present major concerns; it is not intended to be comprehensive or exhaustive.

Multimodal Windowing

The extension of the present capabilities of TAP to multimodal analysis seems, naturally, to be the next order of business. The unimodal capabilities of TAP are clearly insufficient for modern planning. The problems of windowing for transit analysis might be rather complicated; specifically, the structure of transit networks will require more involved network culling techniques, compared to the techniques used for highway networks. Moreover, conventional mode-choice models are rather sensitive to area aggregation (because of the importance of access-egress impedance). They might perform poorly within the framework of windowing, where skim trees are available only for the aggregated zones, which might be rather large.

Trip Distribution for Microassignment

Within TAP, the ALDGRAV model produces trip tables that can be used for microassignment. In some instances, in order to attain sufficient precision in the microanalysis, analysis zones are very small, only a few blocks. There is, as yet, very little experience with the performance of ALDGRAV (and practically all trip distribution models) in such small-scale analysis. A careful study of this issue is much needed.

Need and Justification for Precision

There are a number of areas in which certain increases in the complexity and costs of the analysis might make the results of the analysis more precise. Examples include

1. Making the relative weights of travel cost and time a function of income in impedance calculations,
2. Relating fixed impedance penalties to measurable zone attributes such as cost and availability of parking,
3. Further stratifying home-based non-work trips to short and long in order to attain better duplications of observed trip-length distributions, and
4. Using a number of paths rather than only one path for calculating impedance (the ALDGRAV theory, for example, suggests that both the minimum time path and the minimum cost path should be considered).

In spite of the long experience in travel forecasting, it seems that these issues have never been studied thoroughly. Various assertions, based primarily on so-called behavioral and theoretical considerations, on these subjects have been made; however, there is a need to study these issues by comparatively analyzing them with observed data, as well as by weighing the potential increase in the precision of the results versus increasing the cost of acquiring data and the complexity of the analysis.

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Recent Structural and Empirical Findings in Trade-Off Analysis

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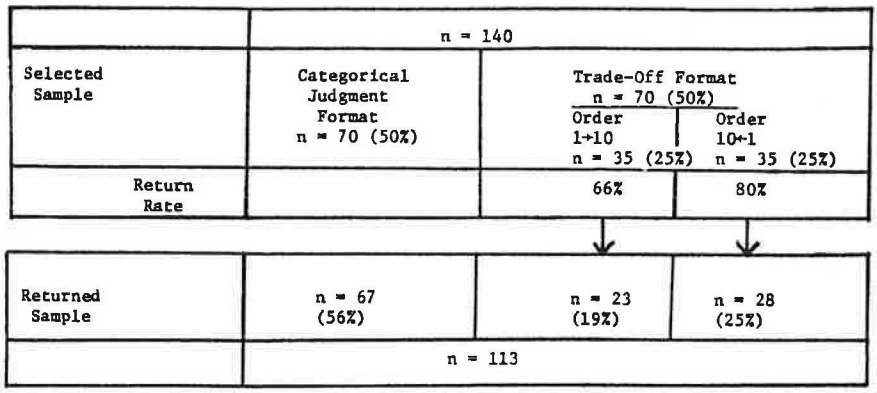
This paper reports on three recent investigations by the New York State Department of Transportation's Planning Research Unit into empirical and theoretical aspects of trade-off analysis, a multidimensional attitude scaling procedure. First, the possible influence of the length of the questionnaire was investigated. Fatigue bias was found to be substantial, and use of abbreviated questionnaires and a random order of items is suggested. Second, tests were made for a degradation in response accuracy, with substantially shortened questionnaires. No significant loss of information was found in reductions of up to 50 percent of a 10-matrix design. Third, the effects of different utility integration rules were studied. Some differences were found but they are too small to be of practical importance. The research concludes that the trade-off procedure is a powerful, robust approach that can be used with confidence.

Figure 1. Split-half partitioning of the sample.



