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Air Passenger Distribution Model for a Multiterminal Airport System

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This paper reports on work aimed at calibrating the concepts of a theoretical air passenger airport distribution model with observations on actual passenger behavior as derived from inflight surveys. The original model, as developed for the U.S. Department of Transportation, has been modified to reflect more realistic passenger behavior patterns. Specifically, the simplistic assumption that passengers always select the most convenient airport regardless of the relative convenience (or inconvenience) of other available facilities or service has been replaced by a formulation that permits a more flexible distribution among facilities. The calibration of this modified distribution model with inflight survey data for the New York-New Jersey metropolitan area shows that model estimates that correspond closely with actual passenger distributions can be obtained, provided proper sensitivity coefficients are selected.

In 1970, Peat, Marwick, Mitchell and Company, under contract to the U.S. Department of Transportation, developed a computerized intercity transportation effectiveness (ITE) model, of which a separate access-assignment (AAM) model deals with airport access problems, other factors related to airport choice such as congestion, and the potential role of sepecialized access systems such as off-airport satellite terminals (1).

The access-assignment model has two components: (a) a demand assignment model and (b) a cost benefit analysis model.

The following report discusses considerable expansions and modifications of the demand assignment model, developed by the Port Authority of New York and New Jersey under contract to the Tri-State Regional Planning Commission. Besides these technical expansions and modifications, the report also deals with the adaptation and application of the model to the Tri-State region. Finally, as its main focus, it discusses some results of the model's premises in terms of observations on actual air passenger behavior observed in Port Authority inflight surveys.

GENERAL STRUCTURE OF THE ITE-AAM MODEL

This model attempts to simulate a transportation system in which passenger behavior and physical elements of the system interact. Such an interactive process is described by an iterative simulation in which one set of variables determines the level of another set in one phase (iteration), while the process is reversed in the next phase. For example, in the first iteration the passenger's airport choice is determined solely by convenience of access. Passenger volumes assigned on that basis then determine congestion levels at each of the airports in the system (aircraft, roadway, check-in delays) and frequency of flights at each facility. These convenience and inconvenience factors are then added to the access factors in redistributing passengers in the next iteration on the basis of total convenience, all expressed in monetary terms. The passengers for whom differences among facilities were marginal may change their choices from one iteration to another.

Total cost as conceived in the model includes all elements of cost incurred by the passenger from point of origination to aircraft take-off. These costs consist of out-of-pocket user costs as well as the cost of time involved in this process. Three such costs are centroid-oriented costs such as over-the-road access time and costs primarily physically (geographically) determined; nonvolume dependent costs such as parking fees, the fare of public transportation, and time lost in moving through the terminal, which do not depend on volume of (assigned) passengers, but are simply given at any point in time; and volume-dependent costs such as costs of congestion delay and schedule waiting time, which depend on passengers, vehicles, and flights assigned by the previous iteration.

The model as originally developed assigned passengers from each origin zone on a winner-take-all basis; i.e., all passengers from each zone were exclusively assigned to the one airport or satellite and airport combination that produced minimum cost to the passenger.

ITE MODEL AND ACTUAL AIR PASSENGER ACCESS PATTERNS

Whereas the original model assigns passengers to facilities on the basis of a priori assumptions, the recurring inflight surveys conducted at the New York-New Jersey metropolitan airports by the Port Authority in cooperation with the airlines contain a wealth of completely empirical information on the passengers' airport choice in the real world, providing information on local origin, choice of airport, ground access mode, access travel time, destination of air trip, purpose of trip, etc. (2).

The obvious question presenting itself is whether the a priori asssumptions of the ITE model are confirmed by these empirical observations and, if not, how the model could be modified to incorporate the results of such observations in the real world.

The basic concept of the original model, that a passenger will always select the facility most convenient to him or her regardless of the relative degree of convenience as compared to alternate facilities (i.e., winner take all), is most likely an oversimplification of passenger behavior. The Port Authority inflight surveys show ample evidence that, when differences in convenience among alternate facilities are small, passengers distribute themselves among the available facilities rather than select exclusively the theoretically most convenient airport as determined by access congestion and schedule frequency. In the New York-New Jersey area this is particularly evident in the distribution of Manhattan passengers. As these account for more than a third of the region's traffic, this is obviously of major significance in any distribution model that is to have practical application in the Tri-State area.

