DISCRETE MODE-CHOICE ANALYSIS OF URBAN TRAVEL DEMAND BY THE ANALYTIC HIERARCHY PROCESS

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ABSTRACT

In this paper we develop an AHP procedure for the problem of multi-modal urban corridor travel demand estimation. A number of conceptual and operational features of the AHP found in common with the discrete choice theory-based modeling approach is noted. The paper concludes by delineating substantive areas for further research in the use of the AHP for the problem of urban travel demand estimation.

INTRODUCTION

Among approaches to travel demand modeling are (a) economic/behavioral and (b) psychometric/attitudinal approaches. The first incorporates the utility maximization assumption of the neo-classical economics and models travel mode decisions as problems in micro-economic consumer choice among discrete alternatives (Anas 1983). The second approach models travel decisions by incorporating consumer attitudes affecting choices among alternatives (e.g., Golob; Dodson 1974) while the first approach lends itself to multi-attribute utility analysis of travel choices. Techniques of multi-dimensional scaling of attitudes and preferences for travel choices have been applied in the second approach. In this paper we develop the AHP as a third approach to travel demand estimation. However, the AHP exhibits a compatibility with both the economic as well as the psychologic theoretic approaches.

The economic theoretic assumption of the AHP is conceptually connected with the behaviorally plausible notion of bounded-rationality (Simon 1954-), which is increasingly realized as more realistic than the neo-classical economic model of perfect rationality, in the face of imperfect or limited information. Further, the AHP has been shown (Saaty 1977-) to corroborate empirically the psychological behavioral postulates originally developed by Miller (1957), that the number of choices considered by individuals simultaneously is not infinite, and that rational comparisons by individuals are cognitively bounded and, as Simon's "satisficing" model has also suggested, informationally constrained (Simon 1979-).

COMMON CONCEPTUAL AND METHODOLOGICAL FEATURES: AHP AND DISCRETE CHOICE THEORY

Here we briefly point out conceptual and methodological features of the AHP which are shared with the discrete choice theory-based modeling approach.

Taking alternatively the probit or logit functional forms, discrete choice models derive the probabilities that an individual chooses among a discrete set of alternatives (e.g., modes, routes, destinations). The model variables commonly include attributes of alternatives (e.g., modes) as well as certain situational and socio-economic characteristics of the trip-makers.

The "behavioral" mode-split models developed in the 1970s received wide-spread attention, in the face of the criticism of the "mechanical" mode-split models of the earlier period in which the competing attributes of alternative travel choices were unaccounted for (FHWA 1970). Ironically, however, the discrete choice models came to comprise a property known as independence from irrelevant alternatives (IIA), which plagued a fundamental behavioral premise of choice models. The IIA property can be characterized by the independence vs. dependence dichotomy. The issue of behavior plausibility is contrasted alternatively by the sequential vs. simultaneous structural specifications of travel choice dimensions, and the associated nested vs. non-nested formulations of the multinomial logit model. Thus, the "nested" logit has emerged as a generalization of the multinomial logit (MNL), in which the unrealistic, IAA property of the MNL is relaxed. Unlike the non-nested MNL, the alternatives that share a certain property are grouped and represented in a nested or a hierarchic system. Composite utility of an aggregate alternative within a nest is then derived by: (1) The expected value of the maximum utility of the member of the nest and (2) The vector of attributes common to all members of the nest, weighted by a vector of parameters (Ortuzar 1983, pp 283-284).

Thus, we observe a hierarchic system which conceptually underpins the later development of the discrete choice theory-based models (with nested structures). The AHP was originally conceived in the context of hierarachically structured problems (Saaty 1977-). The inclusive structure of a hierarchy offers a conceptually plausible principle of aggregation (or disaggregation) of the various dimensions of choice. It is important to emphasize that choice analysis need not end at the level of alternatives, e.g., travel mode-choice, with their attributes treated as a given, as in choice models. The attributes themselves can be further analyzed. But such considerations imply still higher level criteria, such as trip destination, purpose, time of travel, and so on. When all such multiple dimensions are specified and modeled simultaneously and exhaustively, the standard choice models encounter considerable operational intractability. The models are plagued further in the face of data limitations. Here, the AHP offers flexibility, data economy and computational efficiency to structure discrete choice dimensions hierarchically and analyze their interactions exhaustively.

But there is more than a conceptual (hierarchical) structure which is shared between the AHP and the nested version of the MNL. Operationally, there is the classical, multiplicative probability expression which is a common feature of the AHP and the nested multinomial logit models (MNL). We use an example (Anas 1979) in which a sequential structure of a model of location, mode and dwelling choice is specified. Denoting the (expected) frequency of joint location (i) and mode (m) by P_{im}, and the conditional (expected) frequency of dwelling choice (k), given the choice of mode and location by $P_{k/im}$, the frequency of joint location, mode and dwelling choice is expressed by:

$P_{imk} = P_{im} \cdot P_{k/im}$.