Numerous methods of attitude and opinion scaling have been used with increasing frequency by transportation researchers in recent years. A newly developed approach, trade-off analysis, has been used extensively by Market Facts (1, 2), and a similar algorithm was subsequently operationalized by the Planning Research Unit of the New York State Department of Transportation (NYSDOT) (3).

Using data about rank-order preferences of combinations of attribute levels, this procedure estimates the utilities each respondent places on the attributes describing a policy. In a second step, these individual utilities are then aggregated to estimate market shares for proposed objects or policies, defined in terms of these attributes. NYSDOT has used this method extensively in its studies of travel preferences and behavior (4, 5, 6).

However, due to the relative newness of the procedure, until recently little analysis has been conducted on the properties of the procedure itself. This paper summarizes a number of such studies by NYSDOT. Specifically, the following problems are dealt with:

1. Respondent fatigue because of the questionnaire length ("item position bias"),
2. Effects of reductions in the questionnaire size on the relative accuracy of the scaling procedure, and
3. Sensitivity of the procedure to various functional forms of the utility integration model.

The research summarized in this paper is described separately in more detail in other reports (7, 8).

DATA

The data for these analyses were obtained from a study of white-collar employee attitudes toward alternative work schedules (5). A random sample of 140 employees of the main office of NYSDOT was administered a questionnaire on travel patterns, general attitudes toward work schedule changes, perceived impacts of these changes, and detailed attitudes toward five characteristics of work schedules. The five attributes and their levels are as follows:

1. Work week:
   - 4 days/week—Monday - Thursday,
   - 4 days/week—Tuesday - Friday, and
   - 5 days/week—Monday - Friday;
2. Hours per day:
   - 7 hours/day,
   - 8 hours/day, and
   - 9 hours/day;
3. Times worked:
   - Fixed (everyone starts and stops work at the same time),
   - Individual-specific (fixed for each person but allowing for differences between persons), and
   - Variable (start and stop work whenever the employee wants, subject to working a full schedule each day);
4. Parking location:
   - Unassigned spaces in assigned lots,
   - Special location for carpools, and
   - Assigned place in assigned lots; and
5. Cost of parking:
   - Free,
   - $1/month, and
   - $1/week.

The present working arrangement at NYSDOT's main office consists of (a) 5 days, Monday-Friday; (b) 7.5 hours/day; (c) fixed schedule; (d) unassigned parking in assigned lots; (e) free parking.

To investigate the structure of the trade-off model, a split-half approach was used to partition the sample, in which each respondent was randomly assigned one of these three versions of the questionnaire: categorical judgment format, trade-off format (10 matrixes in order 1→10), and trade-off format (10 matrixes in order 10→1). Figure 1 shows the distribution of the selected and returned trade-off sample (n = 51). Characteristics of respondents in each group were statistically similar to the population on three characteristics.

ITEM POSITION BIAS

The questionnaire required by trade-off analysis is very lengthy, and thus we should expect to observe fatigue on the part of the respondents. Two different versions of the trade-off questionnaire, in which the order of matrixes was reversed, were administered to test this hypothesis.

The idea underlying this procedure is that, if an attribute included early in one questionnaire but rather late in the other questionnaire is changed, the result should be two different estimates of the preference shares for the same future. The difference in preference should be most pronounced for attributes presented at the extreme ends of the questionnaire and less pronounced for attributes presented in the middle of the questionnaire.

To determine the position of each attribute in the questionnaire, a ranking of from 1 to 10 was computed as below.

Attribute	Original Rank (Group 2)	Rank Form Reversed (Group 3)	Difference in Rank
1	2.5	8.5	-6
2	4.75	6.25	-1.5
3	6	5	1
4	6.75	4.25	1.5
5	7.5	3.5	4

Ten test policies were then constructed, changing one attribute level at a time. Differences in the predicted preferences for group 2 versus group 3 were plotted against average differences in rank for each attribute. Results are shown in Figure 2. The largest difference in the preference shares does indeed exist for attribute 1 (the attribute with the largest difference in rank), followed by attributes 2 and 3. Attributes 4 and 5, however, do not follow the hypothesis, probably because state workers are extremely sensitive to them and any change from the present status would be uniformly rejected.

