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A Joint Model of Work Mode Choice, Evening Commute Stops, and Post-Home Arrival Stops

By

Chandra R. Bhat

and

Sujit K. Singh

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6. AUTHOR(S)
Chandra R. Bhat
Sujit K. Singh

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Massachusetts
Transportation Center
224 Marston Hall
Amherst, MA 01003

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A Joint Model of Work Mode Choice, Evening Commute Stops, and Post-Home Arrival Stops

Chandra R. Bhat

University of Texas at Austin

Tel: (512) 471-4535; Fax: (512) 475-8744

E-mail: bhat@mail.ce.utexas.edu

and

Sujit K. Singh

University of Massachusetts at Amherst

Tel: (413) 545-0349, Fax: (413) 545-2840

E-mail: ssingh@spock.ecs.umass.edu

Abstract

The research presented here develops a joint model of work mode choice, number of evening commute stops, and number of post-home arrival stops. This model provides an improved basis to evaluate the effect of alternative transportation control measures. The model also contributes toward the modeling of an individual's entire daily activity-travel pattern in the spirit of activity-based travel analysis. Mode choice is modeled using a multinomial logit model; the number of evening commute and post-home arrival stops are modeled using an ordered-response formulation. The joint model is applied to an empirical analysis using data from an activity survey conducted in the Boston Metropolitan area. The results underscore the importance of accommodating the inter-relationship among mode choice to work, number of evening commute stops, and post-home arrival stops. The effects of a variety of congestion-alleviation measures are examined using the model.

1. Introduction

Work mode choice modeling has received substantial attention in the travel demand literature because the work mode decision has an important impact on the number of vehicles on roadways during the morning and evening commute periods. Work mode choice models provide the tool to evaluate the ability of traffic congestion mitigation actions to effect a change in mode of travel from solo-auto to high-occupancy vehicles.

Work mode choice models, however, do not directly provide an assessment of the impact of transportation policy measures on peak period traffic congestion because of non-work vehicle trips made during the work commute or before/after the work commute. Practitioners and researchers have become aware of the substantial contribution (to traffic congestion) of the growing number of non-work trips made by individuals during the peak periods, especially in the evening. For example, Gordon *et al.* (1988) found, based on their examination of the 1983 U.S. Nationwide Personal Transportation Survey, that over 66% of person trips during the evening peak were made for nonwork purposes in large urban areas. Purvis (1994) analyzed the data from the 1990 household travel survey conducted in the San Francisco Bay area and found that over 56% of vehicle trips during the evening peak were nonwork related. The rise in nonwork trips during the expanding evening peak period can be attributed to increased evening commute stops (*i.e.,* nonwork stops made during the evening work-to-home commute, see Lockwood and Demetsky, 1994 and Kim *et al.*, 1994) and to increased post-home arrival activity stops (*i.e.,* out-of-home nonwork activity stops made <u>after</u> arriving home at the end of the work tour, see Bhat, 1997a).

It is clear that work mode choice, number of evening commute stops, and number of post-home arrival stops have an important bearing on transportation policy analysis. The work mode choice, number of evening commute stops, and number of post-home arrival stops decisions are also likely to be intricately linked. For example, Bhat (1997b) has shown that ignoring the joint nature of work mode and number of commute stops decisions (as is done by conventional mode choice models) leads to overly optimistic projections of the reduction in peak-period congestion due to transportation control measures (TCMs). Similarly, a TCM that encourages the use of high-occupancy vehicle modes to work may decrease the number of stops made during the evening commute, but also increase post-home arrival stops because of substitution effects between evening commute stop-making and post-home arrival stop-making. Further, an individual's work mode choice may be influenced by her/his decision to pursue post-home arrival activities. Thus, an individual may choose to drive alone to work to enable an early home arrival that will facilitate participation in post-home arrival activity. These examples illustrate the need to recognize the linkage among work mode choice, choice of evening commute stops and choice of post-home arrival activity stops in evaluating the impact of TCMs.

In this paper, we develop a joint model of work mode choice, number of evening commute stops and number of post-home arrival activity stops. As indicated earlier, the joint model provides an improved basis to evaluate the effect of TCMs on traffic congestion. The joint model also contributes to the development of a "tour-based" travel demand model system in the spirit of activity-based analysis. The current "trip-based" modeling approach assumes that each trip can be analyzed independently without considering the inter-relationships that may exist among travel choices made by individuals for a series of trips. The activity-based approach views travel as a derived demand; derived from the need to pursue activities distributed in space. This approach adopts a holistic framework that recognizes the complex interactions in activity and travel behavior. It focuses on sequences or patterns of activity behavior, with the whole day (or longer periods of time) as the unit of analysis. Bhat (1997c) has recently proposed a tour-based activity framework to model the entire daily activity-travel pattern of a worker on her/his working day (work arrival time, mid-day break time, and work departure time at the evening are considered fixed in the framework). Based on descriptive analyses of activity diary data collected in the Boston area and the Washington, D.C. area, Bhat concludes that it is important to model work mode choice, evening commute stops, and post home arrival stops jointly, but stop-making during the before work, morning commute, and midday periods may be modeled individually and independently. He also notes that the travel mode used for post-home arrival stops is predominantly the auto mode, so mode choice for such stops may be ignored. A possible analysis strategy is then to a) model work mode choice, number of stops during the evening commute, and number of post-home arrival stops jointly, b) model mode choice and number of stops jointly for before work tours and midday tours, and c) model number of stops during the morning commute conditional on work mode choice and number of evening commute stops. Within each of the periods (*i.e.,* before work, morning commute, mid-day, evening commute, and post-home arrival periods) one can then jointly model activity type choice of the first stop, activity duration at the first stop, and travel time duration to the first stop using a generalized proportional hazard model or a discrete/continuous variable system (Bhat, 1996; 1997a). The location choice of the stop can be modeled by circumscribing all possible destinations which can be reached by the travel mode assigned earlier and within the travel time duration estimated in the previous step. Such a procedure accommodates the spatial-temporal constraints in stop-making decisions. The attributes of the second stop within any period (if there is a second stop) can be modeled similarly conditional on the attributes of the first stop, and so on for all the stops in the commute/tour. The home stay duration between arriving home from work and leaving home to pursue any post-home arrival stops may be modeled using a hazard duration model (see Hamed and Mannering, 1993 and Mannering *et al.*, 1994). The complete activity-based system can model an individual's daily activity-travel pattern at a high level of resolution along the time dimension. Further, the activity-based model system can estimate the number of "cold" engine starts and "hot" engine starts during any time period in the day. This information is an important input to improved mobile source emissions modeling (Stopher, 1991; Karash and Schweiger, 1994). The joint model developed in the current paper is a central component of the activity-travel model system presented above.

