Modeling Household Interactions in Daily In-Home and Out-of-Home Maintenance Activity Participation

Sivaramakrishnan Srinivasan
Chandra R. Bhat

The University of Texas at Austin
Department of Civil Engineering
1 University Station C1761
Austin, Texas 78712-0278
Tel: 512-471-4535
Fax: 512-475-8744,
Email: s.siva@mail.utexas.edu
bhat@mail.utexas.edu

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ABSTRACT

The activity travel patterns of individuals in a household are inter-related, and the realistic modeling of activity-travel behavior requires that these interdependencies be explicitly accommodated. This paper examines household interactions impacting weekday in-home and out-of-home maintenance activity generation in active, nuclear family, households. The in-home maintenance activity generation is modeled by examining the duration invested by the male and female household heads in household chores using a seemingly unrelated regression modeling system. The out-of-home maintenance activity generation is modeled in terms of the decision of the household to undertake shopping, allocation of the task to one or both household heads, and the duration of shopping for the person(s) allocated the responsibility. A joint mixed-logit hazard-duration model structure is developed and applied to the modeling of out-of-home maintenance activity generation. The results indicate that traditional gender roles continue to exist and, in particular, non-working women are more likely to share a large burden of the household maintenance tasks. The model for out-of-home maintenance activity generation indicates that joint activity participation in the case of shopping is motivated by resource (automobiles) constraints. Finally, women who have a higher propensity to shop are also found to be inherently more efficient shoppers.

1. BACKGROUND AND RESEARCH OBJECTIVES

There has been substantial interest in the development and refinement of activity-based methods for travel demand modeling in the past couple of decades (see Bhat and Koppelman, 1999 and Pendyala and Goulias, 2002 for detailed reviews on the state-of-the art in activity-based modeling). The main emphasis of such methods is on modeling the complete activity schedule of individuals over a period of a day or a longer unit of time. Individuals, however, do not make their decisions about activity and travel participation in isolation from other individuals in their household (Golob, 1997). Rather, the household members interact in many ways and, consequently, their activity-travel patterns are inter-dependent. In fact, one of the fundamental aspects of the activity-based paradigm is the explicit recognition of these inter-dependencies among the travel patterns of household members (Pas, 1985; Jones *et al.*, 1990). Yet, there has been relatively limited research on the complex linkages that exist among the activity-travel patterns of all individuals in a household.

Within the context of modeling short-term activity-travel demand, four types of household interactions are of importance. These are (1) sharing of household maintenance responsibilities by family members, (2) joint engagement of household members in activities and travel, (3) facilitation of activity participation of household members with restricted mobility by undertaking pick-up and drop-off trips, and (4) sharing the use of common household vehicles. Travel-demand models recognizing these linkages may be expected to better reflect the behavioral responses of households to changes in land-use, transportation system, and demographic characteristics. Hence, such models are necessary for realistic evaluation of the impacts of policy actions (Scott and Kanaroglou, 2002; Vovsha *et al.*, 2003).

In contrast to the importance of recognizing inter-personal dependencies in activity modeling, much of the research efforts to date have accommodated household interaction effects, at best, by using household-level characteristics as explanatory variables in individual-level models. However, there have been some recent efforts to accommodate household interactions more explicitly. These studies may be broadly classified into two groups based on the modeling methodology. The <u>first</u> approach to modeling household interactions involves the joint estimation of multiple continuous choice variables using either the structural equations modeling (SEM) approach or the seemingly unrelated regressions (SUR) approach. These studies include Ettema *et al.* (2004), Schwanen, *et al.* (2004), Zhang and Fujiwara (2004), Zhang *et al.* (2004), Meka *et al.* (2002), Simma and Axhausen (2001), Fujii *et al.,* (1999), and Golob (1997). The second approach involves the use of discrete choice and shares models. These studies include the discrete-choice model system of Vovsha *et al.* (2004a, 2004b, 2003), the trivariate ordered probit model developed by Scott and Kanaroglou (2002), Gliebe and Koppelman's (2002) proportional shares model and the nested-logit model systems of Wen and Koppelman (2000 and 1999).

In this study, we contribute to the growing body of literature on modeling inter-personal interactions by modeling the weekday activity participation choices of adults in active, nuclear family, households (such households include at least one employed adult, comprise a male-female couple, and children, if present, are all <= 15 years of age). In these households, it can be assumed that the daily activity generation comprises three sequential steps: (1) the generation of mandatory activities (activities such as work, school, and pick-up/drop-off of children from/at school which are undertaken with significant regularity and under rather strict spatial and temporal constraints), (2) the generation of maintenance activities (activities such as cooking, cleaning, and shopping which are undertaken for the upkeep of the household), and (3) the generation of discretionary activities (activities such as social visits, recreation, and personal business which are characterized by greater spatial and temporal flexibility and undertaken either independently or jointly with other family members). This sequencing is based on the hypothesis that households operating within the time constraints imposed by mandatory activities prioritize their activity participation choices based on the relative importance of the different activities and the constraints associated with the different activities (Golob, 1997; Goulias, 2002; Ettema *et al.*, 2004).

Within the overall context of modeling the inter-dependent activity participation choices of adults in active, nuclear family, households, the focus of this paper is on modeling maintenance activity participation decisions. Specifically, the model system presented in this paper comprises two components: (1) the in-home maintenance activity generation model and (2) the out-of-home maintenance activity generation model. The in-home maintenance activity participation is modeled using a *seemingly unrelated regression* system of two equations; one equation corresponding to the daily in-home maintenance time invested by the male and the other corresponding to the daily in-home maintenance time invested by the female. The analysis of out-of-home maintenance activity participation involves the modeling of the decision of households to undertake maintenance activity, allocation of this responsibility to the household head(s), and the duration of activity participation for the person(s) allocated the responsibility using a discrete-continuous model system. Specifically, the discrete component of the choice (the household's decision to undertake maintenance activity and its allocation) is modeled using a mixed-logit structure. The continuous component of the choice (the activity duration) is modeled using a hazard-duration model structure. The discrete and continuous components are estimated jointly leading to a *joint mixed-logit hazard-duration* model structure.