The nested logit model corresponding to such a choice structure is then specified, together with utility measures and statistical assumptions of the multinomial logit type (see Anas 1979). The expression above indicates a *two-dimensional* hierarchy within which the second level (dwelling) decision is predicated, or conditioned, upon the first level (location and mode) decision. Thus, the value of P_{imk} represents a *composite* of the two-dimensional problem in a choice-hierarchy.

Alternatively, suppose a hierarchy in which the relative weight of k variables in its ith level (or dimension) is denoted by w_{ik}, and in its jth level by w_{ijk}. The relative weights, however, can be derived through the AHP process of the pairwise comparison of the factors in the ith level. And the relative weight of the factors in the jth level is similarly derived vis-a-vis the ith level factors. The aggregate weights of the factors, denoted by p_{ijk}, can be derived by: $P_{ijk} = W_{ik} \cdot W_{ijk}$.

Thus, Batty and Spooner (1982, p 44) point out this principle of aggregation in a hierarchy as well as its analogy with the classical multiplicative rule to derive probability. We suggest areas for further research on the AHP and the discrete choice theory-based modeling approaches comparatively:

- Comparing MNL and AHP procedures, contrasting the "bottom-up" (MNL) vs. "top-down" (AHP) features of the two models and how decision-processes are being realistically represented in each.
- Relating to the above, specifically showing the link between the notion of "inclusive value" in MNL, which derives choice probabilities linked to and derived from lower level choices vs. the composite weighted summation procedure within the AHP, which, in contrast, derives lower level choice probabilities from the higher level choices.
- Exploring the linkage to and derivation of utility expression of the nested MNL sort from the AHP, since the latter offers a flexible procedure for incorporating qualitative factors in utility assessment.
- Exploring further the behavioral implication in the distinction between simultaneous vs. sequential measurement, in which the former may be conceptually treated as comparisons of travel choice factors *within*, whereas the latter may be treated as comparisons of factors *between*, the levels of a hierarchy.
- Contrasting the implication of (economic) assumptions of perfect vs. imperfect rationality, and how their incorporation in MNL and AHP *empirically* differentiates outcomes which describe observed choices made by individuals.

Our main object remains to develop the AHP as a procedure for urban travel demand analysis. This development complements a previous work (Banai 1984) in which the AHP was applied in the problem of interurban travel demand analysis.

AN AHP PROCEDURE FOR URBAN TRAVEL DEMAND ESTIMATION

Here we develop an AHP procedure for the mode-choice analysis of urban travel demand in a metropolitan corridor. We use the AHP to map the spatial and land use (environmental) characteristics of the corridor with the (behavioral) characteristics of the trip-makers, thereby deriving estimates of the demand for travel mode-choice along the corridor. We limit the scope and develop an illustrative simulation of journey-to-work for downtown destination (CBD). A choice-hierarchy is constructed (Figure 1). We specify three zones by aggregating the origin-destination zones with shared characteristics for which the UTPP (1980) provides commuting data. The three zones are: downtown (DN); suburban (SUB); and rest of the zones (ROZ). The first level of this hierarchy incorporates the trip destination, and the trip origins are specified at the second level of the hierarchy.

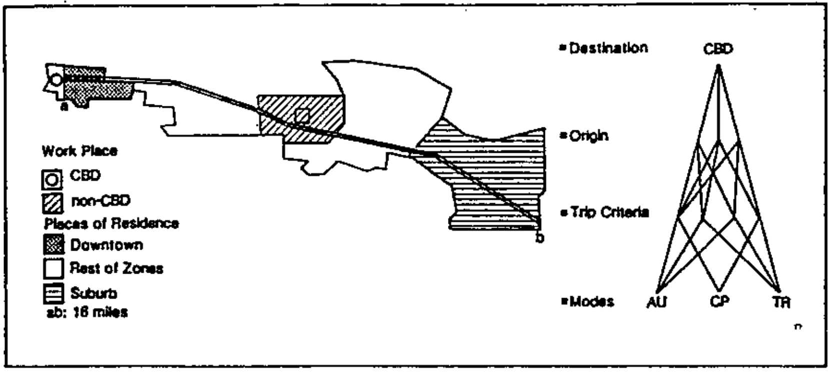

Figure 1. Zone Specification and a Travel Mode-Choice Hierarchy.

First, we set out to interrelate the first and second levels of this hierarchy, origin with destination. To determine the relative attraction (weight) of the destination zone for each of the origin zones, we incorporate a behavioral measure of <u>trip length</u>. We observe the (average) trip length from the three origin zones to the destination zone.