Previous studies have not confronted the simultaneity in the work mode choice decision, the number of activity stops in the evening commute, and the number of post-home arrival stops. Many studies have examined these choices individually, but none have modeled them jointly. For example, Beggan (1988) examines work trip mode choice behavior and uses information on whether an individual makes one or more stops in the evening commute as an independent variable in the model. He does not consider the potential effect of post-home arrival stop-making behavior on work mode choice (see discussion in section 1) or the effect of work mode choice on stop making behavior during the evening commute and after. Strathman *et al.* (1994) study trip chaining behavior during the work commute and use the work travel mode as an explanatory variable. They do not model work mode choice and do not consider the joint nature of stop making during the evening commute and after arriving home at the end of the work tour. A similar observation can be made regarding the work of Hamed and Mannering (1993) and Bhat (1997a). In addition, previous trip-chaining studies have been, for the most part, descriptive in nature as opposed to being policy sensitive (see Adiv, 1983; Golob, 1986; and Strathman *et al.*, 1994). The focus of these previous studies has been to examine the effect of household and personal characteristics on trip chaining behavior. While such studies are valuable in understanding the differential tendencies of households and individuals to chain trips, their value in policy analysis is limited since transportation policies have little impact on household and personal characteristics. On the other hand, a recent trip-chaining study by Metaxatos and Sen, 1997 develops a model that examines the effect of travel time and distance on locational attributes of activity stops, but the study does not accommodate socio-demographic effects on trip chaining and does not model mode choice or number of stops. The joint model in this paper emphasizes the impact of both socio-demographic attributes and policy-relevant exogenous variables on mode choice and stop-making behavior.

The modeling effort that comes closest to the proposed research is the joint work mode choice and number of evening commute stops model by Bhat (1997b). However, that research does not model post-home arrival activity stops. Thus, it ignores any inter-relationship between work mode choice and number of post-home arrival stops, and fails to accommodate substitution effects between evening commute and post-home arrival stops. Disregarding these inter-relationships, and not modeling post-home arrival stop-making behavior, renders Bhat's (1997b) model myopic in scope and perspective.

The next section of this paper advances the econometric framework for the joint model system of mode choice and number of non-work stops. Section 3 discusses the data source and sample used in the empirical analysis. Section 4 focuses on empirical results. Section 5 examines the impact of policy actions using the model. The final section summarizes the important findings from the research.

2. Econometric Framework

2.1. Background

The econometric framework jointly models work mode choice, the number of non-work evening commute stops, and the number of post-home arrival stops. Work mode choice is modeled using an unordered multinomial logit discrete choice model; the number of evening commute stops and the number of post-home arrival stops are modeled using an ordered-response discrete choice model. The ordered-response formulation for number of stops recognizes the ordinal and discrete nature of stops.

The joint nature of mode choice to work, number of evening commute stops, and number of post-home arrival stops arises because the three choices are caused or determined by certain common underlying observed and unobserved factors (see Train, 1986; page 85). For example, if the travel time by the drive alone mode is much less than transit, it may result in the choice of the drive alone mode. Also, the low travel time by the drive alone mode may relax time constraints and enable more stop-making during the evening commute and or after arriving back from work (which may be the reason, in part, for the choice of the drive alone mode in the first place). Thus, we will find a positive association between the choice of driving alone and stop-making. We may also find a similar association because of positive correlation in unobserved factors (such as dynamic life style, impulsiveness, need to be in control, *etc.*) that increase the choice of driving alone and also increase stop-making. Thus, the reason for the joint nature of the work mode choice, number of evening commute stops and number of post-home arrival stops is because of common underlying factors, not because of direct causation between the choices. A different, but related, interpretation is that individuals choose a particular combination or "package" of mode choice and stops. Since these choices are determined simultaneously, "it is not possible for one choice to cause the other, in a strict sense of causality" (Train, 1986; page 85).

2.2. Structure and Estimation

In the following presentation of the model structure, we will use the index i to represent mode (i=1,2,...I), index k to represent the number of non-work evening commute stops (k=0,1,2,...K), index l to represent the number of post-home arrival stops (l=1,2,...L), and the index q to represent the qth individual (q=1,2,...Q). The equation system is then as follows:

$$
\begin{aligned}
u^*_{qi} &= \beta_i' z_{qi} + \epsilon_{qi}, \text{ mode } i \text{ chosen } if\ u^*_{qi} > \max_{\substack{j=1,2,\ldots,I \\ j \neq i}} u^*_{qj} \\
s^*_{qi} &= \gamma_i' x_{qi} + \eta_{qi},\ s_{qi} = k\ if\ \delta_{i,k-1} < s^*_{qi} \leq \delta_{i,k} \\
w^*_{qi} &= \alpha_i' y_{qi} + \lambda_{qi},\ w_{qi} = l\ if\ \theta_{i,l-1} < w^*_{qi} \leq \theta_{i,l}\,.
\end{aligned}
\tag{1}
$$

u^*_{qi} is the indirect (latent) utility that the qth individual derives from using the ith mode, s^*_{qi} is the (latent) evening commute stop-making propensity of the qth individual should s/he use mode i, s_{qi} is the observed number of evening commute stops conditional on choice of mode i to work (s_{qi} is unobserved for the non-chosen modes), w^*_{qi} is the (latent) post-home arrival stop-making propensity of the qth individual should s/he use mode i for the work commute, and w_{qi} is the observed number of post-home arrival stops if the individual q chooses work mode i (w_{qi} is unobserved for the non-chosen work modes). s_{qi} is characterized by the evening commute stop-making propensity s^*_{qi} and the threshold bounds (the δ's) in the usual ordered-response fashion. A similar relationship holds between w_{qi}, w^*_{qi}, and the threshold bounds represented by the θ's. z_{qi}, x_{qi}, and y_{qi} are column vectors of exogenous variables, and β_i, γ_i, and α_i are corresponding column vectors of parameters to be estimated. We assume that the ϵ_{qi}'s are identically and independently extreme-value distributed (with a location parameter of zero) across alternatives i and individuals q. η_{qi} and λ_{qi} are assumed to be identically (and independently) normal-distributed across individuals q and modes i, each with a marginal standard normal distribution function $\Phi(.)$.

Let R_{qi} be a dummy variable; $R_{qi}=1$ if the *ith* mode is chosen by the *qth* individual for her/his work travel, and $R_{qi}=0$ otherwise. Define

$$v_{qi} = \left\{ \max_{j=1,2,...I, j \neq i} u_{qj}^{*} \right\} - \epsilon_{qi}. \tag{2}$$

The equation system in (1) can now be structured as:

$$\begin{aligned} R_{qi}^{*} &= \beta_i' z_{qi} - v_{qi},\ R_{qi} = 1 \text{ if } R_{qi}^{*}>0,\ R_{qi} = 0 \text{ otherwise} \\ s_{qi}^{*} &= \gamma_i' x_{qi} + \eta_{qi},\ s_{qi} = k \text{ if } \delta_{i,k-1} < s_{qi}^{*} \leq \delta_{i,k} \\ w_{qi}^{*} &= \alpha_i' y_{qi} + \lambda_{qi},\ w_{qi} = l \text{ if } \theta_{i,l-1} < w_{qi}^{*} \leq \theta_{i,l}. \end{aligned} \tag{3}$$