In summary, the objective of this current paper is to contribute to the understanding of the household interactions by modeling the generation of in-home and out-of-home maintenance activities as an outcome of household needs, desires, opportunities, and constraints. Methodologically, this paper contributes by developing a joint mixed-logit hazard duration (discrete-continuous) model and applying it in the context of the generation of out-of-home maintenance activity generation. To our knowledge, this is the first application of a joint mixed-logit hazard-duration model system in the econometric literature.

The rest of this paper is organized as follows. Section 2 describes the econometric model structures and the estimation procedures. Section 3 identifies the data sources. Section 4 presents the empirical model results for in-home maintenance activity generation, and Section 5 presents the results for out-of-home maintenance activity generation. Finally, Section 6 presents a summary of the research effort and identifies the major conclusions.

2. ECONOMETRIC MODEL STRUCTURES AND ESTIMATION PROCEDURES

As already indicated in the previous section, the model system presented in this paper comprises two components: (1) A seemingly unrelated regressions model for in-home maintenance activity generation and (2) A joint mixed logit hazard-duration model for out-of-home maintenance activity generation. The structure of the seemingly unrelated regressions model is straightforward. So, we present the structure for only the joint mixed-logit hazard-duration model in this paper.

We consider grocery shopping (referred to simply as shopping henceforth) as the only out-of-home maintenance activity type in this analysis. Let i represent the index for the discrete choice alternatives, which can be one of the following: (1) Household does not shop (i=N), (2) Male is the only one allocated the shopping responsibility (i=M), (3) Female is the only one allocated the shopping responsibility (i=F), and (4) Both the male and female shop jointly (i=J).

The reader will note that this choice structure assumes that the shopping responsibility is either assigned to one of the household heads or to both to be undertaken jointly, and that households do not choose a combination of these choices (for example, both household heads undertaking independent shopping, the female undertaking independent shopping in addition to joint shopping with the male, etc.) This assumption is also supported by the data used in the analysis.

The discrete component in the choice structure (*i.e.,* the household's decisions to shop and the allocation of this task) is modeled using a mixed-logit structure. The utility functions for the discrete choice alternatives are specified as:

$$U_{iq} = \beta_i Z_{iq} + \omega_{iq} + \varepsilon_{iq}, \tag{1}$$

where, U_{iq} is the indirect utility that household q derives from alternative i. Z_{iq} is the vector of exogenous variables for household q and alternative i, and β_i is the vector of coefficients on exogenous variables for alternative i. ω_{iq} and ε_{iq} are stochastic error terms. Assume that ω_q = [ω_{Nq}, ω_{Mq}, ω_{Fq}, ω_{Jq}] is multivariate normal distributed with a mean vector of zero and covariance matrix Σ. It is also independently and identically distributed across households. Assume that ε_{iq} is independently and identically gumbel-distributed (with a unit scale) across the choice alternatives and across households (this assumption leads to the multinomial logit structure for the discrete choice conditional on ω_q).

Next, define the following variable:

$$\upsilon_{iq} = \left\{ \max_{j=N,M,F,and\, J\&j\neq i} (\beta_j Z_{jq} + \omega_{jq} + \varepsilon_{jq}) \right\} - \varepsilon_{iq} \tag{2}$$

Based on the gumbel-distribution assumption on ε_{iq}, this newly defined random variable, υ_{iq}, has a logistic distribution (conditional on ω_q). Let $F_i(\upsilon_{iq} \mid \omega_q)$ represent this cumulative density function. Defining a dichotomous variable R_{iq} such that R_{iq} = 1 if household q chooses alternative i and 0 otherwise, the conditional probability (conditional on ω_q) that household q chooses discrete alternative i is given by:

$$\text{Prob}(R_{iq} = 1 \mid \omega_q) = F_i(\beta_i Z_{iq} + \omega_{iq} \mid \omega_q) = \frac{\exp(\beta_i Z_{iq} + \omega_{iq})}{\sum_{j=N,M,F,J} \exp(\beta_j Z_{jq} + \omega_{jq})} \tag{3}$$

The choice of shopping duration is modeled using a hazard-based duration model system. Note that there is *no* choice of duration when the household chooses not to shop (i = N). Under each of the other three discrete choice alternatives (i = M, F, and J), there is a corresponding choice of duration. Each of these three hazard functions is specified using the proportional hazard form (Kiefer, 1998) as follows:

$$\begin{aligned}\lambda_{iq}(T) &= \lim_{\delta \to 0^+}\left(\frac{\Pr ob\left[T+\delta > s_{iq} \geq T \mid s_{iq} \geq T\right]}{\delta}\right) \\ &= \lambda_{0i}(T)\exp(-\gamma_i X_{iq}),\end{aligned} \tag{4}$$

where, for household q, and for each of i = M, F, and J, $\lambda_{iq}(T)$ is the continuous time hazard, $\lambda_{0i}(T)$ is the baseline hazard at time T, X_{iq} is a vector of exogenous variables, and γ_i is the vector of coefficients on these exogenous variables. The above specified hazard function can be written in the following equivalent form (Bhat, 1996):

$$\begin{aligned}s^*_{iq} &= \ln \Lambda_{0i}(s_{iq}) = \ln \int_0^{s_{iq}} \lambda_{0i}(T)dT \\ &= \gamma_i X_{iq} + \eta_{iq},\end{aligned} \tag{5}$$

where s^*_{iq} is household q's integrated hazard for the duration corresponding to the discrete choice i. η_{iq} is the stochastic error term that takes the extreme value distribution with the cumulative density function given by: $G(\eta) = 1\text{-}exp(\text{-}exp(\eta))$.