MODIFIED DISTRIBUTION FUNCTION

A more general model formulation that permits much more flexibility and presents many more opportunities for verification with and adaptation to empirical data is one similar to a model developed by the Rand Corporation in a 1967 study for the Port Authority (3). Adapted to the basic structure of the ITE model, this formulation says that, for each origin zone, the distribution among alternate airport facilities will follow the function

$$W_{ij} = (C'_{ij}/C_{ij})^{\alpha} \Big/ \left[\sum_{j=1}^{P} (C'_{ij}/C_{ij})^{\alpha}\right] \qquad (1)$$

where

W_{ij} = fraction of passengers from centroid i who will select airport j,
i = area (centroid) = 1, . . . , C,
j = airport = 1, . . . , P,
C_{ij} = cost for a passenger from centroid i to use airport j (roadway time, process time, waiting time, etc.),
C'_{ij} = cost of the cheapest airport j for a passenger from centroid i, and
α = an index of passenger sensitivity with respect to cost differences among airports.

This model says in essence that the fraction W of total passengers originating in a particular centroid i who are to select a particular airport j is a function of the cost involved in using that particular airport versus the cost of using any of the other competing airports.

Although the particular functional relationship chosen is not necessarily the only one possible, it is clear that the relationship, as expressed in general terms, is logical; in a multiterminal situation, the passenger is assumed to be confronted with a choice among available airports and, in making a choice, will weigh the airports for relative convenience in a particular situation. The cost elements specified in the ITE model are obviously major components of this factor convenience.

Some more specific mathematical properties of this model are also appealing, as they further demonstrate the generality in the logic of the model as a mathematical description of passenger behavior.

In the first place, it satisfies the condition of conceptual logic that if passengers were infinitely sensitive to differences in access time, then they would always select the nearest airport. In this case, the coefficient α would approach infinity (or become infinitely large), and under that condition the value of W_{ij} approaches zero for all airports except the nearest one, for which it approaches a value of one. This is the all-or-nothing or winner-take-all concept.

On the other extreme, if passengers were absolutely insensitive to differences in access times (if α were assumed to approach zero), the model would produce an equal distribution of passengers among the three airports, regardless of differences in access time.

The mathematical formulation of the model, finally, ensures that the sum of the individual shares of each airport for each particular centroid by definition always equals one, or, in other words, there never is an undistributed residual

$$\sum_{j=1}^{P} W_{ij} = 1 \qquad (2)$$

Numerical examples illustrating these properties are given by Augustinus (4).

Although a passenger's sensitivity with respect to access time is probably high, it is not a priori infinitely high; therefore it is likely that in real life the coefficient will have a value somewhere between zero and infinity.

To provide an indication of the impact of changes in the value of α on passenger allocation estimates, Rand in their report produced a figure (Figure 1) showing the passenger distribution between two airports (W_{ij}) as a function of the ratio of access times to each airport (T_{i1}/T_{i2}). It is clear from this figure that, with increasing values of α, except for the very low ones, the curve rapidly approaches the shape of the zero-one distribution that results from an assumed $\alpha = \infty$. Probably, this is also a fairly good reflection of real life because most of the passengers, in particular when access differences are significant, will select the nearest airport. If, however, major segments of the passenger market are located in centroids where the differences in convenience among available airports are