The jointness in the three choices (work mode, number of evening commute stops, and number of post-home arrival stops) arises because of potential correlation among the random components $(v_{qi}, \eta_{qi}, \lambda_{qi})$. The key to accommodating these correlations is to transform the random variable v_{qi} into a standard normal random variable v_{qi}^{*} as follows:

$$v_{qi}^{*} = \Phi^{-1}\left[F_i(v_{qi})\right], \tag{4}$$

where $\Phi(.)$ is the standard normal distribution function and F_i is the multinomial logit distribution function of v_{qi} implied by equation (2) and the assumed iid extreme value distribution for the $\epsilon_{qi}'s$. Now, since $\Phi(v_{qi}^{*}) = F_i(v_{qi})$ by construction (see equation 4), we can specify a trivariate distribution L_3 for v_{qi}, η_{qi}, and λ_{qi} having the marginal distributions $F_i(.)$ for v_{qi}, and $\Phi(.)$ for η_{qi} and λ_{qi}, as (Lee, 1983):

$$L_3(v_{qi}, \eta_{qi}, \lambda_{qi}, \rho_{v_i\eta_i}, \rho_{v_i\lambda_i}, \rho_{\eta_i\lambda_i}) = \Phi_3(v_{qi}^{*}, \eta_{qi}, \lambda_{qi}, \rho_{v_i\eta_i}, \rho_{v_i\lambda_i}, \rho_{\eta_i\lambda_i}), \tag{5}$$

where $\Phi_3(.)$ denotes the trivariate normal distribution. From equation (3) and equation (5), the joint probability of choosing mode i, number of evening commute stops k, and number of post-home arrival stops l for individual q is:

$$\begin{aligned} P(R_{qi}=1,s_{qi}=k,w_{qi}=l) = {} & \Phi_3\left[\Phi^{-1}\{F_i(\beta_i' z_{qi})\},(\delta_{i,k}-\gamma_i' x_{qi}),(\theta_{i,l}-\alpha_i' y_{qi}),\rho_{v_i\eta_i},\rho_{v_i\lambda_i},\rho_{\eta_i\lambda_i}\right] - \\ & \Phi_3\left[\Phi^{-1}\{F_i(\beta_i' z_{qi})\},(\delta_{i,k-1}-\gamma_i' x_{qi}),(\theta_{i,l}-\alpha_i' y_{qi}),\rho_{v_i\eta_i},\rho_{v_i\lambda_i},\rho_{\eta_i\lambda_i}\right] - \\ & \Phi_3\left[\Phi^{-1}\{F_i(\beta_i' z_{qi})\},(\delta_{i,k}-\gamma_i' x_{qi}),(\theta_{i,l-1}-\alpha_i' y_{qi}),\rho_{v_i\eta_i},\rho_{v_i\lambda_i},\rho_{\eta_i\lambda_i}\right] + \\ & \Phi_3\left[\Phi^{-1}\{F_i(\beta_i' z_{qi})\},(\delta_{i,k-1}-\gamma_i' x_{qi}),(\theta_{i,l-1}-\alpha_i' y_{qi}),\rho_{v_i\eta_i},\rho_{v_i\lambda_i},\rho_{\eta_i\lambda_i}\right], \text{ where} \end{aligned} \tag{6}$$

$$F_i(\beta_i' z_{qi}) = Prob(v_{qi} < \beta_i' z_{qi}) = \frac{\exp(\beta_i' z_{qi})}{\sum_{j=1}^{I} \exp(\beta_j' z_{qj})}, \quad i=1,2,\ldots,I. \tag{7}$$

The parameters to be estimated in the joint model are the (K-1) $\delta_{i,k}$ parameters $(\delta_{i,0}=-\infty, \delta_{i,K}=+\infty)$, the (L-1) $\theta_{i,l}$ parameters $(\theta_{i,0}=-\infty, \theta_{i,L}=+\infty)$, and the vector $(\beta_i', \gamma_i', \alpha_i', \rho_{v_i\eta_i}, \rho_{v_i\lambda_i}, \rho_{\eta_i\lambda_i})'$ for each mode i (as structured, x_{qi} and y_{qi} do not include a constant). Defining a set of dummy variables

$$M_{qkl} = \begin{cases} 1 \text{ if individual } q \text{ makes } k \text{ evening stops and } l \text{ post-home arrival stops} \\ \qquad (q=1,2,\ldots Q,\ k=1,2,\ldots K,\ l=1,2,\ldots L) \\ 0 \text{ otherwise,} \end{cases} \tag{8}$$

the log likelihood function for the estimation of the parameters in the model takes the form

$$\log \mathcal{L} = \sum_{q=1}^{Q} \sum_{i=1}^{I} \left\{ R_{qi} \left(\sum_{k=1}^{K} \sum_{l=1}^{L} M_{qkl} \log\left[P(R_{qi}=1,s_{qi}=k,w_{qi}=l)\right] \right) \right\}. \tag{9}$$

It is easy to see that if $\rho_{v_i\eta_i}, \rho_{v_i\lambda_i}$ and $\rho_{\eta_i\lambda_i}$ are equal to zero for each (and every) mode i, then the likelihood in equation (9) partitions into a component corresponding to that of a multinomial logit model for mode choice, a second component that represents an independent univariate ordered response model of number of evening commute stops by the chosen work mode, and a third component that represents an independent univariate ordered response model of number of post-home arrival stops by the chosen work mode. In general, ignoring the correlation parameters and estimating independent models of evening commute and post-home arrival stops by the chosen mode will lead to biased parameter estimates.

The maximization of the function in equation (9) is achieved using a full-information maximum likelihood procedure (maximization is done using the GAUSS matrix language; the analytic derivatives of the log-likelihood function with respect to parameters have been derived and coded).

3. Data Source and Sample

The data source used in the present study is a household activity survey conducted by the Central Transportation Planning Staff (CTPS) in the Boston Metropolitan region. The survey was conducted in April of 1991 and collected data on socio-demographic characteristics of the household and each individual in the household. The survey also included a one-day (mid-week working day) activity diary to be filled out by all members of the household above five years of age. Each activity pursued by an individual was described by: a) start time, b) stop time, c) location of activity participation, d) travel time from previous activity, e) travel mode to activity location, and f) activity type.

The sample for the current analysis comprises 1440 employed adult individuals who made a work-trip on the diary day and were older than 16 years (complete details of the screening and data cleaning procedures employed in arriving at this sample from the overall activity diary data is provided in Singh, 1997). The mode choice estimation is restricted to the choice of three modes due to data limitations and also because the remainder of the modes do not capture much market share. The three modes are drive alone (use of a car/van/pickup truck by one traveler), shared ride (use of a car/van/pickup truck by more than one traveler) and transit (bus, commuter rail, or local rail). The travel mode used for the first leg from work in the evening is used as the work mode choice (thus, if a person picks up another family member or a child by car at an intermediate point in the evening commute and then proceeds to home, the person's work mode choice is classified as drive alone). The number of stops made during the evening commute ranges from zero to four in the sample (picking up individuals during the evening commute is included as a stop; however, if an individual rides with another person from the work place and drops the person at an intermediate point during her/his commute, the work mode assigned to the individual is shared ride and the "drop-off" is not recognized as a stop but considered as an integral part of the shared-ride arrangement).

