INCORPORATING ACTIVITY UTILITY, AT-HOME ACTIVITIES AND LIFESTYLE IN AN ACTIVITY-BASED TRAVEL DEMAND MODEL

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ABSTRACT

Continuing development of the discrete choice activity schedule approach to travel demand modeling, this paper presents methods for specifying activity utility, at-home activity participation and lifestyle factors in activity pattern choice. It assumes a previously reported model structure in which a person's activity schedule is viewed as an activity pattern and a set of tours, with expected tour utility capturing dependence of pattern choice on activity and travel conditions.

In an empirical implementation for Portland, Oregon, estimation results match *a priori* expectations of lifestyle effects on activity selection, including those of (a) household structure and role, such as for females with children, (b) capabilities, such as income, and (c) activity commitments, such as usual work levels. They also reconfirm the significance of activity and travel accessibility in pattern choice. Application of the model with road pricing demonstrates the effects of at-home activities, lifestyle effects and accessibility in the specification.

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INTRODUCTION

Background

This paper continues development of the discrete choice activity schedule approach to travel demand modeling (Adler and Ben-Akiva, 1979; Bowman, 1995; Ben-Akiva and Bowman, 1999), presenting methods for explicitly specifying activity utility, at-home activity participation and lifestyle factors in activity pattern choice.

The approach, by its reliance on disaggregate discrete choice random utility models (see Ben-Akiva and Lerman, 1985) stands in contrast to other econometric approaches that employ continuous decision variables (see, for example, Bhat, 1996) and rule-based simulations (often called computational process models) that assume various non-optimizing decision protocols (see, for example, Ettema, Borgers and Timmermans, 1993). The reader is referred to Bowman (1998) for the authors' comparison of these approaches, and to Ettema (1996) for an alternative view.

The activity schedule approach represents the third step, following integrated trip-based and tour-based methods, in the evolution of discrete choice travel demand models toward an activity-based approach, in which travel is viewed as being chosen as part of a larger activity scheduling decision. In this evolution the unit of analysis expands from the trip (a journey from an origin to a destination) to the tour (a journey beginning and ending at home that includes all intermediate stops) and on to the activity schedule (a set of tours and at-home activity episodes spanning a scheduling timeframe). Ben-Akiva and Bowman (1998) describe the three step evolution in greater detail. In this paper, the scheduling timeframe is assumed to be a 24 hour day, so the model is sometimes referred to as the day activity schedule model.

The day activity schedule model

Ben-Akiva and Bowman (1999) present the day activity schedule model, including an empirical prototype based on 1991 Boston survey and network data. In their words,

> *Demand for activity and travel is viewed as a choice among all possible combinations of activity and travel in the course of a weekday. The model uses a day timeframe because of the day's primary importance in regulating activity and travel behavior; people organize their activities in day sized packages, allowing substantial interactions among within-day scheduling decisions as they cope with time and space constraints while attempting to achieve their activity objectives. As shown in Fig. 1, the day activity schedule consists of a set of tours tied together by an overarching activity pattern (pattern). The activity pattern extends the linkage beyond that of a tour-based model to include all the tours that occur in a single day, thereby explicitly representing the ability of individuals to make inter-tour and at-home vs on-tour trade-offs. For example, the model can capture the choice between combining activities into a single tour and spreading them among multiple tours, incorporating the factors that influence this type of decision. Many situations of interest, such as demand management programs, ITS deployment and increased fuel prices, can induce these kinds of activity and travel schedule responses.*
>
> *In the model, tour decisions are conditioned, or constrained, by the choice of activity pattern. This is based on the notion that some decisions about the basic agenda and pattern of the day's activities take precedence over details of the travel decisions. The probability of a particular activity schedule is therefore expressed in the model as the product of a marginal pattern probability and a conditional tours probability*

$$p(schedule) = p(pattern)\,p(tours|\,pattern) \tag{1}$$

where the pattern probability is the probability of a particular activity pattern and the conditional tours probability is the probability of a particular set of tours, given the choice of pattern.

