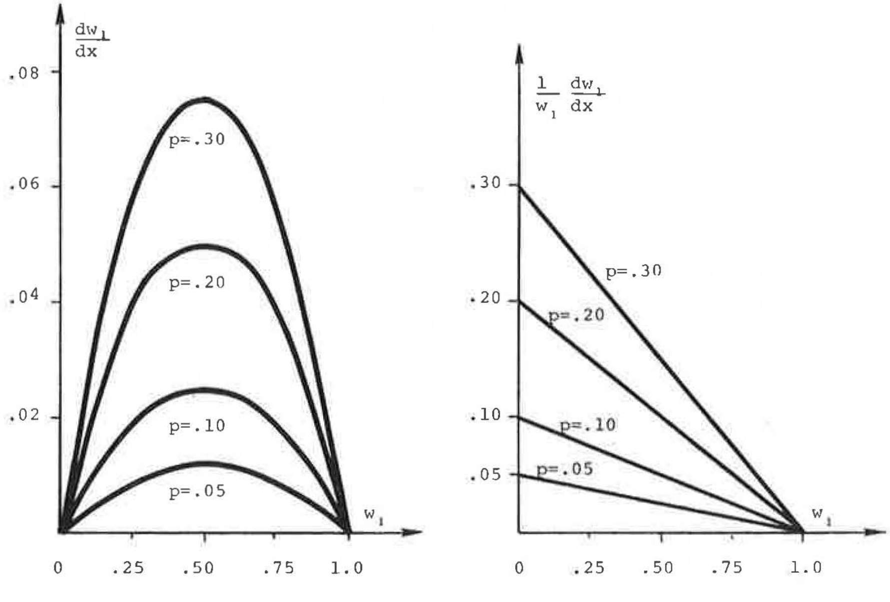

Figure 1. Parametrical sensitivity curves of the diversion model.

As an example, if dx = 6, which corresponds to an improvement of air travel time by 1/2 hour (as it will be seen in the retained model), and if p - 0.02, the values of dw_1 and dw_1/w_1, expressed in percentages, are as follows:

w_1	dw_1	dw_1/w_1
0	0	12
10	1.08	10.8
20	1.92	9.6
30	2.52	8.4
40	2.88	7.2
50	3.00	6.0
60	2.88	4.8
70	2.52	3.6
80	1.92	2.4
90	1.08	1.2
100	0	0

The change in modal split given by Eq. 1 implies only an aggregate change in x. However, if it is desired to evaluate the variations of w_1 because of variations of a p or x or both that enter in the expression of the modal split, the total differential of w must be used. In such a case, the change in w is

$$dw_1 = \frac{\partial w_1}{\partial x} dx + \frac{\partial w_1}{\partial p} dp + \frac{\partial w_1}{\partial a} da$$

Note that the preceding expressions contain implicitly the components of x (i.e., Δc, Δt, α, and β).

Calibration

The model was calibrated by simple linear regression. For this, Eq. 3 can be written as

$$1 - \frac{w_2}{w_1 + w_2} = \frac{1}{1 + \exp(-px - a)}$$

which is linearized by taking the natural logarithm of the reciprocal of each side, i.e.,

$$\text{Log} \frac{w_1}{w_2} = px + a$$

In the expression of x, the coefficient α was set equal to 0 or 1 whereas β was searched for (by increments of 0.5 starting at 0) to obtain the best possible fit.

Because of the availability of air and highway network data for 1967, base-year air, automobile, and total person trip tables were developed for 1967, which was chosen for calibration of the intercity air-versus-automobile modal-split model. Because a major purpose of the study was to analyze the competition between the air and automobile modes and because over 96 percent of the air travel in the United States took place among 144 SMSA's or air hubs, it was decided that the interchanges used to calibrate the air-versus-automobile modal-split model should be selected from a sample of these 144 air hubs.

Two calibration data sets were developed, differing only with respect to their automobile impedances that included or excluded overnight times and costs. Each of the 2 data samples was stratified into 7 categories of trip lengths. Finally, to properly reflect the relative importance of a data point required that observations in each calibration data set be weighted according to the total number of trips relative to a given interchange.

TABLE 1

CALIBRATION RESULTS FOR TRIP LENGTHS GREATER THAN 99 MILES

Independent Variable	p	Standard Error of p	a	R
Δc	-0.0604	0.0010	2.697	-0.66
Δt	+0.1983	0.0029	2.780	+0.68
$\Delta c + 1.0\Delta t$	-0.0688	0.0014	2.244	-0.57
$\Delta c + 2.0\Delta t$	-0.0547	0.0019	1.331	-0.37
$\Delta c + 5.0\Delta t$	+0.0410	0.0012	1.461	+0.43
$\Delta c + 10\Delta t$	+0.0234	0.0004	2.371	+0.61
$\Delta c + 12\Delta t$	+0.0192	0.0003	2.470	+0.63

Results of Calibrations

Observations including automobile overnight cost and time yielded generally poor results. The value of p was not positive for all trip-length strata; even when p was positive, the corresponding correlation coefficients were much too low to be acceptable. When automobile overnight costs and times were excluded, regression runs performed on stratified samples yielded acceptable results for the short-length trips (0 to 99 miles). However, for the other strata as well as the unstratified sample, the same difficulties as in the preceding cases were encountered.

To partially remove the "noise" in the data, we decided to exclude observations relative to trips under 100 miles. The results of selected runs are given in Table 1. The highest correlation coefficient (among those associated with positive values of p) corresponded to $\beta = 0$; i.e., the difference between automobile and air times was the independent variable. Note that, because of the high value of p, the model would be extremely sensitive to time. However, if the independent variable were the difference in cost, p would be negative, and the equation should be rejected. To incorporate time and cost in the equation, together with the correct sign for p and an acceptable regression coefficient, required that α be increased to the vicinity of 10, as given in Table 1. The values of R increased rapidly and stabilized around 0.625 when α is more than 10.