Level of service data were generated for each mode for each individual's trip to work. These data were generated (by the Central Transportation Planning Staff of the Boston Metropolitan Planning Organization) based on a combination of home location and work location information, manual reconstruction of most likely path for non-chosen modes, estimated times from an interim regional model for drive alone and shared-ride in-vehicle travel, estimated times from published transit schedules for the transit mode, and estimated parking, access/egress, and line-haul costs. A detailed description of the actual procedures and assumptions is beyond the scope of the current paper, but is available in Gallagher, 1993.

The sample is representative of the market work mode shares as reflected in the 1990 Census Journey-to-Work results for the Boston Metropolitan area. Table 1 provides selected

Table 1 : Selected Descriptive Statistics

Category	Solo-Auto	Shared-Ride	Transit
Sample mode shares (%)	76.5	11.3	12.2
% making commute stops	37.8	26.5	17.7
% making post-home arrival stops	38.6	36.8	36.6
% making commute stops or post-home arrival stops or both (across all modes)	63.0%		
% making commute stops if post-home arrival stops are made (across all modes)	25.0%		
% making commute stops if post-home arrival stops are not made (across all modes)	39.6%		

descriptive statistics on work mode choice and stop-making in the sample. A number of interesting observations can be made from this table. First, there is a positive association between making evening commute stops and choosing the drive alone mode (see second row of Table 1). A similar, though weaker, association exists between making post-home arrival stops and choosing the drive alone mode (third row of Table 1). Second, about 63% of workers do not have any out-of-home activity involvement after work, while 37% make activity stops after work (either during the evening commute or after arriving home from work or both; see third rows of Table 1). Third, there is a substitution effect between stop-making during the evening commute and stop-making after arriving home from work, as can be observed from the final two rows in the table.

The distribution of number of stops during the evening commute is as follows: 0 stops (66.0%), 1 stop (22.4%), 2 stops (7.4%), 3 stops (2.7%), and 4 stops (1.5%). The distribution of number of stops after arriving home from work is as follows: 0 stops (61.9%), 1 stop (24.4%), 2 stops (9.4%), 3 stops (2.8%), and 4 stops (1.5%). These statistics reveal that there is more stop-making during the post-home arrival period than during the evening commute.

4. Empirical Analysis

4.1. Model Specification

The choice of variables for potential inclusion in the model was guided by previous theoretical and empirical work on mode choice modeling and trip chaining analysis, and intuitive arguments regarding the effects of exogenous variables. We arrived at the final specification based on a systematic process of eliminating variables found to be statistically insignificant in previous specifications. Some variables with marginally significant coefficients are retained in the final specification, either for the sake of completeness or because they provide useful and suggestive insights. Tables 2a and 2b provide a list of exogenous variables used in the model, their definitions, and associated descriptive statistics in the sample.

We constrained the parameters on all non-level of service variables (*i.e.*, socio-demographic attributes, residential/employment location variables, and work schedule characteristics) to be equal across the different mode regimes for the evening commute and post-home arrival stop-making propensity equations. We adopted such a specification because we did not have any strong theoretical reason to believe that the effect (on stop-making propensity) of non-level of service measures should be different for different modes. Also, constraining parameters enhances the stability of the model and preserves degrees of freedom. We empirically tested for different parameters on the level-of-service variables in the stop-making propensity equations for the different mode regimes. However, a likelihood ratio test of equality of the level-of-service parameters across the mode regimes could not be rejected. Hence, we maintained equal parameters on all exogenous variables across the different mode regimes for the evening commute and post-home arrival propensity equations.

We attempted two different specifications for the thresholds (the δ_{ik} and θ_{il} parameters in equation 1) that determine the correspondence between the latent stop-making propensity and the actual number of stops in the ordered response formulation. The first specification allowed the thresholds to be completely unconstrained across the mode regimes (there are 4 thresholds in each mode regime and, since there are three modes, the total number of thresholds for each stop-making equation in this specification is 12). In the second specification, we restricted the thresholds to be the same for each mode regime up to a structural shift (that is, all thresholds for each mode regime are shifted by the same amount relative to the corresponding threshold in a

Table 2 (a). Non-level of service variable definitions and sample statistics (n = 1440)

Variable	Definition	Sample Statistics	
		Mean	Std. Dev.
Socio-demographic variables			
Income	Annual household income in (10^{-4}) $	6.19	2.83
Age	Age of individual in (10^{-1}) yr.	4.12	1.25
Single parent household	1 if single parent household, 0 otherwise	0.02	0.13
Vehicles per worker in household	Number of vehicles per worker in the household	1.08	0.47
Presence of children < 12 years	1 if presence of children 0-11 yr. in the household, 0 otherwise	0.26	0.44
Presence of children 12 -16 years	1 if presence of children 12-16 yr. in the household, 0 otherwise	0.14	0.35
Number of adults	Number of adults in the households	2.35	0.94
Married female	1 if individual is a female and married, 0 otherwise	0.26	0.44
Location characteristics			
Population density at home zone	Population density of the home-zone (10^{-5})	0.76	0.97
Employment density at work zone	Employment density of the work-zone (10^{-5})	5.14	14.4
Work schedule characteristics			
Work duration	Work duration (in 10^{-2} min.)	4.92	1.23
Arrival at work before 8 a.m.	1 if individual arrives at work before 8 a.m., 0 otherwise	0.50	0.50
Departure from work before 4 p.m.	1 if individual departs from work before 4 p.m., 0 otherwise	0.27	0.44
Departure from work between 4-6 p.m.	1 if individual departs from work between 4-6 p.m., 0 otherwise	0.62	0.49

Table 2 (b) Level-of-service variables and associated sample statistics (n = 1440)

Variables (all variables refer to one way travel)	For solo-auto		For shared-ride		For transit	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Total travel time to work - in min.	23.34	15.73	28.72	16.86	63.86	36.55
Out-of-vehicle travel time over distance to work - in min/mile	1.34	2.28	2.07	3.30	9.10	10.25
Travel cost to work - $	1.86	1.75	0.74	0.70	2.08	1.72

base mode regime; the total number of parameters characterizing the thresholds in this specification is six in each stop-making equation, four thresholds in the base mode regime and two structural shift terms for the two remaining mode regimes). This second specification is equivalent to maintaining the same thresholds for all mode regimes, but introducing constants in the stop propensity equations in two of the three mode regimes. A likelihood ratio test between the two specifications did not reject the second specification relative to the first. Hence we used the second specification for the thresholds in the current analysis. Further, the effect of the structural shift terms were very insignificant in the post-home arrival stop-making propensity equation, and so we maintained the same threshold values (without structural shift) for the post-home arrival stops equation.