Next, in order to specify a non-parametric baseline hazard, the continuous time T, is divided into discrete periods represented by the index k_i (k_i =1,2,3… K_i) for each of i=M, F, and J as:

$$k_i = 1 \text{ if } T \in [0, T_i^1],\ k_i = 2 \text{ if } T \in [T_i^1, T_i^2], \ldots\ k_i = K_i \text{ if } T \in [T_i^{K_i\text{-}1}, \infty]$$

Let t_{iq} be the discrete period of termination of duration corresponding to discrete choice i and for household q. Also, define a dichotomous variable, $M_{k_i q}$, such that $M_{k_i q}$ = 1 if household q chooses discrete period k_i (*i.e.,* $t_{iq} = k_i$) for the duration corresponding to discrete choice i, and 0 otherwise. Now, based on the extreme value distribution assumption for the error term η_{iq}, we have:

$$\begin{aligned}&\text{Prob}(M_{k_i q} = 1) = G\left(\delta_{i,k_i} - \gamma_i X_{iq}\right) - G\left(\delta_{i,k_i-1} - \gamma_i X_{iq}\right), \\ &\text{where, } \delta_{i,k_i} = \ln \Lambda_{0i}(T^{k_i}) \quad \text{and} \quad \delta_{i,k_i-1} = \ln \Lambda_{0i}(T^{k_i-1})\end{aligned} \tag{6}$$

To complete the specification of the model system, define ρ_i as the correlation between υ_{iq}, in the discrete part of the model system and η_{iq}, in the continuous duration part of the model system (for i = M, F, and J). The likelihood function can be constructed by converting the non-normal error terms into normal random variables (Lee, 1983):

$$\upsilon_{iq}^{*} = \Phi^{-1}\left[F_i(\upsilon_{iq} \mid \omega_q)\right]$$
$$\eta_{iq}^{*} = \Phi^{-1}\left[G(\eta_{iq})\right] \tag{7}$$

Using the above-specified transformations, the appropriate joint distributions between the error terms of the discrete and continuous components may be written as:

$$P_2\left[\upsilon_{iq}, \eta_{iq}, \rho_i\right] = \Phi_2\left[\upsilon_{iq}^{*}, \eta_{iq}^{*}, \rho_i\right] \ \forall i = M, F, \text{and } J \tag{8}$$

Therefore, from equations (3), (6), and (8), the joint probability that any household q chooses the discrete outcome i (for i = M, F, and J) and a corresponding discrete duration k_i (and conditional on ω_q) is given by:

$$P_q(R_{iq} = 1 \,\&\, M_{k_i q} = 1 \mid \omega_q) = \begin{Bmatrix} \Phi_2\left\{\Phi^{-1}\left(F_i(\beta_i Z_{iq} + \omega_{iq} \mid \omega_q)\right), \Phi^{-1}\left(G(\delta_{i,k_i} - \gamma_i X_{iq}\right), \rho_i\right\} - \\ \Phi_2\left\{\Phi^{-1}\left(F_i(\beta_i Z_{iq} + \omega_{iq} \mid \omega_q)\right), \Phi^{-1}\left(G(\delta_{i,k_i - 1} - \gamma_i X_{iq}\right), \rho_i\right\} \end{Bmatrix} \tag{9}$$

Further, the probability that household q chooses not to shop (*i.e.,* i = N) conditional on ω_q, is given by:

$$P_q(R_{Nq} = 1 \mid \omega_q) = \frac{\exp(\beta_N Z_{Nq} + \omega_{Nq})}{\sum_{l=N,M,F,J} \exp(\beta_l Z_{lq} + \omega_{lq})} \tag{10}$$

Therefore, the conditional likelihood function for household q is:

$$L_q \mid \omega_q = \left[P_q(R_{Nq} = 1 \mid \omega_q)\right]^{R_{Nq}} \prod_{i=M,F,J} \left[\prod_{k_i=1}^{K_i} \left[P_q(R_{iq} = 1; M_{k_i q} = 1 \mid \omega_q)\right]^{M_{k_i q}}\right]^{R_{iq}} \tag{11}$$

The unconditional likelihood function can then be obtained by integrating over the elements in the vector ω_q:

$$L_q = \int_{\omega_q} (L_q \mid \omega_q) f(\omega_q) d\omega_q, \tag{12}$$

where $f(\omega_q)$ is the density function of the multivariate normal distribution function with a mean vector of zero and covariance matrix Σ.

It is not possible to identify all the elements in the covariance matrix, Σ. Hence, it is required to pre-specify the structure of the covariance matrix that is estimatable and also appropriate for describing the problem. The computation of the likelihood function in equation (12) involves the estimation of a multi-dimensional integral. We use simulation methods to evaluate this multi-dimensional integral. The conditional likelihood function from equation (11) is computed for different realizations of ω_q drawn from a multivariate normal distribution function (f) and averaged to obtain an approximation of the unconditional likelihood function value. The realizations of ω_q can be obtained from their multivariate normal distribution function (f) using Quasi-Monte Carlo techniques. In this research, we use 150 draws of the Halton sequence (Bhat, 2001). Multivariate draws with the appropriate covariance structure can be obtained by multiplying a vector of independent univariate draws by the Cholesky decomposition of the covariance matrix. The parameters are estimated using the maximum (log) simulated likelihood (MSL) estimation procedure.

3. DATA

The primary data source used for this analysis is the 2000 San Francisco Bay Area Travel Survey (MORPACE International Inc., 2002). In addition, data on zonal-level land-use and demographics, and inter-zonal transportation level-of-service measures, were obtained from the Metropolitan Transportation Commission (MTC). These secondary data sources were used to construct measures of zonal accessibility. In addition, the level-of service data were also used to determine the no-stop commute duration for persons going to work. Details on the sample formation process and the sample characteristics are provided in Srinivasan and Bhat (2004).