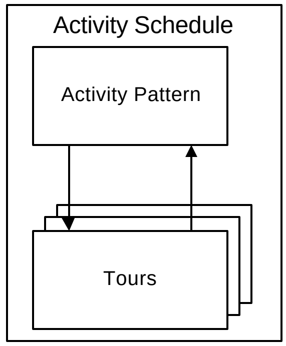

Fig. 1: The Activity Schedule model framework. An individual's multidimensional choice of a day's activities and travel consists of tours interrelated in an activity pattern.

But the choice of pattern is not independent of the conditional tours decisions. Rather, the relative attractiveness—or utility—of a pattern depends on the expected value of the maximum utility to be gained from its associated tours. Through the expected utility, the pattern's choice probability is a function of the attributes of all its available tours alternatives. This relation captures sensitivity of pattern choice—including inter-tour and at-home vs on-tour trade-offs already mentioned—to spatial characteristics and transportation system level of service, and is the most important feature of the proposed model system.

Bowman, et al, (1999) and Bradley, *et al* (1998) describe the first implementation, in Portland, Oregon, of the activity schedule model for urban policy analysis.

THE ACTIVITY PATTERN: AT-HOME ACTIVITIES, ACTIVITY UTILITY AND LIFESTYLE

Whereas Ben-Akiva and Bowman (1999) establish the basic structure of the activity schedule model and the effect of accessibility on pattern choice, in this paper we enhance the specification of the activity pattern itself, giving attention to the choice set, the utility function and the effect of lifestyle on activity pattern choice. Each of these aspects is discussed in turn. Notably, the resulting specification explicitly models at-home activity participation and associates a pattern's utility with its activities.

Pattern model choice set

The activity schedule approach calls for a pattern model that accounts for all activity participation in the day, by purpose and priority, placing the activities in a configuration of tours and at-home episodes. If the model doesn't account for all **activity participation**, then it will be unable to capture changes induced by conditions that affect unmodeled activity utility, and unable to distinguish changes in overall activity participation from shifts between modeled and unmodeled activity participation. For instance, suppose the activity pattern model does not explicitly identify participation in at-home activities. Suppose also that technology and policy changes make it easier to work at home, so that at-home work participation replaces some on-tour work activities, and the overall participation in work increases. If the cause comes only from the ease of at-home work participation, then the model will completely miss the effect. If, on the other hand, it becomes more difficult to work on-tour, the model will confound shifts to at-home participation with (a) drops in work participation and (b) shifts toward on-tour work patterns that gain advantage as a result of the change.

Purpose is also important, since it is a fundamental attribute of activity, and arguably the primary determinant of activity utility. Accessibility depends on purpose because spatial distribution of activity opportunities is purpose-specific. If purpose is defined coarsely, then important purpose-specific accessibility information is lost and the model will be insensitive to policy or external changes that affect accessibility differently for different purposes. **Priorities** are important because of their importance in the activity participation and sequencing decision. The scheduling process is not temporally sequential, but is governed by commitments and priorities, within the constraints of the given scheduling time period. The **at-home vs on-tour** distinction is important as the most basic aspect of schedule choice affecting travel and influenced by accessibility. Additionally, the pattern should locate each on-tour activity in sequence on a particular tour. This is needed to capture inter-tour trade-offs people make in their schedules; that is, whether to combine activities in chains on one tour, or conduct separate tours.

Table 1 shows how the above requiements are operationalized in the empirical model presented subsequently in this paper. The lefthand column lists the dimensions defining each alternative. An alternative in the choice set must take exactly one value from the righthand column for each pattern dimension. This definition yields a choice set with 570 alternatives, in contrast to the 54 alternatives of Ben-Akiva and Bowman (1999). One such alternative has on-tour subsistence as the primary activity, occurring on a tour with maintenance stops before and after the primary destination, no subtour on the primary tour, and 1 secondary leisure tour.