Finally, we constrained the correlation in unobserved factors affecting the evening commute and post-home arrival stop-making propensities to be equal across the mode regimes (*i.e.*, $\rho_{\eta_i\lambda_i} = \rho_{\eta\lambda}\ \forall i.$). The correlation between unobserved factors affecting the propensity to choose the shared ride mode to work and the post-home arrival stop-making propensity was found to be statistically insignificant and so it was dropped from the specification. A similar result was found for the transit mode and so the correlation between transit mode choice propensity and post-home arrival stops in the transit regime was also dropped. The unobserved correlation in mode choice and evening stop propensity was not statistically different between the shared-ride and transit regimes and so these two correlations were constrained to be the equal. There are four correlation parameters in the final specification representing correlation in unobserved factors affecting a) drive alone mode choice propensity and evening stop-making propensity, b) shared ride/transit mode choice and evening stop-making propensity, c) drive alone mode choice propensity and post-home arrival stop-making propensity, and d) evening stop-making and post-home arrival stop-making propensities (same across all mode regimes).

4.2. Overall Empirical Results

The log-likelihood value at convergence for the joint model system is -3437.09. The log-likelihood when only alternative specific constants are included in the mode choice model and when only the threshold parameters are introduced in the number of stops model (with all correlation parameters set to zero) is -3881.05. A log-likelihood ratio test clearly rejects the null hypothesis that all exogenous variable parameters and error correlations are zero. A further test of the joint model with an independent model (where all the correlation terms are set to zero) rejects the hypothesis that mode choice, number of evening commute stops, and number of post-home arrival stops are independently determined (the log-likelihood value of the independent model is -3456.56; the likelihood ratio value for the test is 38.94 which is larger than the chi-squared statistic with four degrees of freedom at any reasonable level of significance).

The next four sections of the paper present the results of the multinomial mode choice model, the evening commute stop-making model, the post-home arrival stop-making model, and the error correlation parameter estimates, respectively. It should be noted that the exogenous variable parameters in the different sub-models and those of the error correlations are all estimated simultaneously. We discuss them separately for ease in presentation.

4.3. Mode Choice Model

Table 3 presents the results of the mode choice model. The effects of the socio-demographic variables are as expected. Individuals with high income tend to prefer the drive

Table 3 : Mode choice model results

Variable	Coefficient	*t*-statistic
Mode constants (solo-auto is base)		
Shared-ride	-1.117	-3.12
Transit	1.408	3.42
Socio-demographic characteristics		
Income - in $\$10^{-4}$/yr.		
Solo-Auto	0.118	4.60
Vehicles per worker in household		
Solo-Auto	1.044	5.90
Number of Adults in household		
Shared ride	0.254	3.00
Location characteristics		
Population density in household zone		
Solo-Auto	-0.098	-1.55
Employment density at work zone		
Transit	0.029	6.29
Work schedule characteristics		
Arrival at work before 8 a.m.		
Transit	-0.656	-3.03
Departure between 4 and 6 p.m.		
Shared ride	0.274	1.52
Level-of-service measures- generic		
Total travel time to work - in min.	-0.043	-4.88
Out-of-vehicle travel time over distance to work - in minutes/ mile	-0.122	-3.93
Total travel cost - in $	-0.419	-8.26

alone mode over other modes. As the ratio of the number of vehicles to workers in a household increases, there is less competition for cars among the workers and hence a higher tendency to use the drive alone mode. Individuals in households with many adults are more likely to choose the shared ride mode, possibly because of greater opportunity to form a ridesharing arrangement with other household members. Another reason for the positive effect of number of adults on shared ride utility may be the higher competition for cars among household members (working and non-working).

Two variables associated with residential/workplace location characteristics affect work mode choice. Population density at the residence end of a worker has a negative impact on choice of the drive alone mode, while employment density at the work end has a highly significant positive impact on choice of the transit mode. The direction of the effect of these location attributes is quite intuitive: a high density at the home end is likely to increase the opportunity for ridesharing arrangements, while a high density at the work end may imply better transit service provision to the work end and also stressful driving (because of stop-and-go traffic) if one used the drive alone mode.

Among the work schedule characteristics, the arrival and departure times to/from work influence work mode choice. Individuals who arrive at work before 8 am in the morning are less likely to choose the transit mode (compared to individuals who arrive after 8 am), while individuals who depart from work between 4 pm and 6 pm in the evening are more likely to choose the shared ride mode (relative to those who leave before 4 pm or after 6 pm). The first effect may be a reflection of time constraints in the morning; the second effect can be attributed to the greater opportunity to form ride sharing arrangements since most individuals leave work between 4 pm and 6 pm.

The level-of-service measures yield reasonable parameters (an earlier specification that deflated travel cost by income was found to be less satisfactory than the cost specification adopted here). The implied cost of in-vehicle travel time is \$6.21 per hour and that of out-of-vehicle time is \$8.10 per hour (computed at the mean one-way travel distance to work of 9.36 miles).

4.4. Number of Evening Commute Stops Model

The effect of exogenous variables on evening commute stop-making propensity are shown in Table 4. The positive influence of income on stop-making propensity is consistent with the results from earlier studies (see Strathman *et al.*, 1994; Goulias and Kitamura, 1989). We did not find any gender-based differences for unmarried individuals; however, married women were more likely to make stops than married men. This may be a reflection of the continuing trend of women to be primarily responsible for household maintenance activities and for dropping/picking up children from day-care (see Mensah, 1995). The presence of children less than 12 years in a household has been known to influence the post-work activity participation behavior of adults in the household (see, for example, Jones *et al.*, 1990 and Bhat, 1996). Our results suggest that individuals in households with young children make less evening commute stops, possibly because they are faced with the responsibility of taking care of young children at home. The number of adults in a household has a highly significant negative influence on stop-making propensity: the greater the number of adults, the more opportunity there is to share the responsibility of household maintenance activities. The final socio-demographic variable affecting evening commute stop-making is associated with household structure. Specifically, individuals who are single parents make more evening commute stops than other individuals.

Table 4 : Number of evening commute stops model results

Variable	Coefficient	*t*-statistic
Work mode		
Shared ride	0.159	1.49
Transit	-0.071	-0.64
Socio-demographic characteristics		
Income - in $\$10^{-4}$/yr.	0.0345	2.83
Female and married	0.241	3.36
Presence of children < 12 yr.	-0.168	-2.19
Number of Adults	-0.204	-5.76
Single parent households	0.599	2.07
Work schedule characteristics		
Work duration (in 10^{-2} min.)	-0.107	-3.25
Departure before 4 p.m.	0.598	3.97
Departure between 4 & 6 p.m.	0.461	3.59
Level-of-service measures		
Total travel time to work - in min.	-0.0042	-1.96
Out-of-vehicle time over distance - in minutes/mile	-0.0304	-2.45
Threshold propensity demarcating		
zero and one stop	0.016	0.07
one and two stops	0.840	3.36
two and three stops	1.396	5.48
three and four stops	1.871	7.16

Work schedule characteristics play an important role in determining number of evening commute stops. The duration at work determines the time available for post-work activities and, consequently, has a negative effect on evening commute stop-making propensity. The departure time variables from work are introduced with the departure time after 6 pm being the base. The results indicate that individuals who leave work earlier are more likely to make commute stops.