4. IN-HOME MAINTENANCE ACTIVITY GENERATION: EMPIRICAL RESULTS

This section presents the empirical results for the generation of in-home maintenance activities. For this analysis, we segment the sample into the following four groups: (1) single-worker households without children, (2) dual-worker households without children, (3) single-worker households with one or more children, and (4) dual-worker households with one or more children. Separate models were estimated for each of these four segments. The empirical model results for models for single- and dual-worker households without children are presented in Section 4.1 and the models for households with children are presented in Section 4.2.

4.1 Models for Single- and Dual-Worker Households Without Children

The models for in-home maintenance activity generation for single- and dual- worker households without children are presented in Table 1. The explanatory variables are classified into household characteristics, individual characteristics, mandatory activity participation characteristics, and day-of-the week variables.

Husbands in dual-worker Caucasian families are found to spend more time undertaking household chores when compared to husbands in Asian, Hispanic, or other types of families. Adults in dual-worker households who own their home are found to spend more time in household chores than those who live in rented dwellings. This is perhaps because of the additional time investments for the general upkeep of one's own home (for example, mowing the lawn) when compared to a rented apartment. Female heads in single-worker households with access to the Internet from home are found to invest more time in chores than those who live in households without Internet access.

Younger adults (age 16-35) are found to invest lesser time performing in-home maintenance tasks, when compared to older adults, perhaps reflecting a greater overall out-of-home orientation of the younger adults. Further, elder persons may quite naturally, due to physical reasons, require more time for undertaking household chores. Full-time employees are estimated to spend less time in household chores (when compared to part-time employees and unemployed persons in the case of single-worker household and in comparison to part-time employees in the case of dual-worker households), presumably due to time constraints imposed by the work activity. Similarly, adults in dual-worker households who are students are found to spend lesser time in household chores than those who are not students.

The time invested in in-home work during the day negatively impacts the time investment of both the male and female heads in household chores. In the case of females in dual-worker households, the rate of decrease of in-home maintenance duration with increase in in-home work time is found to be much less for in-home work durations less than four hours when compared to in-home work durations between four and eight hours. Specifically, for each additional log-minute of in-home work time between 0 and 4 hours, the logarithm of in-home maintenance time decreases by 0.162 (computed as -0.204+1.310-1.268 = -0.162) while the corresponding number for in-home work duration between 4 and 8 hours is 1.472 (computed as: -0.204-1.268 = -1.472). In the case of single-worker households, the out-of-home work duration is found to negatively impact the in-home maintenance time investment of only the husband. This result, along with the stronger negative impact of the full-time employee variable for the male compared to the female, indicates that, employed women in single-worker households without children, share a higher responsibility in household chores than employed men in similar households even if the durations spent at work are the same. In the case of dual-worker households, the out-of-home work duration has a negative impact on the in-home duration for household chores for both men and women. The commute duration is found to negatively impact the in-home time investment only for males in single-worker households.

The wife's in-home maintenance duration is positively impacted by the out-of-home work duration of her spouse (The husband's in-home maintenance duration, however, is not affected by his wife's out-of-home work duration.). This result, along with the direct negative effect of the male's work duration on his in-home time, suggests that the longer the husband spends at work, greater is the disparity in the maintenance time investments for household chores between the household heads (especially for single-worker households).

Finally, among the different days of the week, females in dual worker households are found to spend more time in household chores during the mid-week (Tuesdays and Wednesdays). The standard deviation of the error term is found to be greater for the males when compared to the females suggesting greater random variations in the male's time investments for household chores when compared to the female's time investment. The correlation between the error terms was estimated to be positive. This indicates that unobserved factors about a household (such as perhaps life style, habits, in-home orientation etc.) that positively impact the in-home duration of the male also positively impact the in-home time investment of the female.

4.2 Models for Single- and Dual-Worker Households With One or More Children

The models for in-home maintenance activity generation for single- and dual- worker household with one or more children are presented in Table 2. The explanatory variables are classified into household characteristics, individual characteristics, and mandatory activity participation characteristics.

Caucasian males in single-worker households are found to spend longer time in in-home chores when compared to men of other ethnicities. The number of children in the household positively impacts the wife's in-home maintenance duration in dual-worker households. In the case of single-worker households, the age composition of the children in the household has a significant impact on the wife's in-home time investment for chores. Specifically, women spend the least amount of time in household chores when all the children are greater than 5 years of age, more time when all the children are younger than 5 years of age (presumably because younger children need more care and attention than older ones) and the most time when both young and old children are present (the base alternative). This high time investment corresponding to the base alternative could be because of the differences in the needs of the young and old children. Neither the number nor the age composition of the children in the household was found to have a significant impact on the male's in-home time investments.

Several individual-level characteristics are found to impact in-home maintenance time allocation of adults in dual-worker households. Younger men (age <= 35 years), adults who are full-time employees, and women who are students are found to invest lesser time in household chores. In contrast, women who have access to their own personal vehicle spend more time in household chores than those who do not. Perhaps, women without a personal vehicle have to rely on transit or other means to commute, thereby decreasing the time available for household chores.

Among the mandatory activity participation characteristics, both the in-home and out-of-home work durations of a person negatively impact his/her in-home maintenance activity duration. The commute duration negatively and non-linearly impacts the husband's in-home maintenance time investment in single-worker households with children. Further, the time allocations of the household adults for household chores are positively impacted by the out-of-home work duration of their spouse in both single and dual worker households, perhaps as a consequence of the presence of children at home who require care and supervision by either of the parents. This effect is unlike in the case of households without children in which the husband's in-home time investment was not impacted by the wife's work duration. Finally, adults who drop-off or pick-up their child(ren) at/from school are also found to invest more time in household chores than those who do not (except females in single-worker households).

As in the case of households without children, the standard deviation of the error term is found to be greater for the males when compared to the females in both single and dual worker households. Further, these standard deviations are lesser when compared to the corresponding values for the households without children suggesting more random variations in in-home maintenance time investments when no children are present in the household. The correlation between the error terms is again estimated to be positive.