Thus, the result of this study is that lengthy applications of trade-off analysis are likely to contain position bias and that appropriate measures (e.g., reversing order) should be taken to remove position bias. One additional method of avoiding such a bias, reducing questionnaire length, is examined in the next section.

Table 1. Mean utilities for attribute levels under full and reduced data sets.

Attribute	Percentage of Data Remaining				
	100	60	50 Stepwise	50 Circular	40
1. Work week					
4 days, M-Th	0.3806	0.3862	0.3772	0.3798	0.3726
4 days, T-F	0.3697	0.3747	0.3584	0.3693	0.3597
5 days, M-F	0.2496	0.2390	0.2644	0.2509	0.2677
2. Hours per day					
7	0.4321	0.4583	0.4199	0.4477	0.4470
8	0.5292	0.3275	0.3253	0.3254	0.3085
9	0.2387	0.2142	0.2548	0.2269	0.2446
3. Work schedule					
Fixed	0.2917	0.2810	0.2857	0.2962	0.2916
Specific	0.3148	0.3140	0.3107	0.3151	0.3122
Variable	0.3935	0.4049	0.4036	0.3887	0.3962
4. Parking location					
Anywhere in lot	0.3899	0.4025	0.3924	0.3949	0.4145
Specific if carpool	0.2743	0.2657	0.2723	0.2731	0.2548
Assigned	0.3358	0.3317	0.3353	0.3320	0.3306
5. Parking fee					
Free	0.5823	-[a]	0.5636	0.5919	0.5632
$1 per month	0.2988	-[a]	0.2862	0.2799	0.2753
$1 per week	0.1189	-[a]	0.1503	0.1281	0.1614

[a]Since all matrixes relating to attribute 5 were excluded, no mean utility was calculated.

REDUCTION IN QUESTIONNAIRE LENGTH

Not only could the effects of respondent fatigue be reduced by a shorter questionnaire (i.e., reduction of the number of matrixes presented), but substantial economic savings in survey administration and processing could result from such a reduction as well.

To test the sensitivity of the trade-off technique to data reduction, four reductions of 40, 50, 50, and 60 percent were performed by eliminating matrixes from the existing data set. A test policy was selected in which the time schedule (attribute 3) was changed from fixed to completely variable. The mean utilities obtained are given in Table 1. Overall, the differences in mean utilities between the full set of data and the reduced sets are small. Expectedly, this leads to the same predicted preference patterns for the full and all reduced data sets, as shown in Figure 3. In general, even a 50 percent reduction in questionnaire length does not lead to a significant loss of information.

A circular design in the selection of the attribute pairings is probably superior to other designs, in the absence of prior knowledge about the dominance of any attribute. The 60 percent reduction possibly does not lead to a significant loss of information, but its performance depends critically on the dominance of the pivotal element(s); in the absence of prior knowledge, such a design is not advisable.

FUNCTIONAL FORMS OF THE MODEL

All the preceding tests were done by using a multiplicative utility integration rule:

Figure 2. Differences in policy preferences versus differences in attribute location.