The level-of-service of travel between home and work affects number of stops during the work commute. A higher travel time to work results in tighter time constraints and reduces number of evening commute stops. The negative coefficient on the out-of-vehicle travel time over distance variable suggests that out-of-vehicle time is perceived as being more onerous and tiring (particularly when the distances traveled are short) than in-vehicle time, leading to a greater reduction in evening stop-making propensity. Travel cost to work had a very insignificant impact on stop-making propensity. Since we also did not have any strong theoretical reason to expect travel cost to affect non-work stops, we did not include it in the specification.

We would like to note here that the effects of the travel time variables were statistically insignificant in the independent model, unlike the results for the joint model presented in Table 4. On the other hand, the parameters on the shared-ride and transit mode constants were negative and highly significant in the independent model while the constants in the joint model are statistically insignificant. These differences in level-of-service parameters and mode constants are associated with the different structures of the independent and joint models. The independent model assumes that the mode choice decision is made prior to the number of evening commute stops decision. Since the choice of shared-ride or transit is generally associated with larger travel times than the choice of driving alone (see Table 2), any negative effect of travel times on evening stop-making propensity is implicitly captured in the negative shared-ride and transit mode constants. This leads to the (incorrect) conclusion that individuals make fewer evening commute stops *because* of an earlier decision to rideshare or use transit. In contrast, the joint model recognizes the endogenous nature of mode choice; that is, it recognizes that an individual might "select" a particular travel time to work based on the number of stops s/he would like to make and the "selection" of this travel time effectively determines which mode s/he chooses. Thus, the apparent effect of travel mode on number of evening commute stops in the independent model is an artifact of the "selection" of travel time to work while making a "package" choice of both travel mode and number of evening commute stops at the same time.

4.5. Number of Post-Home Arrival Stops Model

Table 5 presents the results of the post-home arrival stops model (the parameters indicate the effect of variables on the latent post-home arrival stop-making propensity). Among the socio-economic variables, the effect of age indicates that older people are likely to make fewer post-home arrival stops relative to younger individuals (See Damm, 1980 and Hamed and Mannering, 1993 for a similar result). This may be because of physiological considerations that decrease the mobility (and mobility desires) of older individuals. Individuals who are single parents make fewer post-home arrival stops, possibly because they bear all the responsibility of child care and would like to spend time with their children. The effect of children depends on their age. As in the case of evening commute stops, individuals with children less than 12 years in their household make fewer post-home arrival stops. However, the presence of children in the age group of 12-16 years tends to increase post-home arrival stop-making. This latter result may be a combination of two factors. First, older children require less attention and supervision compared to younger children, thus allowing adults in the household to pursue out-of-home activities. Second, the

Table 5 : Number of post-home arrival stops model results

Variable	Coefficient	*t*-statistic
Socio-demographic characteristics		
Age (in 10^{-1} yr.)	-0.055	-2.17
Single parent households	-0.412	-1.22
Presence of children < 12 yr.	-0.178	-2.43
Presence of children 12-16 yr.	0.524	6.90
Work schedule characteristics		
Work duration (in 10^{-2} min.)	-0.116	-3.66
Departure before 4 p.m.	0.962	6.59
Departure between 4 & 6 p.m.	0.559	4.47
Level-of-service measure		
Total travel time to work - in min.	-0.0036	-1.822
Threshold propensity demarcating		
zero and one stop	0.098	0.40
one and two stops	0.950	3.89
two and three stops	1.619	6.37
three and four stops	2.186	8.29

recreational desires of older children may encourage the entire family to participate in out-of-home activity.

The impact of work schedule characteristics on post-home arrival stop-making are reasonable. It is interesting to note that the effects of work duration on evening commute stop making propensity and post-home arrival stop-making propensity are about the same.

The only level-of-service variable found to impact post-home arrival stops was total travel time to work. As expected, a larger travel time to work leaves less time available for post-home arrival stops and hence decreases post-home arrival stop-making propensity.

4.6. Correlation Parameters

The joint modeling of mode choice, number of stops during the evening commute, and number of stops after arriving home from work is necessitated by the potential presence of correlation in unobserved elements affecting the three decisions. The results (see Table 6) indicate statistically significant correlations.

Table 6. Estimates of Correlation

Correlation in error components between...	Estimate	t-statistic
Drive alone utility and evening stop-making propensity equations	-0.4233	-2.71
Shared-ride/Transit utility and evening stop-making propensity	0.1503	2.24
Drive alone utility and post-home arrival stop-making propensity	-0.2112	-1.92
Evening and post-home arrival stop making propensities	-0.2819	-5.26

The parameter estimates in the first and second rows of Table 4 represent the correlation between the error terms v_{qi} and η_{qi} for the drive alone mode and shared-ride/transit modes, respectively (see equation 5). Since the error term v_{qi} enters the mode choice utility equation negatively (see equation 3), a positive parameter in the first two rows of Table 6 actually indicates a negative correlation between unobserved factors affecting the corresponding mode utility and evening stop-making propensity, while a negative parameter implies a positive correlation. A similar result holds for the correlation in unobserved factors between the drive alone mode utility and the post-home arrival stop-making propensity in the third row of the table. The results show that unobserved factors (say, need for control and independence, impulsiveness, *etc.*) that increase the preference for the drive alone mode also increase stop-making propensity during the evening commute and the post-home arrival periods. On the other hand, unobserved factors (say, low activity levels) that increase the preference for the shared-ride and transit modes decrease evening commute stop-making propensity. Thus, the choice of mode is not exogenous to stop-making; individuals who would like to make more evening commute stops and more post-home arrival stops tend to choose the drive alone mode to work, all observed characteristics being equal. The last row of Table 6 shows a negative association in unobserved factors influencing evening stop-making and post-home arrival stop-making, suggesting the presence of substitution effects in stop-making between the two periods. As we will see in the next section, the correlations in Table 6 have substantial implications for policy analysis.

5. Policy Implications

The model formulated and estimated in this paper can be used to examine a wide variety of policy actions. Most transportation congestion management actions attempt to effect a change in mode choice or reduce trip-making by directly or indirectly impacting the level-of-service variables (see Bhat, 1997b). Conventional mode choice models only consider the potential impact on work trips due to such policy actions; they are unable to estimate the impacts on trips made for non-work purposes. Since non-work trips also contribute to traffic congestion, conventional mode choice models do not provide adequate information on the effectiveness of alternative congestion-alleviation actions. An alternative approach to the evaluation of congestion-alleviation actions may involve the development of independent mode choice and number of stops models. The joint choice probability of each mode, evening commute stops, and post-home arrival stops combination can then be obtained by multiplying the estimated probabilities of each individual choice. However, as indicated earlier, this approach ignores the correlation in unobserved factors that affect the three choices (*i.e.*, it ignores the joint nature of the three decisions). Consequently, this alternative approach can also provide misleading projections of the impact of policy actions.