Table 1 Day activity pattern choice dimensions and choice set for each dimension

Day activity pattern dimension	Choice set within dimension
Primary activity	
Purpose	subsistence, maintenance, leisure
Location	at-home, on-tour
Primary tour structure	
intermediate stop(s) before primary destination	none, maintenance, leisure
subtour (subsistence patterns only)	none, maintenance, leisure
intermediate stop(s) after primary destination	none, maintenance, leisure
Secondary tours, number and purpose	none, 1 maintenance, 1 leisure, 2+ maintenance, 2+ leisure, 2+ mixed (1+ maintenance & 1+ leisure)
At-home maintenance activity participation	yes, no

Pattern utility function

A utility function must be specified for each alternative p in the pattern choice set P. We assume it includes additively a component V_a for each activity, a component $\tilde{V}_p$ for the overall pattern, representing the effect of time and energy limitations and activity synergy, and a component V_t for the expected utility of each tour t, given pattern p. This yields

$$V_p = \tilde{V}_p + \sum_{a \in A_p} V_a + \sum_{t \in T_p} V_t, \qquad p \in P, \tag{2}$$

where A_p and T_p are the sets of activities and tours in p, respectively.

V_t is the component that integrates the activity pattern with the tour models. It makes the choice of activity pattern sensitive to travel conditions and the temporal-spatial distribution of activity opportunities.

The V_a components can have estimated parameters distinguished by activity priority, purpose and whether the activity occurs at home or on tour, since the pattern choice set distinguishes activities by these attributes. Thus, for example, a set of distinct parameters can be estimated for primary work activities occurring on tour, and included in the utility function of each pattern alternative for which work on tour is the primary activity. As another example, a set of parameters for secondary maintenance activities on tour can be included once per on-tour secondary maintenance activity occurring in each pattern alternative.

The utility functions include parameters for three main types of pattern components $\tilde{V}_p$. One type identifies utility associated with the placement of secondary activities in the pattern, differentiating utility of secondary activities that share a common purpose but occur at different places in the pattern or in different pattern types. The second type identifies utility of particular combinations of two or more secondary activities on primary tours. The third type identifies utility (or more accurately, disutility) associated with particular pattern-wide combinations of activities, taking into consideration multiple primary tour activities, multiple tours and at-home maintenance participation.

In summary, the structure of the pattern utility function accounts for the effects of accessibility through the V_t components, for activity utility through the V_a components, and for pattern-wide attributes through $\tilde{V}_p$.

Lifestyle and mobility factors in the pattern utility functions

The activity scheduling decision is conditioned by the household's lifestyle and mobility, which are outcomes of longer-term processes. All components of the activity pattern utility function depend on lifestyle and mobility. We define lifestyle as the set of individual and household attributes—established as outcomes of (a) major life decisions and events and (b) the gradual accumulation of minor changes, habits and preferences—that determines needs and preferences for activities, and the resources available for their satisfaction. Lifestyle attributes can be grouped in categories, including household structure (such as single adult, married couple with pre-school children or non-family adult group); individual role in the household (such as principal income earner or childcare giver); activity priorities, commitments and habits (such as absolute and relative time commitment to job, property maintenance, hobbies, recreation and participation in civic, religious or social organizations); and financial and personal capabilities or limitations (such as wealth, income, vocational skills and physical disabilities).

Mobility is another set of individual and household attributes—established by lifestyle-constrained decisions and events—that determines the availability and cost of access to activities. Mobility attributes are mostly determined by clearly defined choices occurring on an irregular and infrequent basis (such as a car purchase), but can also involve unchosen events (such as a job transfer) and emergent phenomena (such as the gradual selection of a favorite shopping location). Although mobility decisions occur within a given lifestyle context, some of these decisions may be so major as to cause significant lifestyle changes. A mobility decision cannot be conditioned by the more frequent activity and travel decisions, but is influenced by expectations about the benefits to be gained from the activity and travel opportunities made possible by the choice, given the current lifestyle. Mobility decisions include location choices for work, residence, school and other repetitive activities determined by lifestyle; auto acquisition and other transportation arrangements; and arrangements for repetitive conduct of other activities by electronic or other non-travel means.

Table 4 shows how the above requirements are operationalized in the empirical model presented subsequently in this paper. For each lifestyle category, we examined the available data and identified variables that might capture important lifestyle effects. Using these variables we conducted exploratory analysis with the Portland pattern choice data set, using simple logit models for single dimensions of the pattern choice, to identify which variables might have the most important effects, and in which dimensions. Based on this analysis we selected a set of lifestyle variables, shown in Table 2, for the pattern utility function specification.