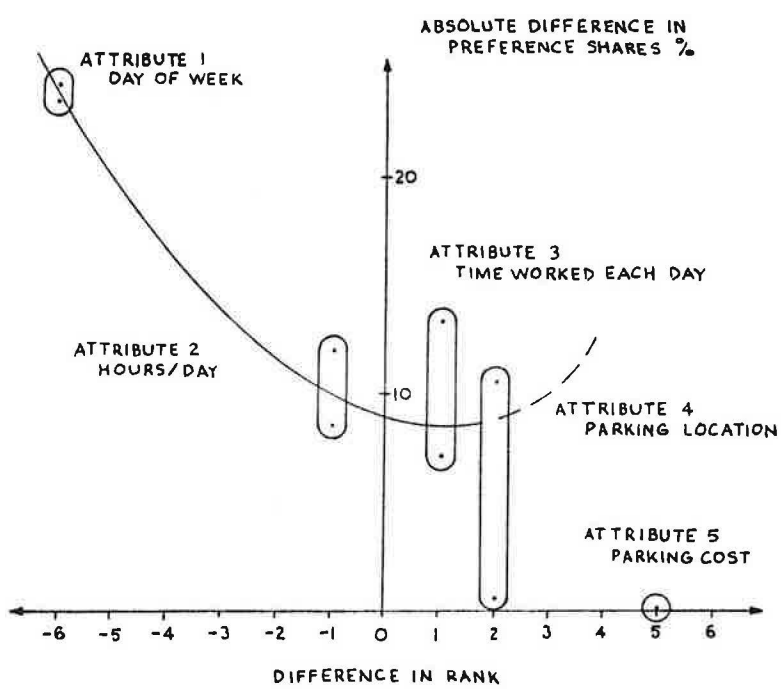


Figure 3. Preference predictions under full and reduced data sets.

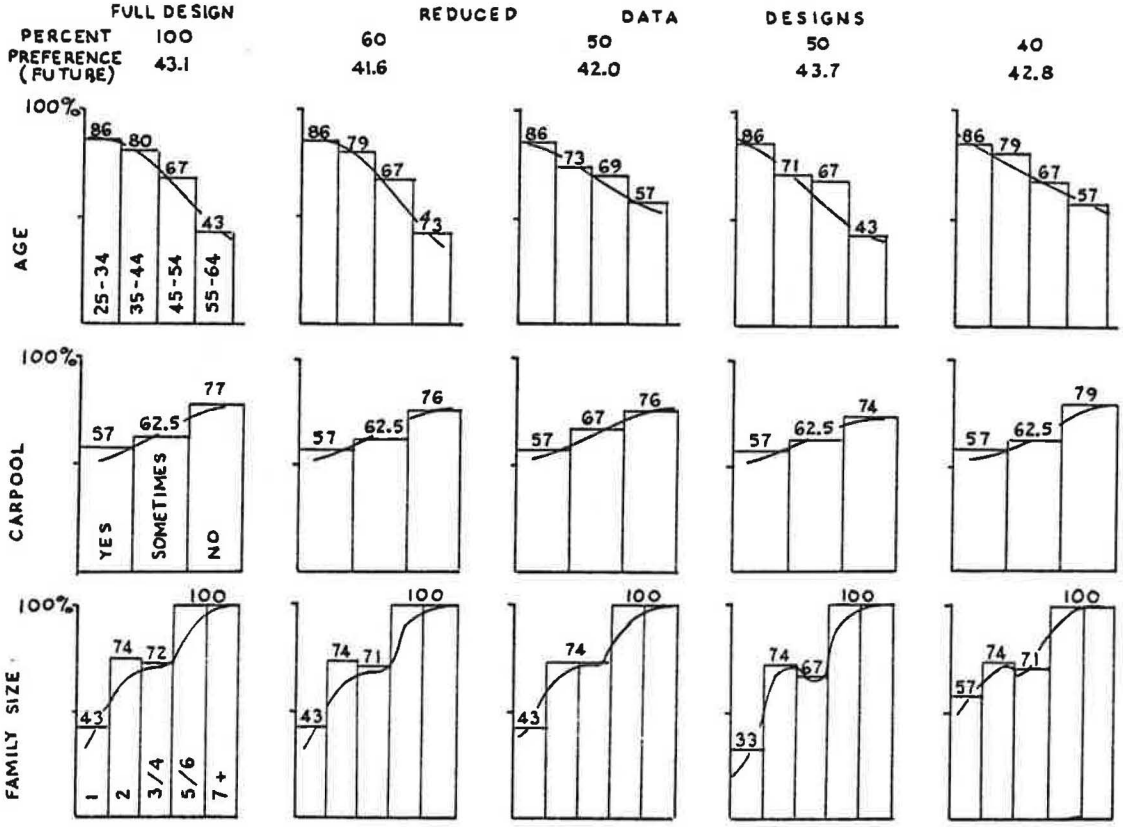


Table 2. Mean utilities under different functional forms.