In the rest of this section, we examine the impacts of changes in policy-relevant exogenous variables on number of stops by the drive alone mode during the evening commute and total number of stops during the post-home arrival period. We confine our attention to the impact on stops made by the drive alone mode for the evening commute because drive alone stops contribute most to traffic congestion (on the other hand, transit stops do not contribute to vehicle-trips since transit service is independent of whether an individual using transit decides to make a stop or not). Almost all stops made after arriving home are made by the auto mode and so we compute the effect on total post-home arrival stops (independent of the work mode used).[1]

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[1]The reader will note that the current model can provide, if needed, much more detailed effects on stop-making than the effect on drive alone evening stops and total post-home arrival stops. Specifically, the model can provide the impact on each mode, evening stop, and post-home arrival stop combination

The impact of policy actions on drive alone stops during the evening commute can be evaluated by modifying exogenous variables to reflect a change, computing revised disaggregate probabilities for each "evening stop-post home arrival stop" combination by the drive alone mode to work, summing the disaggregate probabilities across all post-home arrival stop categories for each evening stop category, computing revised expected aggregate values for number of evening stops by the drive alone mode, and then obtaining a percentage change from the baseline estimates. The effect of policy actions on total post-home arrival stops is obtained by modifying exogenous variables to reflect a change, computing revised disaggregate probabilities for each "work travel mode-evening stop-post home arrival stop" combination, summing the disaggregate probabilities across all evening stop categories and work travel modes for each post-home arrival stop category, computing revised expected aggregate values for number of total post-home arrival stops, and then obtaining a percentage change from the baseline estimates.

Table 7 provides the estimated percentage change (at the aggregate level) in evening stops by the drive alone mode and in (total) post-home arrival stops in response to transit service improvements and an increase in auto-use costs. The transit service improvements involve a five minute decrease (on average across the sample) in transit in-vehicle and out-of-vehicle travel times (note that since some individuals have a current in-vehicle/out-of-vehicle time of less than five minutes, it is not possible to decrease travel time by five minutes on an individual basis and hence the scenario of a five minute decrease on average). The five minute decrease (on average)

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due to the implementation of policy actions. Such an evaluation would be useful if the current model is part of a larger model system that subsequently analyses temporal and spatial attributes of each stop (please refer to the discussion in section 1). The output of such a larger model system would be change in number of stops by time-of-day in the afternoon/evening and by spatial corridor.

Table 7: Impact of Policy Actions

Policy Scenario	Model	Stop Category	Percentage aggregate change						
			0 stops	1 stop	2 stops	3 stops	4 stops	Net effect	Total net effect
5 minute reduction (on average) in transit in-vehicle travel time	Independent	Evening	-1.066	-1.174	-1.125	-1.121	-1.102	-1.118	-0.432
		Post-Home	-0.049	0.060	0.103	0.125	0.134	0.091	
	Joint	Evening	-1.323	-0.902	-0.707	-0.580	-0.446	-0.737	-0.234
		Post-Home	-0.074	0.089	0.156	0.196	0.222	0.141	
5 minute reduction (on average) in transit out-of-vehicle travel time	Independent	Evening	-1.930	-1.955	-1.956	-1.949	-1.932	-1.951	-0.824
		Post-Home	-0.021	0.028	0.043	0.046	0.037	0.036	
	Joint	Evening	-2.410	-1.518	-1.139	-0.899	-0.655	-1.200	-0.394
		Post-Home	-0.103	0.109	0.225	0.316	0.408	0.209	
50 cents increase (on average) in drive alone cost	Independent	Evening	-4.218	-4.165	-4.075	-3.980	-3.824	-4.067	-1.859
		Post-Home	0.093	-0.114	-0.193	-0.245	-0.284	-0.175	
	Joint	Eveming	-4.810	-3.064	-2.378	-1.954	-1.514	-2.492	-1.033
		Post-Home	-0.024	0.012	0.062	0.109	0.158	0.058	

corresponds to about a 17.7% (22%) decrease in transit in-vehicle (out-of-vehicle) time for each individual in the sample. The increase in auto cost involves a 50 cents hike (on average across the sample) in drive alone costs to work. This hike corresponds to a 26.9% increase in drive alone cost for each individual in the sample (in the rest of this section, we will refer to evening commute stops by the drive alone mode as "evening stops" for brevity).

The results in Table 7 indicate that the independent model shows an almost equal percentage decrease across evening stop categories for all the congestion-alleviation policy measures. However, the joint model shows that an improvement in transit service or increase in drive alone cost to work draws individuals traveling by the drive alone mode very unevenly based on the number of evening stops that they make. The largest draw is from drivers who do not make any stops and the smallest draw is from drivers who make four stops. This is a consequence of the significant and large positive correlation between the solo-auto utility and evening stop-making propensity; individuals who make many stops are unlikely to be drawn away from the drive alone mode.

The results for the post-home arrival stops in response to the transit service improvements show that the independent model underestimates (relative to the joint model) the increase in post-home arrival stops . This is because of a combination of several (not easily disentangled) reasons. First, the draw away from the drive alone mode to work due to the transit service improvements is largest for individuals who make fewer post-home arrival stops and smallest for individuals who make many post-home arrival stops (for example, the draw away from the drive alone mode to work due to the improvement in transit out-of-vehicle time was in the range of 1.74-1.98% for all the post-home arrival stop categories in the independent model; the corresponding draw values varied much more from 2.24% for individuals making no post-home arrival stops to

1.14% for individuals making 4 stops in the joint model). The uneven draw in the joint model is due to the positive correlation in unobserved factors between the drive alone utility and post-home arrival stop-making propensity. Now, those who "switch" to transit from the drive alone mode make fewer post-home arrival stops because the travel time to work tends to be higher after the "switch". Since the "switchers" are evenly drawn from all post-home arrival stop categories in the independent model, but drawn most from people making fewer post-home arrival stops in the joint model, the net result is that there is an under-estimation in total post-home arrival stop-making by the independent model. Second, those who "switch" from drive alone to transit as the work mode are much less likely to make evening commute stops by the specification of the joint model because of the negative correlation in unobserved factors influencing transit use and number of evening commute stops. The decreased number of evening commute stops of these "switchers" leads to more post-home arrival stop-making due to the negative correlation (or substitution effect) between evening commute stop-making propensity and post-home arrival stop-making propensity. By ignoring the correlation effects just discussed, the independent model again under-estimates post-home arrival stops. Third, for transit users, the decrease in transit travel time to work implies more time availability and so more post-home arrival stop-making (this effect is almost the same in both the independent model and the joint model, since the coefficient on travel time to work in the post-home arrival stops model was found to be about the same in both models). The combination of the three effects discussed above leads to a net increase in post-home arrival stops in both the independent and joint model, but an under-estimation of the increase by the independent model.

The underestimation in the change in post-home arrival stops in response to a congestion pricing strategy (*i.e.*, increase in drive alone cost to work) by the independent model can be explained in a similar manner as for the transit service improvements. The only difference is that the third effect is not present because travel cost to work does not affect post-home arrival stop-making propensity. Consequently, the independent model predicts (incorrectly) that there is an overall decrease in post-home arrival stops.