Table 2 Lifestyle and mobility variables in the Portland day activity pattern utility functions

Lifestyle Category	Variable Category	Variable Definition
Household structure	family vs nonfamily	family: At least one member of the household is related to the household's responding representative by blood or marriage
	2+ adults	the household has 2 or more members 18 or older
		nonfamily with 2+ adults
	Disabled members	the number or presence of persons in the household with a disability that makes it difficult to travel outside the home without assistance.
Role in household	adult child	a person 18 years or older who is the child of the household's responding representative
	gender	female (or male)
	gender (with household interactions)	female (or male) with children 0-4
		female (or male) with children 0-12
		female (or male) in family with children 0-12 or disabled household members
		number of children 0-17 plus # disabled, for female (or male)
		male or female in family with 2+ adults
	relative workload	person's usual work hours minus (household's total usual weekly work hours)/(number of household members 18 through 64)
Capabilities	per capita income	household annual income divided by household size
		per capita income, for full-time worker (or other)
	disabled	person has a disability that makes it difficult to travel outside the home without assistance.
	occupation	professional (or nonprofessional)
	age	
Activity commitments and priorities	household workforce participation rate	proportion of household's adults 18-64 who are employed or students
	employment status	full-time worker
	student status	full-time student
	usual weekly work hours	the number of hours per week the person reports or is exogenously predicted to usually work
	housing tenure	principal residence is owned (or rented)
Mobility	1+ vehicles in household	household has 1 or more vehicles
	1+ vehicles per adult	household has 1 or more vehicles per person 18 or older

EMPIRICAL MODEL

Portland data set and summary estimation results

In this section we present an empirical implementation of the activity pattern model, for which parameters were estimated using 6475 one-day activity schedules from a 1994 activity diary survey conducted in the Portland, Oregon, metropolitan area. (See Bradley, et al. (1998)and Bowman (1998) for details about the data set and its preparation for use in the day activity schedule model system.). Tables 3 through 5 present the sample distribution in several dimensions of the choice set, and Table 6 presents their distribution in the lifestyle and mobility variables.

Table 3 Sample pattern distribution by primary activity, at-home vs on-tour and primary tour type

Pattern description	Percent in sample
Subsistence at home	2.6
Maintenance at home	7.7
Leisure at home	5.3
Subsistence on tour	
without a work-based subtour	
no extra stops	29.0
stop before	3.9
stop after	9.3
stop before and after	3.0
with a work-based subtour	
no extra stops	5.0
stop before	.6
stop after	2.2
stop before and after	0.7
Maintenance on tour	
no extra stops	10.6
stop before	3.7
stop after	4.4
stop before and after	2.4
Leisure on tour	
no extra stops	6.8
stop before	1.0
stop after	1.2
stop before and after	0.6

Table 4 Sample pattern distribution by primary activity and at-home maintenance participation

Pattern description	Percent in sample
Subsistence at home	
without at-home maintenance	1.7
with at-home maintenance	.9
Maintenance at home	7.7
Leisure at home	
without at-home maintenance	3.8
with at-home maintenance	1.5
Subsistence on tour	
without at-home maintenance	39.2
with at-home maintenance	14.4
Maintenance on tour	
without at-home maintenance	6.8
with at-home maintenance	14.4
Leisure on tour	
without at-home maintenance	4.0
with at-home maintenance	5.7
All primary activity types	
without at-home maintenance	55.5
with at-home maintenance	44.5

Table 5 Sample pattern distribution by number & purpose of secondary tours

Pattern description	Percent in sample
0 secondary tours	65.7
1 secondary maintenance tour	14.2
1 secondary leisure tour	3.0
2+ secondary maintenance tours	12.3
2+ secondary leisure tours	1.2
1+ secondary maintenance and 1+ secondary leisure tours	3.5

Table 6 Distribution of the sample patterns, classified by lifestyle and mobility variables in the model