5. OUT-OF-HOME MAINTENANCE ACTIVITY GENERATION: EMPIRICAL RESULTS

This section of the paper discusses the empirical model results for the out-of-home maintenance activity generation. As already indicated, the out-of-home maintenance activity participation choices are modeled using a joint mixed-logit hazard duration model system. We explored different specifications for the structure of the error-covariance (Σ) among the discrete choice alternatives. However, there was no statistical evidence for the presence of correlations or hetroskedasticity in the vector of error terms ω_q. Subsequently, we also explored different nested structures for the discrete choice alternatives (*i.e.,* correlations among the error terms ε_{Nq}, ε_{Mq}, ε_{Fq}, and ε_{Jq}). Again, there was no statistical evidence for a nested structure. Therefore, we chose to specify a simple multinomial logit structure for the discrete component of the model. Hence, the overall model structure reduces to a joint MNL-hazard duration model. For ease in presentation, the results for the discrete (decision to shop and task allocation) and the continuous (shopping duration) components are discussed in separate sections below (Sections 5.1 and 5.2 respectively). Section 5.3 presents and interprets the estimated correlations between the discrete and continuous components.

5.1 Discrete Component: Decision to Shop and Task Allocation

The exogenous variables impacting the choice of undertaking shopping and the allocation of this task to one or both of the household heads (Table 3) are broadly classified into household-level characteristics, person-level characteristics, mandatory activity participation characteristics, and in-home maintenance time investment characteristics.

Young households (age of elder adult <= 35 years) are found to be least likely to undertake shopping (as indicated by the positive coefficient for “no-shopping”), whereas elderly households (age of the elder adult > 50 years of age; the base alternative) are most likely to undertake shopping. This is perhaps reflective of overall time constraints faced by younger adults who may be involved in various kinds of activities during the weekday. Households without any cars are found to be more likely to undertake shopping on any weekday (as indicated by the negative coefficient for “no-shopping”). These households may have to undertake frequent trips to the grocery store, as they do not have the means to transport groceries in bulk. Households with few autos (number of cars < number of licensed drivers) are found to be very likely to undertake joint shopping. Among the other household-level characteristics, Caucasians are found to be more likely to undertake shopping during weekdays. Households without children and low-income households (income <= $ 60K) are found to be more likely to undertake joint shopping.

Non-employed males are found to be more likely to undertake grocery shopping compared to employed males. Females who are have access to their own vehicle (*i.e.,* the female is licensed and there are at least as many vehicles in the household as there are licensed drivers) are more likely to undertake the grocery shopping for the household compared to women who do not have their own vehicle. In the latter case of women without a personal vehicle, perhaps the shopping is undertaken jointly (as also indicated by positive coefficient on the variable "few autos"). Alternatively, it is also possible that shopping is undertaken during weekend days when the vehicle is readily available for non-work use.

The mandatory activities to be performed during the day are found to have a very strong influence on choices relating to undertaking grocery shopping during the day. Employed men and women go to work are found not to prefer shopping. This negative effect is found to be stronger for the women than the men. In addition, the longer the person spends at work, the less likely is he/she to undertake grocery shopping during the day. This negative influence of the work duration on the utility for undertaking shopping suggests that shopping activities in the case of dual-worker households may not be pursued on weekdays, but perhaps undertaken on weekend days. Men who commute longer are found to be less likely to undertake shopping. In contrast, the men who undertake serve-child activities to transport their children to/from school are found to be more likely to undertake shopping for the household.

The final set of explanatory variables describes the persons' time investments for in-home maintenance. Men and women who spend less than 2 hours in undertaking in-home maintenance activities are also the ones who are unlikely to shoulder the household shopping responsibilities. This is perhaps reflective of the life-style and habits of these people (for example, being oriented away from household maintenance and possibly more focused on work and/or discretionary activities). This negative influence is found to be stronger for non-employed men than employed men.

The constants indicate the generic bias for the various choice alternatives. The coefficient on joint shopping is significantly smaller than the coefficients on the other alternatives, indicating that joint shopping is generically the least preferred option.

5.2 Continuous Component: Shopping Duration

This section presents the hazard-duration models for shopping activity duration. The estimated continuous-time baseline hazards for the male-, female-, and joint-shopping durations are presented in Figure 1. This figure also compares the baseline hazards from joint discrete-continuous models with the baseline hazards estimated from independent hazard-duration models. The baseline hazards for male- and joint-shopping durations are identical for both the independent and joint models as the corresponding correlations turned out to be statistically not different from zero. In the case of female shopping duration, the correlation was positive (the correlations are discussed in detail in Section 5.3). The plots indicate that ignoring this positive correlation results in over-estimation of the duration dependence as indicated by the higher hazards rates for female shopping duration from the independent model.

In general, the plots show an upward trend for the hazard; *i.e.,* the probability that a shopping episode will terminate increases with increase in duration of the activity. This is intuitive given the "focused" nature of grocery shopping pursuits. The duration dependence effect is the strongest for joint shopping for durations upwards of 30 minutes, possibly reflecting the time constraints of multiple people involved in the activity. In contrast, for durations less than 30 minutes, the baseline hazard is estimated to be the greatest for men, suggesting that men are more likely to undertake shopping for shorter durations. The model also indicates that the duration dependence effects are not as strong in determining the shopping time of women as they are in determining the shopping time of men. This is perhaps because women are often the primary shoppers for the household hence require a certain minimum amount of time to complete the shopping.

The effects of the covariates are presented in Table 4. These are classified into household level characteristics, mandatory activity participation characteristics, in-home time investment characteristics, and day-of-the-week variables. Note that, as specified in equation (4), a negative coefficient implies a higher hazard or equivalently, a lower duration.