The net percentage change in evening commute stops and post-home arrival stops can be computed as:

$$\text{Net \% change in stops} = \sum_{k=0}^{K=4} \left(\frac{k n_k}{\sum_k k n_k} \right) \zeta_k \qquad (10)$$

where n_k is the expected number of individuals who make k evening commute (or k post-home arrival) stops before implementation of the policy action, and ζ_k is the percentage aggregate change in each stop category. This overall effect on number of stops is shown in the column labeled "Net Effect". The independent model projects a substantially more optimistic view of the reduction in evening commute stops than the joint model; in particular, the independent model overestimates the percentage reduction in evening stops by more than 50% for every policy scenario. The independent model also underestimates the increase in post-home arrival stops in response to transit service improvements to work by 36% for transit in-vehicle time and by 84% for transit out-of-vehicle time. As discussed earlier, the direction of the change in post-home arrival stops predicted by the independent model is itself incorrect in response to an increase in drive alone cost to work.

The net effect on the sum of evening commute stops and post-home arrival stops (or total post-work stops) is provided in the final column of Table 7. The figures in this column show that use of the independent model overestimates the decrease in total post-work stops due to congestion alleviation actions by 80% to 109%. Such substantial overestimates of the benefits of traffic control measures can lead to misdirected policy actions and underscores the need to model work mode choice and non-work activity stop-making jointly. The results are also important from a mobile-source emissions standpoint, since the independent model overestimates the reduction in total vehicle stops in response to Transportation Control Measures (TCMs).

6. Summary and Conclusions

In this paper, we have developed a joint model of work mode choice, number of non-work activity stops during the evening commute, and number of non-work stops after arriving home from work. The methodology developed here represents, to the authors' knowledge, the first attempt in discrete choice literature to formulate and estimate a model with an unordered multinomial choice as well as two ordered multinomial choices.

The empirical analysis uses a data set from the Boston Metropolitan area. The results indicate the strong effects of socio-economic variables (household income, number of vehicles per worker in the household, and number of adults in the household, work duration), residential/workplace location characteristics (population density at residence and employment density at the work place), work schedule characteristics (work arrival and departure time), and level-of-service measures on mode choice to work. Socio-economic variables and work schedule characteristics significantly influence stop-making propensity during the evening commute and the post-home arrival period. In-vehicle and out-of-vehicle travel times to work negatively influence the number of evening commute stops and the number of post-home arrival stops, but we did not find any significant effect of travel cost to work on stop-making propensity. Our empirical analysis also shows strong correlations in random components among mode choice utility, evening commute stop-making propensity, and post-home arrival stop-making propensity. Ignoring these correlations leads to inappropriate estimates of the effect of the level-of-service measures on stop-making propensity. The correlations also have a substantial impact on the aggregate percentage change in number of stops during the evening commute and post-home arrival periods due to changes in policy-relevant exogenous variables. In general, ignoring the correlations leads to a rather substantial overestimate of the decrease in stop-making after work. This can lead to misdirected policy actions for traffic congestion alleviation and for mobile-source emissions reduction.

The current model is conceived as part of a larger model system that analyses the entire daily activity-travel pattern of individuals, including the temporal and spatial attributes of each activity stop made by individuals. Such a larger model system would be able to provide more detailed information on the changes in number of stops by time-of-day and by spatial corridor. The modeling of this larger model system is currently ongoing.

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References

Adiv, A. (1983). The structure of work-trip based on analysis of trip diaries in the San Francisco Bay area, in S. Carpenter & P. Jones (eds.), *Recent Advances in Travel Demand Analysis*, 335-349, Gower, Aldershot, England.

Beggan, J.G. (1988). The Relationship Between Travel/Activity Behavior and Mode Choice for the Work Trip, unpublished Master's Thesis, Northwestern University.

Bhat, C.R. (1996). A generalized multiple durations proportional hazard model with an application to activity participation behavior during the work commute, Transportation Research, 30B, 432-452.

Bhat, C.R. (1997a). A model of post-home arrival activity participation behavior, working paper, Department of Civil and Environmental Engineering, University of Massachusetts, Amherst.

Bhat, C.R. (1997b). Work travel mode choice and number of nonwork commute stops, Transportation Research, 31B, 41-54.

Bhat, C.R. (1997c). An econometric framework for modeling the daily activity-travel pattern of individuals, paper presented at the activity-based analysis workshop held at the National Institute of Statistical Sciences (NISS), North Carolina, May.

Gallagher, J. (1993). Development of regional interim home-based work mode choice models, Technical Memorandum, May 14.

Golob, T.F. (1986). A non-linear canonical correlation analysis of weekly chaining behavior, *Transportation Research*, 20A, 385-399.

Gordon, P., Kumar, A. and Richardson, H.W. (1988) Beyond the journey to work, *Transportation Research*, 21A, 6, 419-426.

Goulias, K.G. and R. Kitamura (1989). Recursive model system for trip generation and trip chaining, *Transportation Research Record*, 1236, 59-66.

Hamed, M.M and F.L. Mannering (1993). Modeling travelers' postwork activity involvement: toward a new methodology, *Transportation Science*, 27, 4, 381-394.

Jones, P. M., F.S. Koppelman, and J.P. Orfeuil (1990) Activity analysis: state of the art and future directions, *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, 34-55, Gower, Aldershot, England.

Karash, K.H. and C. Schweiger (1994). Identification of Transportation Planning Data requirements in Federal Legislation, Final Report, Prepared for the Volpe National Transportation Systems Center, Sponsored by the U.S. Department of Transportation and the U.S. Environmental Protection Agency, July.

Kim, H.J., S. Soot, A. Sen, and E. Christopher (1994). Shopping trip chains: current patterns and changes since 1970, *Transportation Research Record, 1443*, 38-44.

Lee, L.F. (1983). Generalized econometric models with selectivity, *Econometrica*, 51, 2, 507-512.

Lockwood, P.B. and M.J. Demetsky (1994). Nonwork travel - A study of changing behavior", presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, D.C., January.

Mannering, F., E. Murakami and S.G. Kim (1994). Temporal stability of travelers' activity choice and home-stay duration: some empirical evidence, Transportation, 21, 371-392.

Mensah, J. (1995). Journey to work and job characteristics of the urban poor: A gender analysis of a survey data from Edmonton, Alberta, *Transportation*, 22, 1-19.

Purvis, C.L. (1994). Changes in regional travel characteristics and travel time budgets in the san francisco bay area: 1960-1990, presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, D.C., January.

Singh, S.K. (1997) A joint model of work travel mode choice and number of non-work activity stops, forthcoming Master's Thesis, Department of Civil and Environmental Engineering, University of Massachusetts, Amherst.

Stopher, P.R. (1991) Deficiencies of travel-forecasting methods relative to mobile emissions, *Journal of Transportation Engineering*, 119, 5, 723-741.

Strathman, J.G., K.J. Dueker and J.S. Davis (1994). Effects of household structure and selected travel characteristics on trip chaining, *Transportation*, 21, 23-45.

Train, K. (1986). *Qualitative Choice Analysis: Theory, Econometrics, and an Application to Automobile Demand*, The MIT Press, Cambridge, Massachusetts.