Category	Variable name and description	Percent of patterns
household structure	family with 1 adult	3.0
	family with 2+ adults	73.4
	nonfamily with 1 adult	19.4
	nonfamily with 2 adults	4.2
	household with disabled members	8.1
role in household	male	47.6
	adult child	6.2
	male with children 0-4	4.7
	female with children 0-4	5.6
	male with children 0-12	10.2
	female with children 0-12	11.5
	male with children 0-17	14.9
	female with children 0-17	16.7
	male in family with 2+ adults	36.0
	female in family with 2+ adults	37.4
	relative workload (usual weekly work hours minus household avg.)	
	less than –40	2.5
	between –40 and –20	8.8
	between –20 and 0	14.5
	0	53.5
	between 0 and 10	8.0
	between 10 an 20	6.1
	over 20	6.6
capabilities	per capita income	
	under $10,000	21.6
	10,000 to 20,000	34.8
	20,000 to 30,000	25.4
	over 30,000	18.3
	disabled	4.6
	professional	31.5
activity commitments and priorities	workforce participation (# workers divided by # working age adults)	
	0	24.4
	over 0 and under 1	14.4
	1	61.2
	full-time worker	52.1
	full-time student	6.7
	usual weekly work hours	
	0	37.4
	1 to 19	3.1
	20 to 34	8.9
	35 to 44	34.1
	45 to 54	11.1
	55 and over	5.4
	homeowner	75.2
Mobility	household has 1+ vehicles	94.3
	1+ vehicles per adult	76.9

The pattern model is specified with 276 parameters distributed by utility component and variable type as shown in Table 7. The parameters were estimated by maximum likelihood, yielding a rho squared fit statistic of .3876, and other summary statistics shown in Table 8.

Table 7 Day activity pattern model—number of parameters by utility component and variable type

Utility component \ Variable type	Constants and gender	Household structure	Role in household	Financial and personal capabilities	Activity commitments	Mobility decisions	Tour expected utility
Primary activity (V_a)	8	3	18	10	13	4	
Secondary activity (V_a)	18	9	42	21	11	12	
Secondary activity placement ($\tilde{V}_p$)	20	2	4	3	5	10	
Primary tour combinations ($\tilde{V}_p$)	7		2	1		1	
Inter-tour combinations ($\tilde{V}_p$)	34		4	3	1		
Tour expected utility (V_t)							10
Total	87	14	70	38	30	27	10

Table 8 Summary statistics from day activity pattern model estimation

Number of observations	6475
Number of cases	2,983,715
Number of parameters	276
LL(0)	-39241
LL(final)	-24033
rho squared	.3876

Detailed estimation results

Detailed parameter estimates appear in the next several sections. We identified in advance those variables expected to be important. Many are retained in the presented specification, even if they are not statistically significant at typical confidence levels, and occasionally when they are not significant at all or even take the unexpected sign. In cases where the standard error is approximately as large as the estimate and the sign matches our reasoning we would retain the parameter in a production version of the model. In cases where the parameters are insignificant and perhaps also take the wrong sign, we would remove the parameters, although they are retained here to provide awareness of the model specification process and results. In cases where the estimate takes the wrong sign and is significant, we have sometimes also retained the parameter, admitting an imperfect specification or faulty reasoning, or both.

Primary activity components

The analysis of pattern utility begins by considering its components directly associated with participation in a particular activity, differentiating activities by priority in the pattern (primary vs secondary), purpose and whether it is conducted on-tour or at home.

For workers and students there are three possible choices of the primary activity's purpose—subsistence, maintenance and leisure—and it may be conducted either at home or on tour. For other people, subsistence activity is considered unavailable. Leisure at home is the base case, so the utility of the remaining five components is relative to leisure at home.

Primary subsistence activity

Work participation follows a long-term commitment made to satisfy household income needs. Activity commitment data is available in the form of part or full-time worker (and student) status, and usual weekly work hours. These serve as the principal explanatory variables for subsistence at home and subsistence on tour. We specify them separately for at-home and on-tour components, anticipating that usual workload can affect the choice between working at home vs on tour.

The Table 9 constants show that people who work few hours are more inclined than others to work at home. As the usual weekly work hours increase, the likelihood of working on tour increases more rapidly than working at home, but as work hours increase beyond 40, people again shift toward working at home.