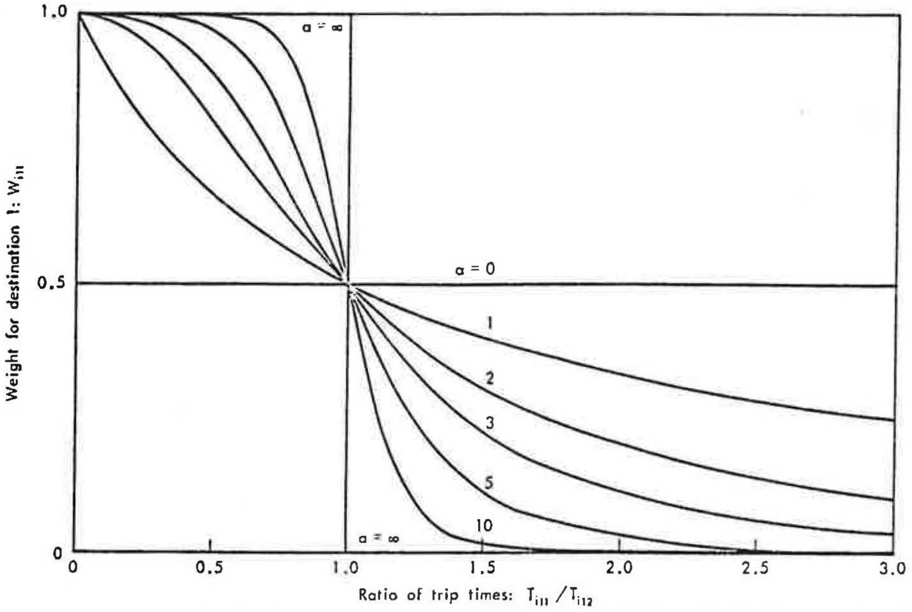

Figure 1. Behavior of the volume allocation weighting function for different values of α.

marginal or at best small, as is the case in New York for many origin zones in the central business district, this assumption becomes clearly defective.

MODEL CALIBRATION AND MEASUREMENTS

Having modified the model in such a way that it can reflect proportionate distributions of passengers among airports rather than only exclusive choices of one facility, a number of steps had to be taken to calibrate this modified model with actual survey data and to establish optimum values for the α coefficient.

Aviation Planning Zones

For purposes of this study, the Tri-State region was broken down into 131 analysis zones (aviation planning zones). In addition, 11 zones bordering on but outside the region were included, as Port Authority inflight surveys indicate that these zones generate not insignificant numbers of passenger trips through the three metropolitan airports. The zone structure selected was primarily based on the availability of data (the smallest zone unit for passenger origin data was the zip-code designation), the trip-generating density, and the geography of the access network. With a total of 142 origin zones and three airports serving the region, the model had to deal with 142 × 3 = 426 origin-to-airport links.

Trip Generation by Zone

The number of air passenger trips per aviation planning zone, rather than being computed from a theoretical trip generation model (as in the original ITE-AAM model), in this calibration study was determined from actual inflight survey data on passenger originations collected in 1972 (2).

As expected, the core area, and specifically Manhattan, is the largest traffic generator relative to its size, generating approximately one-third of the total locally generated trips. Moving out from the core area, trip generation density generally diminishes.

Besides passenger originations, the inflight surveys provide information on other items, such as trip destination, trip purpose, and residences of passengers. In the calibration study, the destination of the air trip (as represented by length-of-haul brackets) has been used to stratify the passenger market to determine differences in sensitivity to airport access convenience. Stratification with respect to other passenger characteristics that conceivably could reveal differences in access sensitivity, such as trip purpose (business versus personal air trips) or passenger residence (Tri-State region residents versus visitors to the region from elsewhere), have not yet been tested in this study.

Zone Centroids

For each zone a geographic centroid was selected from which data on travel times and cost to airports and satellite terminals were measured. Centroids were selected on the basis of two factors: (a) traffic-generating density, defined by the areas of relatively high traffic generation within a zone, and (b) geographic location with respect to major highway intersections.

Network Data: Access Times and Cost

For all practical purposes, airport access in 1972 was exclusively over highways. All travel times used in the calibration phase, therefore, reflect only highway times, by private car, taxi, or airport limousine. Times used are arithmetic averages of peak and off-peak travel times, as Port Authority airport statistics indicate that approximately one-half of the air passengers travel to and from the airports during highway peak hours and the other half during the off-peak hours.

The data do reflect today's congestion patterns in the region and thus do assume differing speeds over different highway segments.