Attribute	Level	Utilities: Additive Mean	Utilities: Multiplicative Mean
1. Work week	4 days, M-Th	0.3903	0.3806
	4 days, Tu-Fr	0.3795	0.3697
	5 days, M-Fr	0.2302	0.2496
2. Hours per day	7	0.4458	0.4321
	8	0.3396	0.3292
	9	0.2147	0.2387
3. Work schedule	Fixed	0.2865	0.2917
	Specific	0.3173	0.3148
	Variable	0.3966	0.3935
4. Parking location	Unassigned	0.3950	0.3899
	Prefer for carpool	0.2675	0.2743
	Assigned	0.3376	0.3358
5. Parking fee	Free	0.6203	0.5823
	$1 per month	0.3094	0.2988
	$1 per week	0.0703	0.1184

$$U_p = u_{p,1}(u_{p,2} \ldots u_{p,n}) \quad (1)$$

where

U_p = utility of policy p and
$u_{p,i}$ = utility of attribute i as defined for policy p.

A number of objections to this model have been raised, the most important being the requirement of ratio scales, which are difficult to establish from the preference information in the questionnaire. Two other models, therefore, were compared to the multiplicative model: an additive model

$$U_p = u_{p,1} + u_{p,2} + \ldots + u_{p,n} \quad (2)$$

and the additive exponential model

$$U_p = \exp(u_{p,1} + u_{p,2} + \ldots u_{p,n}) \quad (3)$$

In each case, the probability of policy choice is then computed as a Luce share model:

$$\text{Prob}_p = U_p \Big/ \sum_q U_q \quad (4)$$

Obviously, these models are related by the exponential transformation, since

$$u_{p,1}(u_{p,2}) \ldots u_{p,n} = \exp(v_{p,1} + \ldots + v_{p,n}), \text{ with } u_{p,1} = \exp(v_{p,1}) \quad (5)$$

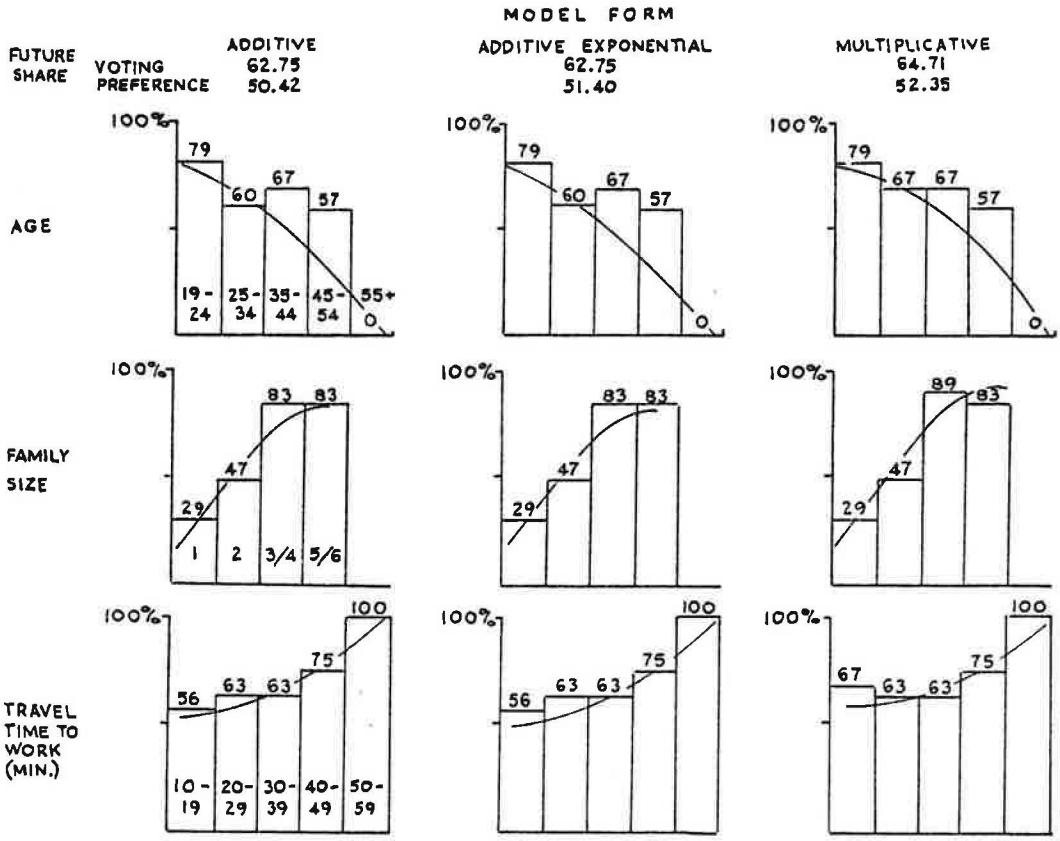
The additive exponential model takes the form of the multinomial logit model when combined with the Luce share model.