Table 1. Trip length to CBD (miles)

Origin Zone	Distance	Reciprocal	Normalized
DN	2	.5	.73
ROZ	8	.125	.18
SUB	16	.0625	.09

We, then, take the reciprocal of the trip lengths, since trip length is a behavioral measure of trip <u>impedance</u>, measuring the decay in the volume of trips with distance, and normalizing shown above. Thus, we derive the trip destination attraction weight for each origin zone. The weight of factors in the subsequent levels of the hierarchy will be weighted by these zonal (attraction) weights.

Next, we specify the criteria against which the utility (or satisfaction) of tripmakers is estimated. We incorporate four criteria: in-vehicle travel time (IVT), out-of-vehicle time (OVT), cost, and comfort and convenience (CC) and compare them pairwise. To capture the variation in the valuation of trip utility, however, the tripmakers are stratified by using a socio-economic variable (income). The tripmakers are grouped by low, middle and high incomes. Thus, our objective to estimate the relative weight of the trip criteria by each income stratum.

Empirical observations on the relative importance of travel choice factors provide useful inputs in the process of the pairwise comparison of time, cost, comfort and convenience. A growing number of <u>behavioral</u> studies of travel demand has been emerging since the 1960s. Prominent among them are studies of mode-choice (Warner, 1962; Manheim 1979; Kirby et al. 1980; Stopher et al. 1981; Ortuzar 1983; Jones et al. 1983; Train 1986; and others). However, such observations involve further interpretation, accounting for the behavioral and contextual variation (preferance, cost, density, auto ownership, mode availability, travel network, etc.) affecting estimation. Nonetheless, the following observations have been made in previous studies. For the upper income individuals, travel time is more important than cost, whereas for the lower income individuals the value of time is lower than for the upper income individuals. Out-of-vehicle time (e.g. transit wait time, or for auto, the time spent for parking) is observed to be 2 to 3 times higher than in-vehicle travel time. Further, studies suggest the level of service is more important in influencing the decision to travel than changes in the travel cost (Kraft; Domencich 1970). We form the comparison matrices which follow (Table 2), and use the AHP scale suggested by Saaty (1980).

Table 2. Deriving the relative weight of the trip criteria by tripmakers' income

L-INC	IVT	OVT	COST	CC	Weight
IVT	1	1/2	1/5	1/2	0.0868
OVT	2	1	1/3	1/3	0.1323
COST	5	3	1	5	0.5719
CC	2	3	1/5	1	0.2088

Lambda(max)=4.279 CI=0.09

H-INC	IVT	OVT	COST	CC	Weight
IVT	1	1/3	5	2	0.2498
OVT	3	1	7	3	0.5223
COST	1/5	1/7	1	1/5	0.0510
CC	1/2	1/3	5	1	0.1768

Lambda(max)=4.134 CI=0.04

M-INC	IVT	OVT	COST	CC	Weight
IVT	1	1/5	1/3	1/2	0.0921
OVT	5	1	1/2	1/2	0.2362
COST	3	2	1	3	0.4337
CC	2	2	1/3	1	0.2377

Lambda(max)=4.371 CI=0.12

Next we aggregate the trip criteria weight across the three income groups and normalize to obtain the second level weights of the mode-choice hierarchy, which results in the income vector:

INC: [0.4287 0.8908 1.0566 0.6233] or
INC(N): [0.1429 0.2969 0.3522 0.2077] after normalization.

The next level comparisons are straightforward (Table 3). These comparisons show the relative competitiveness of the modes measured against the trip criteria, with their relative importance just determined. We compare the modes as travel choices for each criterion of time, cost, and comfort and convenience. The three modes fare as follows:

Table 3. Modal Comparisons

IVT	AU	CP	TR	Weight	$(\mathrm{IVT})^{-1}$
AU	1	2	4	0.5584	0.1364
CP	1/2	1	3	0.3196	0.2384
TR	1/4	1/3	1	0.1219	0.6252

Lambda(max)=3.018 CI=0.009

OVT	AU	CP	TR	Weight	$(\mathrm{OVT})^{-1}$
AU	1	3	1/5	0.2225	0.3230
CP	1/3	1	1/3	0.1268	0.5669
TR	5	3	1	0.6506	0.1104

Lambda(max)=3.294 CI=0.14

Cost	AU	CP	TR	Weight	$(\mathrm{Cost})^{-1}$
AU	1	5	7	0.7222	0.0692
CP	1/5	1	4	0.2049	0.2440
TR	1/7	1/4	1	0.0727	0.6880

Lambda(max)=3.123 CI=0.06

CC	AU	CP	TR	Weight
AU	1	3	6	0.6348
CP	1/3	1	5	0.2872
TR	1/6	1/5	1	0.0779

Lambda(max)=3.094 CI=0.04

To capture the effect of time and cost (IVT, OVT, CC) on trip <u>disutility</u> (i.e., decrease in utility of mode-choice with the increase in travel time and cost), we take the reciprocal of the relative weights (eigenvectors) and normalize (just as we took the reciprocal of distance to indicate that trip-making utility decreases with increasing distance), shown in the final column of the comparison matrices.