As to the costs of access for 1972, the cost of using private automobile was computed on the basis of a cost of 4.0 cents/km (6.5 cents/mile), which included the cost of maintenance, tires, and gas, but no fixed cost such as depreciation, garage insurance, etc. This reflects the cost as presumably perceived by the passenger. Other (unrelated) Port Authority modal split studies produced the most realistic distributions between public and private modes when applying this concept for private automobile users. Taxi rates were computed on the basis of the then existing (1972) fare structure of 50 cents for the first 0.12 km (0.2 mile) plus 10 cents per additional 0.12 km, the structure in effect in New York City, but fairly representative for most other taxi fares in the metropolitan area. For Manhattan access cost, a taxi-private car mix of 70:30 was assumed, and a (reverse) 30:70 ratio for Brooklyn, Queens, the Bronx, and the nearby urban areas across the Hudson. Access costs to all other parts of the region were based exclusively on the use of private automobile. Highway, bridge, or tunnel tolls were added where applicable.

Airline Schedules

Although airline schedules can be generated by the ITE model internally, in the calibration of the model with passenger survey data, airline schedules by distance range were fed into the model as they actually existed in 1972. This procedure should produce better measurements of passenger behavior, as actual schedules in the model simulate congestion and level of service conditions as actually experienced by passengers in making their selection of airport decisions during the survey period.

Market Breakdown

In the calibration runs the total domestic passenger market was broken down in five markets by length of haul: under 300 km (250 miles), 300-800 km (250-499 miles), 800-1280 km (500-799 miles), 1280-2400 km (800-1499 miles), and over 2400 km (over 1500 miles). Such a breakdown was meaningful for these reasons.

First, from a theoretical point of view it is reasonable to postulate that short-haul passengers would be more sensitive with respect to access time and cost and more discriminating in their choice of airport than long-haul passengers. If confirmed, this should manifest itself in the values of the coefficients in the model that produce passenger distributions most corresponding to those observed in the passenger surveys.

Second, the level of service at each airport is not uniform in each market, partly for historical, partly for operational reasons (e.g., no transcontinental service at La Guardia). Thus, empirical measurements made separately for each market permit changes in service patterns in the future if indicated by expected technological developments or plans for airport expansion.

Calibration Results

After feeding the input data as described into the ITE model, the distribution of the air passengers in each market among the three airports, as simulated by the model under varying values of α, was calibrated against the actual distributions observed in the 1972 inflight survey. The results are shown in Table 1.

The model estimates appear to reflect actual distributions fairly well for any of the selected α values, which indicates a basic soundness of the logic of the model as a simulation of actual behavior.

It is also evident from the table that certain α values produce numerically better results than others. This supports the original premise of the study that, once a proper theoretical framework (model) has been developed, passengers' sensitivities to convenience differences can be estimated from actual survey observations.

It should be emphasized that there is no a priori connection between the model estimates and survey observations other than the common base of passenger originations (the origin numbers used as input in the model were taken from the survey). The airport distributions developed by the ITE model are generated through the model's internal logic. The survey data show which airports were actually selected by the passengers.

Although no overall measure of goodness of fit has been incorporated into the model at this time, the results strongly indicate that very high values of α (most closely corresponding with $\alpha = \infty$; i.e., the all-or-nothing hypothesis) generally produce less realistic results than α values in the general range of 5-15. Where deviations of some significance occur with respect to an individual airport, a more detailed analysis of the underlying market structure (business versus personal travelers, residents of the region versus visitors) might well explain some of such deviations and enable us to further refine the measurements and reduce the differences.

Although some irregularities occur, the data do further indicate that in the lower distance ranges the best-fitting results are produced by higher values of α, while in the longer ranges lower values of α produce better results. This confirms the a priori expectation that access and convenience factors are more important to short-haul than to long-haul travelers, as they account for a relatively larger share of the time and cost of the total trip.

It may be mentioned that, in deriving this conclusion, less weight was given to the longest range, where service at Kennedy and Newark in 1972 definitely favored Kennedy. Equal service levels might well have reduced actual passenger levels at Kennedy to the benefit of Newark.

Table 1. ITE model estimates versus actual regional totals.