Table 9 Primary subsistence activity lifestyle variables

	Subsistence on tour		**Subsistence at home**	
	Coeff.	Std. Err.	Coeff.	Std. Err.
constant(Leisure at home is primary activity base)	-.2297E+1	.68E+0	-.1965E+1	.44E+0
female w children 0-4	-.6920E+0	.18E+0	-.3113E-1	.39E+0
professional	.3062E+0	.10E+0	.4049E+0	.19E+0
usual weekly work hours up to 40 (40 if work hours exceed 40)	.4407E-1	.66E-2	.1363E-1	.11E-1
usual work hours 41 to 50 (10 if work hours exceed 50)	.1283E-1	.14E-1	.7377E-1	.25E-1
full time student	.1855E+1	.25E+0	.1038E+1	.40E+0

The choice between working at home and on-tour is influenced by coupling constraints operating at either or both places. The coupling constraints for some workers may be atypical, so we include variables for them in both work components. These include professionals, expected to have more flexibility to work at home, and working mothers with young children, expected to have strong home-based coupling constraints.

Primary maintenance activity

Every person in a household requires a certain amount of maintenance activity. This may vary across individuals based on lifestyle, and we anticipate a gender difference based on activity priorities, with females more inclined to conduct maintenance activity. Household structure causes variation in maintenance need, interacting with gender-based role specialization. In particular, maintenance needs may increase with the number of children and disabled in the household, with females picking up more of the load. The presence of additional adults in the household may decrease the maintenance work due to scale economies of role specialization, with greater effects in families, and females in families taking more of the maintenance load. There may be additional role specialization effects, with adult children and those with larger relative workloads picking up less of the maintenance load. The commitment of homeowners to maintain their residence should increase the load. Persons with disabilities may have less ability to meet maintenance needs. Persons in higher income households have more material possessions to buy and maintain, but a greater ability to pay for maintenance services. We expect to see most of these effects, with some important variation, in the demand for primary and secondary maintenance activity, on-tour and at-home.

Considering maintenance as the primary activity, females may be more likely to take maintenance activity at home as their primary task of the day, especially in the presence of children or other adults in the household. When the household has two or more adults, specialization may increase the likelihood of men and women to choose maintenance as the primary activity, although adult children may avoid at-home maintenance responsibilities. On their days off work, persons with higher relative workloads in the household may be more inclined to conduct maintenance activity on-tour and less inclined to conduct it at home. Homeowners, on the other hand, may be more inclined than others to devote their primary activity to at-home maintenance rather than maintenance on tour. As per capita income—and the relative value of time—increases, people may be less likely to choose maintenance as a primary activity, choosing instead to purchase services that reduce the need to spend large amounts of maintenance time. Finally, the availability of vehicles, especially one or more vehicles per adult, should increase the likelihood of choosing primary maintenance on tour.

Table 10 lists the parameter estimates for on tour and at home maintenance patterns. For the most part the parameter estimates are consistent with the stated expectations. In many cases the standard errors are approximately as large as the parameter estimates.

Primary leisure activity

Since leisure naturally ranks behind subsistence and maintenance in activity priority, variation in leisure participation may depend as much on lifestyle outcomes for subsistence and maintenance activity as it does for direct leisure outcomes. In this sense, leisure demand is a derived demand, taking up the time that subsistence and maintenance activity do not require. However, leisure demand also depends on lifestyle outcomes directly related to leisure, such as ownership of recreational real estate and personal property, club memberships or avocational commitments. Unfortunately, this information is not generally collected in activity and travel surveys, and is not available for including in demand models, making it necessary to seek proxies.