To synthesize the weight of the factors in level III with those of level IV of the choice hierarchy, we perform the following weighted summation procedure and use the income vector (INC) obtained earlier:

$$\begin{array}{cccc} & & & (3x4) \\ (\mathrm{IVT})^{-1} & (\mathrm{OVT})^{-1} & (\mathrm{Cost})^{-1} & \mathrm{CC} \\ 0.1364 & 0.3230 & 0.0592 & 0.6348 \\ 0.2384 & 0.5669 & 0.2440 & 0.2872 \\ 0.6252 & 0.1104 & 0.6880 & 0.0779 \\ & & & \end{array} \times \begin{array}{c} (4x1) \\ \mathrm{INC} \\ 0.1429 \\ 0.2969 \\ 0.3522 \\ 0.2077 \end{array} = \begin{array}{cc} (3x1) & \\ & \\ 0.223 & \mathrm{AU} \\ 0.347 & \mathrm{CP} \\ 0.380 & \mathrm{TR} \\ & \end{array}$$

To capture the effect of trip length on travel mode-choice decisions, we weigh the result obtained above by the trip-destination attraction weights for each origin zone, which we obtained in Table 1. We get:

<u>Modes</u>	Destination <u>Weight</u>		Mode- <u>Shares</u>				<u>Normalized</u>	Observed <u>UTPP(1980)</u>
Auto (AU)	0.73	x	0.223	=	0.162	AU	62.93	64.42
Carpool (CP)	0.18		0.347		0.062	CP	23.93	15.52
Transit (TR)	0.09		0.380		0.034	TR	13.12	11.75

Finally, we normalize this vector and juxtapose against the UTPP (1980) data on mode-shares.

CONCLUSION

The AHP procedure for metropolitan corridor travel demand estimation can be generalized as follows:

a. Structure the travel (mode) choice hierarchy

b. Specify (aggregate/disaggreate) the origin-destination zones based on shared characteristics

c. Identify the characteristics of the trip-makers as well as the characteristics of the travel environment
d. Map the behavioral and the environmental factors hierarchically
e. Evaluate dimensions of choice by using the AHP pairwise comparisons of factors within and between each dimension
f. Synthesize the results of the comparisons to obtain the relative share of the mode-choices

Finally, we suggest a sensitivity analysis to complete this procedure in which the resulting mode-shares are evaluated in the face of decision-variables inputs examined level-by-level within the travel choice hierarchy. We note that the procedure developed here can be used in planning and forecasting the demand for a new travel mode. The criteria for mode-comparisons remain relevant still, particularly when a new mode is introduced. And pairwise comparisons of the modes set out to show their relative competitive attributes, and how the existing modal share are affected (increased/decreased) by the introduction of a new mode, such as a proposed light rail transit (LRT) alternative for the exemplary corridor.

Among a growing diversity of the AHP developments and applications are some recent works that show the connectivity of this new method with a variety of certain established methods, including the standard optimization methods of operations research (e.g., Saaty 1986), utility and multi-criteria analysis (Hughes 1986), as well as models of spatial interaction (Harker 1986). The new developments combining the AHP with the standard methods could offer further insights for new ways of framing and solving transportation issues that have not been adequately explored due to certain limitations of the previous methods. In addition to the methodological issues raised earlier in the paper, a number of substantive areas for further research can be suggested by using the AHP approach, in the face of its data economy, flexibility and complementarity with other methods. These include:

-Identification and evaluation of alternative behavioral hypotheses which elucidate the causal relationships involving the multiple dimensions and subdimensions within a travel choice hierarchy exhaustively.
-Model explicitly (travel) behavior in relationship to the environment or context of trip-making in an integrated or interactive system in which the dynamics of the relationship are examined.
-In the face of a crucial limitation of empirical models, with parameters estimated for one type of environmenet and assumed to be "transferable" to another environment, examine further the issue of uniqueness of the travel context, or even the uniqueness of travel behavior in the context.
-Examine effects of constraints in the environment on travel behavior, particularly in the context of urban travel demand influenced by certain important non-economic factors such as gender or ethnicity.
-Incorporate qualitative and quantitative, economic and non-economic factors to assess their relative importance as factors jointly influencing travel choices.
-Making transportation forecasting technology more accessible to a large number of small, public or private agencies, in the face of the time and resource requirements of standard choice models.
-Making transportation planning process more interactive involving decision-inputs of expert as well as non-expert participants.

These are only a subset of topics for further research and development of the AHP as an alternative, viable behavioral travel demand methodology.

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