Joint-shopping episodes undertaken by adults in households with few vehicles are found to be of shorter duration than those undertaken by adults in households with many vehicles. Perhaps, in the latter case of households with many vehicles, the joint shopping is seen more as family time rather than being motivated by resource constraints and hence leads to longer durations. Further, joint-shopping episodes undertaken by adults and single-worker households and in low-income households (income <= $60K) are found to be of longer durations. The final household-level characteristic impacting shopping duration is the presence of children. When men in households with children undertake shopping, they are found to spend more time in the activity when compared to men in households without children. This is possibly because the men may have to shoulder the primary shopping responsibility with the women having to spend significant time in child-rearing.

The mandatory activity participation characteristics are also found to significantly impact shopping durations. The shopping duration for both males and females is found to be shorter if the person's work ends at 4 PM or later compared to the duration when the person's work ends before 4 PM. Since workers are found to undertake activities predominantly after work (Bhat and Singh, 2000), this result is intuitive as the person has more time to undertake activities, the earlier he/she leaves work. Further, the model also indicates that men, unlike in the case of women, whose work ends between 4 and 6 PM (the peak period) have the shorter shopping durations than even those whose work ends after 6 PM. These results have substantial implications for policy actions like the employer-based demand-management schemes that are aimed at spreading the peak by releasing people earlier from work. In evaluating such schemes the analyst must consider the greater possibility of activity participation (note that the work duration was found to negatively impact the choice of undertaking shopping) and longer durations for the activities undertaken to avoid over predicting the efficiency of the policy action.

The next set of variables in Table 4 present the impact of in-home maintenance time investments on shopping durations. Females who spend very long time (10 hours or more) undertaking household chores are found to spend lesser time in shopping reflecting overall time constraints. In the case of men, the in-home time investment was found to impact shopping durations only for those who are not employed. Non-employed males who spend less than 2 hours in household chores are also found to spend lesser time in shopping. Perhaps such unemployed men who do not substantially contribute to in-home household tasks are also only likely to undertake quick supplemental shopping episodes rather than the primary shopping for the household. In contrast, unemployed men who spend between 2 and 10 hours in household chores are found to spend more time in shopping.

The final set of variables capture the impact of the day of the week. The men who undertake shopping on Mondays are found to spend less time when compared to those that undertake shopping on the other weekdays. In the case of women, shopping undertaken during the mid week (Wednesdays) tends to be of shorter durations. Finally, joint shopping when undertaken on a Friday tends to be of a longer duration when compared to joint shopping undertaken on other days.

5.3 Correlations between the Discrete and Continuous Components

The correlation between the propensity that a female undertakes shopping and the female's shopping duration hazard (ρ_F) is positive indicating that the unobserved factors that *increase* a woman's propensity to undertake shopping also *decrease* her shopping duration (or alternatively increase the hazard rate). This is perhaps because women, who undertake the shopping for the household, do so on a regular basis and hence are inherently efficient shoppers. The correlations between (1) the male's propensity to shop and the male-shopping duration hazard (ρ_M) and (2) the joint shopping propensity and the joint-shopping duration hazard (ρ_J) were not found to be statistically significant.

6. SUMMARY AND CONCLUSIONS

The recognition of household interactions in activity-travel modeling enables realistic analyses of the behavioral responses of households to changes in land-use, transportation system, and individual and household socio-economic characteristics. Toward this end, the overall focus of this study was on modeling daily activity generation of household heads, accommodating various household interaction effects. Specifically, this paper focused on the modeling of in-home and out-of-home maintenance activity generation. Methodologically, this paper contributes by developing a joint mixed logit hazard duration model structure and applying it in the context of modeling of out-of-home maintenance activity generation. Data from the 2000 Bay Area Travel Survey was used in the model estimations.

The models for in-home maintenance activity generation indicate that the daily time investments of the husband and wife in household chores is significantly impacted by individual/household characteristics and the daily mandatory activity participation characteristics of the household heads. In the case of households without children, the husband's out-of-home work duration determines the disparity between the time invested by the husband and the wife for household chores (*i.e.,* the longer the husband works out-of-home, greater is the difference in the in-home maintenance time investment of the household heads). In the case of households with children, the in-home maintenance time investments of both the husband and the wife are found to be influenced by their respective work durations as well as the work duration of their spouses. The commute duration is found to influence the in-home maintenance time allocation only for males in single-worker households. Finally, correlations between the male and female time investment models are positive indicating the influence of common unobserved factors.

The empirical results for out-of-home maintenance activity generation indicate significant impacts of individual and household socio-demographic characteristics, mandatory activity participation characteristics, and in-home maintenance time investments on choices relating to undertaking of grocery shopping for the household. In general, the results indicate that grocery shopping during weekdays is most likely to be undertaken independently rather than jointly, possibly because of efficiency considerations achieved by task specialization. Joint grocery shopping is found to be motivated by resource constraints (*i.e.,* the non-availability of multiple vehicles in the household). Further, the model finds continued evidence for gender-based task allocations with women being generically more likely than men to undertake household's shopping. The duration of work is also found to negatively impact a person's propensity to undertake shopping, with this impact being stronger for women than men. With increasing women in the work force, this result suggests that more and more households may undertake grocery shopping on weekend days. This shift of activities from weekdays to weekends may warrant detailed analysis and modeling of weekend activity-travel patterns. Workers whose workday ends earlier are found to undertake shopping for longer durations. This effect must be accounted for in evaluating policy actions such as peak spreading by measures that release individuals from work early. The model also indicates presence of significant positive correlations between the female's propensity to undertake shopping and her shopping duration hazard due to common unobserved factors.