			Market				
Item	α-Value	Terminal Location	Under 300 km	300-800 km	800-1280 km	1280-2400 km	Over 2400 km
Actual		LGA	189.0	167.3	211.2	232.5	27.4
		JFK	20.6	27.4	18.7	205.8	182.7
		NWK	90.3	81.7	95.1	120.4	45.4
Model estimates	25	LGA	200.1	205.0	221.7	246.7	-
		JKF	18.7	10.0	23.6	200.1	210.3
		NWK	81.0	61.9	80.0	104.5	45.0
	15	LGA	190.6	195.3	214.8	241.4	-
		JFK	30.5	20.2	31.1	219.1	208.3
		NWK	79.1	61.4	79.6	98.6	46.9
	10	LGA	176.4	181.0	202.6	233.8	-
		JFK	45.0	33.8	43.2	229.5	203.3
		NWK	78.2	61.8	79.3	95.9	52.1
	5	LGA	145.8	147.9	171.2	223.2	-
		JFK	73.0	60.2	70.8	231.0	186.3
		NWK	81.0	68.6	84.0	105.1	69.0

Note: 1 km = 0.62 mile.

Table 2. ITE model estimates versus actual Manhattan only.

			Market				
Item	α-Value	Terminal Location	Under 300 km	300-800 km	800-1280 km	1280-2400 km	Over 2400 km
Actual		LGA	150.4	118.7	123.6	100.8	13.5
		JFK	16.4	19.2	10.7	60.1	65.6
		NWK	15.1	21.2	17.3	12.8	2.8
Model estimates	25	LGA	175.7	156.2	148.C	173.7	-
		JFK	1.3	0.4	0.2	3.8	77.4
		NWK	4.8	2.2	3.5	3.9	4.4
	15	LGA	165.6	150.0	143.1	159.1	-
		JFK	8.4	3.9	2.4	15.1	73.8
		NWK	7.9	4.8	6.1	7.1	8.0
	10	LGA	148.8	137.4	132.3	140.5	-
		JFK	19.8	11.7	8.4	28.6	68.8
		NWK	13.2	9.6	10.9	12.3	13.0
	5	LGA	113.8	105.5	102.4	107.7	-
		JFK	40.1	29.6	24.9	47.1	58.1
		NWK	28.0	23.5	24.4	26.5	23.1

Note: 1 km = 0.62 mile.

Table 2 shows the model results versus actual for Manhattan only, which accounts for more than one-third of total regional traffic generation in all distance ranges. Another reason why the model's performance in Manhattan has special significance is that for many zones the differences in accessibility to the airports are relatively small and thus the model estimates are more sensitive to the value of α to be selected. If differences in convenience among airports are large, differences in assumed values of α do not produce significant differences in model estimates.

The optimum values for α appear to be here somewhat lower than in the total regional numbers and generally fall in the 5-10 range. The declining trend as a function of length of haul is also here much in evidence. Recognizing that the actual observations as summarized are subject to sample fluctuations and, moreover, that actual behavior may reflect factors not accounted for in the model, it may be postulated that the α values basically could be represented by a linearly declining curve as a function of length of haul.

The Port Authority report to the Tri-State Regional Planning Commission also included some examples of how a model, as developed here, could be applied in estimating the traffic potential for a couple of off-airport satellite terminals.

The main objective of this paper, however, was to report on some results of the development of a passenger distribution model that could be calibrated against survey data on actual passenger choice patterns. We hope such attempts to merge theoretical model concepts with empirical data on actual passenger behavior will contribute toward the development of more realistic demand forecasting tools for use in transportation planning.

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System for Planning Local Air Service

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Local air service is characterized by a strong sensitivity of traffic to a number of factors such as frequency, time of departure, trip time, and alternative transportation available by ground modes. Consequently, in planning local air service, the demand function and the scheduling constraints must be considered in more detail than is necessary with other types of air transportation. This paper presents a system developed at the University of Pittsburgh for planning local air service. The system was used in studying the potential of air service between the provincial capitals of Austria.

The motivation for this study was an overall regional development plan drawn up by the province of Steiermark in Austria. Although Austria is a federal republic of