The equation corresponding to $\alpha = 12$ was selected because it gave an acceptable sensitivity. However, the large standard error of the equations must be noted (2.54 for a mean log w_1/w_2 of 0.65, a result of the dispersion of the data). The selected equation (for trip lengths greater than 99 miles) is

$$w_1 = \frac{1}{1 + \exp(-0.0192x + 2.470)}$$

where $x = \Delta c + 12\Delta t$. The graph of the equation is given in Figure 2 (times and costs are in hours and dollars respectively).

The model was tested by comparing estimated trips to observed trips for each interchange. The coefficient of correlation between estimated and observed air trips is about 0.80; that is, about 64 percent of the variance in the actual number of air trips was explained by the estimating equation, a considerable improvement over the coefficient of correlation of the logarithmic equation, which is only 0.625 (about 40 percent of the variance explained). Between zones that were less than or 99 miles apart, a constant 100 percent of the interchange was automatically assigned to the automobile mode.

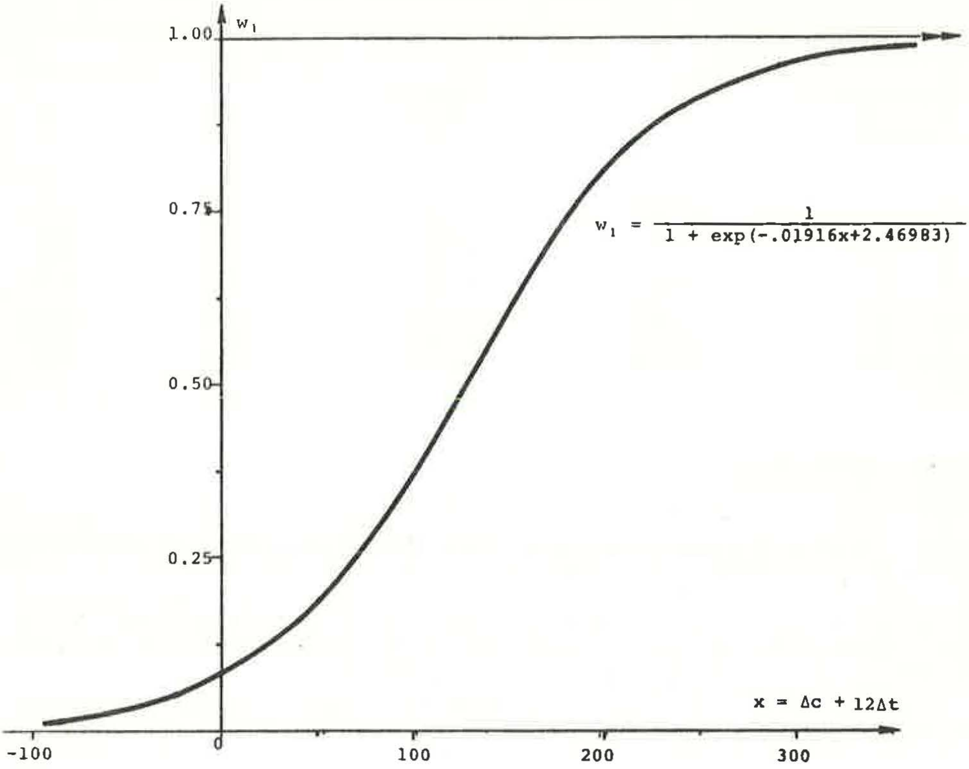

Figure 2. Selected diversion curve of the proportion of air trips.

RECOMMENDATIONS

Several recommendations based on the experience acquired in this study are made for further work. These observations should in no sense be viewed as a comprehensive approach to a demand analysis of national travel.

Results of this investigation emphasize the importance of developing appropriately disaggregate and accurate input data for any analysis of intercity travel demands. The availability and quality of data have been and, in all likelihood, will always be a constraint on the level and quality of an analysis. However, this should not prevent the analyst from developing the best possible solution within the given resources. In view of this fact, any future project to analyze intercity travel demands should carefully incorporate data considerations within the overall study framework, although it clearly would be a mistake if the entire project were limited to data acquisition. Of the 3 types of data required to perform a transportation analysis (namely, activity, network characteristics, and travel), existing travel-pattern data, particularly by automobile, are probably the most difficult to acquire. This analysis suggests the requirement for data on national travel stratified by origin and destination, mode, purpose, and income of the travelers. Other stratification variables might include group size, duration, peak versus off-peak, and occupation.

Additional variables, particularly trip purpose, group size, and income, should be introduced into the demand analysis. Proper use of these variables could, for example, provide a rationale for the parameters of the modal-split model to change through time, instead of imposing the parameters calibrated for 1967 on analyses performed for 1975, 1980, and 1990.

Certain analytical techniques should be introduced into a framework for an intercity travel demand analysis. The access time for air travel constitutes a significant proportion of the total travel time for air, particularly in the 200- to 700-mile distance range in which automobile travel is particularly competitive with air travel. The Access Characteristics Estimation System (ACCESS) that was recently developed and implemented (5) provides a computer-based analytical methodology that can be used to accurately estimate access characteristics for intercity person movements without the relatively expensive acquisition and processing of large amounts of transportation network data.

Although the CAB data probably provide the best available inventory of national travel for a given mode, this information pertains to airport-to-airport travel and not to the true origin and destination of the trip. The technique proposed in this report provides an efficient and potentially reliable method for converting airport-to-airport trip tables into true air origin-and-destination trip tables.

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