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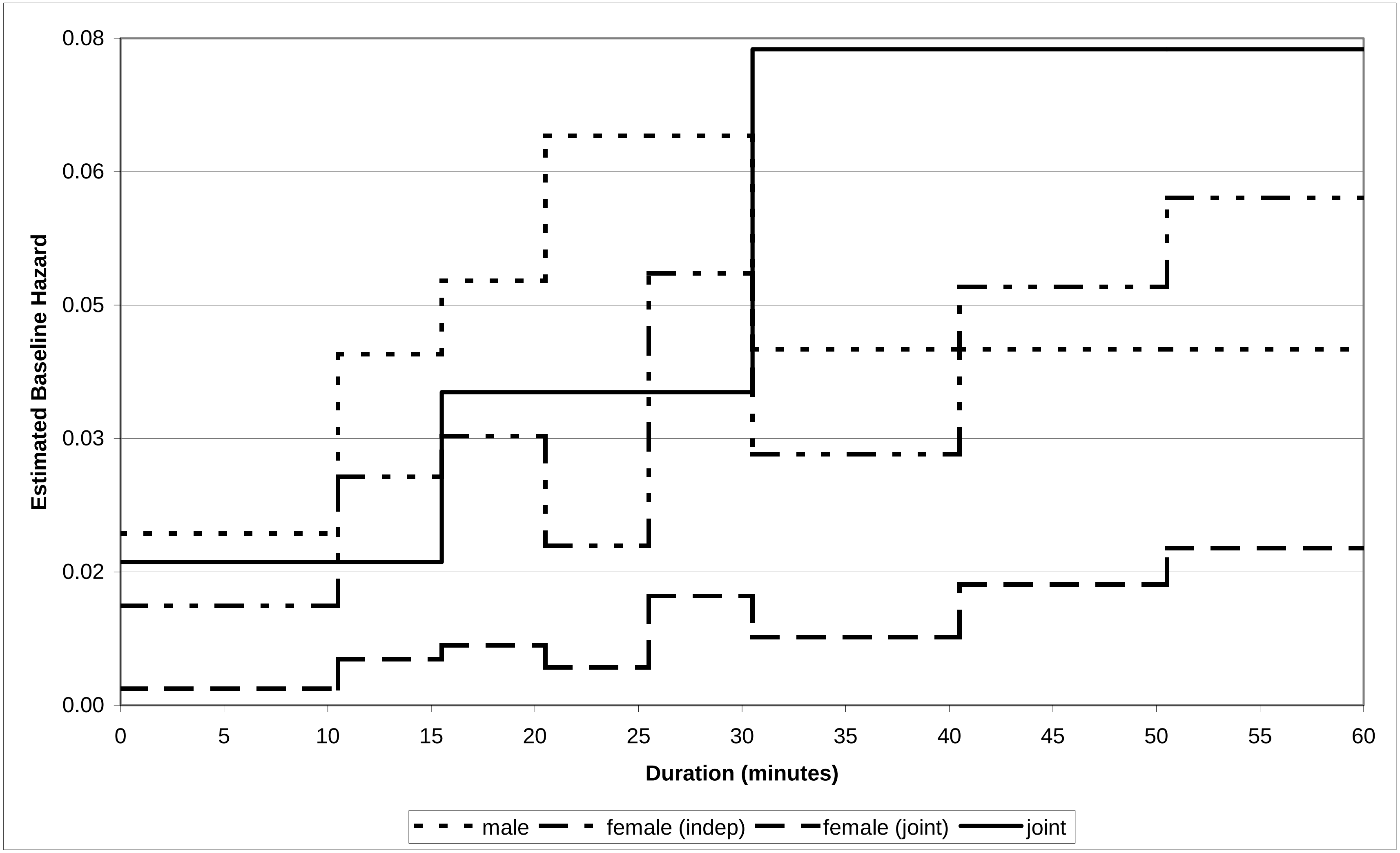

Figure 1. Estimated Baseline Hazard for Shopping Duration

Table 1. Model for In-home Maintenance Activity Generation in Single- and Dual-Worker Households Without Children

	Single Worker Household				Dual Worker Household			
	Male		Female		Male		Female	
	Param.	t stat	Param.	t stat	Param.	t stat	Param.	t stat
Household characteristics								
Caucasian	-	-	-	-	0.182	1.956	-	-
Own household	-	-	-	-	0.256	2.744	0.180	2.252
Access to Internet at home	-	-	0.339	2.739	-	-	-	-
Individual characteristics								
Age 16-35 years	-0.274	-1.643	-0.577	-4.038	-0.206	-2.267	-0.318	-4.220
Full-time employee*	-0.452	-2.309	-0.395	-2.570	-0.294	-2.091	-0.331	-3.947
Student	-	-	-	-	-0.295	-2.326	-0.252	-2.504
Mandatory activity participation characteristics								
<u>In-home work duration</u>								
Ln(IH work dur)	-0.214	-5.755	-0.162	-3.387	-0.134	-7.108	-0.204	-6.502
Ln(IH work dur) * IH work dur <= 4 hours	-	-	-	-	-	-	1.310	2.042
Ln(IH work dur) * IH work dur <= 8 hours	-	-	-	-	-	-	-1.268	-2.057
IH work dur <= 4 hours	-	-	-	-	-	-	-7.175	-1.940
IH work dur <= 8 hours	-	-	-	-	-	-	7.778	2.161
<u>Out-of-home work and commute duration</u>								
Ln(OH work dur)	-0.121	-3.152	-	-	-	-	-0.075	-5.401
Work duration > 8 hours	-	-	-	-	-0.212	-2.628	-	-
Commute duration > 60 minutes	-0.311	-1.755	-	-	-	-	-	-
<u>Spouse's out-of-home work duration</u>								
Ln(OH work dur)	-	-	0.043	1.992	-	-	0.046	3.369
Day of the week								
Tuesday	-	-	-	-	-	-	0.143	1.913
Wednesday	-	-	-	-	-	-	0.141	1.837
Constant	5.426	58.850	5.270	37.912	4.736	26.413	5.503	43.241
S.D. of the error term	1.920	45.621	1.720	45.619	1.792	67.415	1.541	67.407
Correlation (t stat)	0.2129 (7.276)				0.3366(18.036)			
Log-likelihood at Convergance	-4173.22 (1041 cases)				-8626.692 (2274 cases)			

*The base is both part-time and non-employed in the case of single worker households and part-time employee in the case of dual worker households

Table 2. Model for In-home Maintenance Activity Generation in Single- and Dual-Worker Households With One or More Children