Since the exponential transportation is not admissible for ratio or interval scales, if we want to interpret these scales in other than an ordinal manner we can make the following predictions. First, utilities for attribute levels and policies would change slightly, comparing the three forms; second, market preferences based on first choices would not change at all; and, third, market preferences based on preference shares would change slightly.

In the tests done to confirm the above hypotheses, the computer program was modified to allow for the direct estimation of the additive utilities. These same additive utilities were then used to calculate preferences under the logit model, due to restrictions inherent in the programs. The results (Table 2) confirm the above hypotheses. The differences in the mean utilities are indeed so small as to be of no practical value.

For the evaluation of market preferences, the 5 days, variable hours future was used. The resulting market shares are given in Figure 4. As expected, there is no

Figure 4. Preference predictions under different functional forms.



change in the overall voting share for the additive and logit models. In both cases, one person (out of 51) shifted his vote for the future when going from the additive-logit models to the multiplicative model. While we expected no shift at all, this shift does not upset the hypothesis, since the hypothesis is valid only for the case of a perfect fit of the utilities to the data and an infinite data set. Both of these conditions are not true in this (and any practical) application.

In the case of the preference share model, we find, as expected, a slight but insignificant shift. The logit model as applied to additive utilities stands between the additive and multiplicative model. From a demographic viewpoint, the three models are equivalent. If we were to select a model from a psychological point of view, we would tend to favor the additive model, which has been found to be an acceptable representation of many decision processes in other studies. However, from a measurement theoretical point of view, the additive model is to be preferred only for the purpose of a voting share prediction. It is not admissible for the calculation of a preference split unless it is subject to the exponential transformation, leading to the multinomial logit model. If we are interested in the preference split, this is the model with the best theoretical foundation.

On the individual level, the exponential additive model requires scales with known unit and one arbitrary origin per individual. On the aggregate level the unit of measurement does not have to be the same over individuals as long as we interpret the utilities as likelihoods. This represents a significant relaxation of the necessary conditions for the establishment of the utility structure compared to the additive and multiplicative models. Thus, the exponential additive model, which leads to the logit model when standardized, is generally the preferred utility integration rule for trade-off analysis.

SUMMARY

To summarize, we found that the lengthy questionnaire needed for trade-off analysis is likely to lead to "position bias" in the data collected. Randomizing techniques would be needed in the composition of the questionnaires administered. While this may lead to larger variability in the data, it will reduce the effect of bias. We also found, however, that a 50 percent reduction in questionnaire length can be achieved without a significant loss in accuracy. A "circular" design is preferable. Last, for most practical purposes, all three utility models tested (additive, exponential additive, multiplicative) are equivalent. While the additive model is more commonly used, the exponential additive model is superior to the additive model on measurement-theoretical grounds.

The transportation policy planner should find trade-off analysis a helpful tool in the assessment of attitudes toward policy alternatives, and it has in fact been applied usefully in studies of staggered work hours, public transportation, and carpooling. The method is robust to reductions in questionnaire length and to various utility integration rules, and allows for an easy assessment of preferences broken down by demographics. It is hoped that such applications will be extended and further investigated.

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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)