	Single Worker Household				Dual Worker Household			
	Male		Female		Male		Female	
	Param.	t stat	Param.	t stat	Param.	t stat	Param.	t stat
Household characteristics								
Caucasian	0.265	2.020	-	-	-	-	-	-
<u>Number of children</u>								
One child	-	-	-	-	-	-	-0.265	-2.258
Two children	-	-	-	-	-	-	-0.195	-1.717
<u>Age composition of children</u>								
Only young (age <= 4 years) child(ren)	-	-	-0.182	-1.665	-	-	-	-
Only older (age 5-15 years) child(ren)	-	-	-0.195	-1.822	-	-	-	-
Individual characteristics								
Age 16-35 years	-	-	-	-	-0.461	-4.244	-	-
Full-time employee*	-	-	-	-	-0.535	-1.958	-0.263	-3.220
Student	-	-	-	-	-	-	-0.211	-1.601
Access to a personal vehicle	-	-	-	-	-	-	0.300	2.014
Mandatory activity participation characteristics								
<u>In-home work duration</u>								
Ln(IH work dur)	-0.128	-3.701	-	-	-0.060	-2.111	-0.068	-3.103
<u>Out-of-home work duration</u>								
Ln(OH work dur)	-0.057	-1.910	-0.084	-2.498	-	-	-0.058	-3.974
Work duration > 8 hours	-	-	-	-	-0.191	-1.808	-	-
<u>Commute duration</u>								
Ln(Comm. dur.) * comm. dur. <= 30 mins	1.041	1.597	-	-	-	-	-	-
Ln(Comm. dur.) * comm. dur. <= 60 mins	-1.095	-1.933	-	-	-	-	-	-
Comm. dur. <= 30 mins	-4.041	-1.729	-	-	-	-	-	-
Comm. dur. <= 60 mins	4.330	2.029	-	-	-	-	-	-
<u>Spouse's out-of-home work duration</u>								
Ln(OH work dur)	0.131	2.813	0.064	3.374	0.029	1.706	0.035	2.128
<u>Serve-passenger activities</u>								
Pick-up/drop-off of child(ren) at/from school	0.412	2.181	-	-	0.363	3.126	0.223	2.967
Constant	4.891	26.305	5.903	46.285	5.396	19.257	5.743	28.751
S.D. of the error term	1.688	41.081	1.275	41.103	1.669	49.397	1.305	49.399
Correlation (t stat)	0.2449 (7.521)				0.3188 (12.352)			
Log-likelihood at Convergance	-3019.43 (845 cases)				-4350.692 (1221 cases)			

*The base is both part-time and non-employed in the case of single worker households and part-time employee in the case of dual worker households

Table 3. Model for Out-of-Home Maintenance Activity Generation: Decision to Shop and Task Allocation

	No Shopping		Male Shops		Female Shops		Joint Shopping	
	Param.	t-stat.	Param.	t-stat.	Param.	t-stat.	Param.	t-stat.
HH-level characteristics								
Age								
Young household	0.302	2.996	-	-	-	-	-	-
Middle-aged household	0.155	2.007	-	-	-	-	-	-
Vehicle ownership								
No autos	-1.013	-2.782	-	-	-	-	-	-
Few autos	-	-	-	-	-	-	0.992	3.361
Other variables								
Caucasian	-0.277	-2.957	-	-	-	-	-	-
No children in HH	-	-	-	-	-	-	0.574	1.982
Income <= 60K	-	-	-	-	-	-	0.830	3.289
Person-level characteristics								
Not employed	-	-	0.699	3.243	-	-	-	-
Student	-	-	-	-	-0.215	-1.479	-	-
Has access to personal vehicle	-	-	-	-	0.568	3.601	-	-
Mandatory activity participation characteristics								
Out-of-home work and commute duration								
Person goes out-of-home to work	-	-	-0.392	-1.934	-1.192	-10.150	-	-
Work duration <= 4 hours	-	-	0.757	3.371	0.341	1.835	-	-
Work duration <= 8 hours	-	-	0.329	1.915	0.581	3.980	-	-
Expected no-stop commute duration	-	-	-0.218	-1.554	-	-	-	-
Serve-passenger activities								
Pick-up/drop-off child(ren) from/at school	-	-	0.358	1.642	-	-	-	-
In-home maintenance time investment								
In-home maintenance <= 2 hours	-	-	-0.230	-1.685	-0.451	-3.955	-	-
In-home maintenance <= 2 hours * Not employed	-	-	-0.885	-1.758	-	-	-	-
Constant	-	-	-2.541	-14.435	-2.053	-11.289	-5.078	-17.332

Table 4. Model for Out-of-Home Maintenance Activity Generation: Shopping Duration

	Male Shops		Female Shops		Joint Shopping	
	Param.	t-stat.	Param.	t-stat.	Param.	t-stat.
HH-level characteristics						
Few autos	-	-	-	-	-1.007	-2.702
Single worker HH	-	-	-	-	0.959	2.846
Income <= 60K	-	-	-	-	0.694	2.150
One or more children in HH	0.270	2.061	-	-	-	-
Mandatory activity participation characteristics						
Work ends between 4 and 6 PM	-0.685	-4.658	-0.457	-2.219	-	-
Work ends after 6 PM	-0.500	-2.748	-0.479	-1.870	-	-
In-home maintenance time investment						
In-home maintenance > 10 hours	-	-	-0.240	-2.175	-	-
In-home maintenance <= 2 hours * Not employed	-1.028	-1.969	-	-	-	-
In-home maintenance <= 10 hours * Not employed	0.488	1.943	-	-	-	-
Day-of-the-week						
Monday	-0.301	-2.056	-	-	-	-
Wednesday	-	-	-0.207	-1.765	-	-
Friday	-	-	-	-	1.409	3.012
Correlation term	-	-	0.729	6.411	-	-

Log-Liklihood at convergence: -5212.31(5381 cases)