Table 10 Primary maintenance activity lifestyle variables

	Maint on tour		**Maint at home**	
	Coeff.	Std. Err.	Coeff.	Std. Err.
constant, male	-.8030E+0	.56E+0	-.9697E-2	.29E+0
constant, female	-.1094E+1	.56E+0	.7154E+0	.22E+0
female w children 0-4			-.2004E+0	.22E+0
# children 0-17 plus # disabled, male	-.1151E+0	.14E+0	-.2060E-1	.12E+0
# children 0-17 plus # disabled, female	-.1809E+0	.12E+0	.3721E+0	.88E-1
nonfamily with 2+ adults	.3059E+0	.34E+0	.4254E+0	.36E+0
family with 2+ adults, male	-.2834E+0	.25E+0	.4744E+0	.28E+0
family with 2+ adults, female	.2460E+0	.23E+0	.1561E+0	.20E+0
adult child	.1722E+0	.32E+0	-.1025E+1	.36E+0
relative workload	.1707E-2	.65E-2	-.1051E-1	.54E-2
disabled	-.4731E+0	.25E+0	-.1533E+1	.23E+0
per capita income	.5757E-1	.61E-1	-.6401E-1	.60E-1
workforce participation rate	-.2860E+0	.16E+0		
full-time worker or student	.6863E-1	.17E+0	-.2878E+0	.18E+0
homeowner	-.1723E-1	.16E+0	.2292E+0	.15E+0
1+ cars in HH	-.4983E-2	.22E+0		
1+ cars per adult	.1596E+0	.14E+0		

We consider primary leisure activity at home as the base case for specifying primary activity utility, and identify factors that affect the likelihood of choosing primary leisure activity on tour. The presence of children may decrease the probability of choosing leisure activity on tour. Members of non-family households and adult children may have greater demand for leisure on-tour, to satisfy social needs that family members satisfy at home. Persons with disabilities may be more constrained to home than other people. Income for non-full-time workers and availability of at least one car per adult should both increase the probability of choosing leisure activity on tour. The greater schedule flexibility of professionals may enable them to more frequently choose leisure on tour as the primary activity of the day. Full-time workers may be accustomed to leaving home for the day, and on their days off be more inclined to travel for leisure activities than to remain at home.

Table 11 lists the parameter estimates for on-tour primary leisure activities. The results for nonfamily members, adult children and professionals are not as expected, and these along with several other parameters have large standard errors relative to the magnitude of the estimates. This component of the utility function is specified with greater lifestyle variation than the data and the coarse resolution of the activity schedule categories can support. It is also possible that important factors have been missed and correlation with included variables is confounding the reported results.

Table 11 Primary leisure activity lifestyle variables

	Leisure on tour	
	Coeff.	Std. Err.
constant, male	-.1392E+1	.76E+0
constant, female	-.1548E+0	.15E+0
children 0-12 are in HH, male	-.2214E+0	.32E+0
children 0-12 are in HH, female	-.1711E+0	.23E+0
nonfamily	-.2152E+0	.18E+0
adult child	-.3055E+0	.37E+0
disabled	-.9632E+0	.25E+0
per capita income ($10K), full time worker	-.8319E-1	.10E+0
per capita income ($10K), not full time worker	.1743E+0	.65E-1
professional	-.3056E+0	.20E+0
workforce participation rate	-.2552E+0	.18E+0
full-time worker or student	.4679E+0	.25E+0
1+ cars are in HH	-.5252E-1	.27E+0
1+ cars per adult	.3786E+0	.16E+0

Secondary activity components

We define only two possible choices of secondary activity purpose—maintenance and leisure—including any secondary work and work related activity as maintenance. As with the primary activities, these may be conducted on tour or at home. On-tour activity utility is associated with a particular episode of activity. In contrast, at-home maintenance utility is associated with all at-home maintenance of the day, and secondary at-home maintenance is not distinguished from the primary activity if it is maintenance at home. We separately specify secondary activity utility components for subsistence, maintenance and leisure patterns. In each case the utility is measured against a base of "no participation", which implicitly allows more time for at-home leisure activity.

Secondary maintenance activity

The general maintenance activity demand effects described above probably apply to secondary activities, but with some differences because here maintenance is a secondary activity. Households with greater workforce participation may have more adults out and about, thereby spreading the on-tour maintenance load. Households with at least one auto may generate more on-tour maintenance demand because car availability reduces the marginal cost of additional trips. Availability of one auto per adult may increase this effect.

Secondary on-tour maintenance activity coefficients are listed in Table 12. As expected, children induce additional secondary on-tour maintenance activities, except for males with subsistence patterns. The presence of more than one adult in the household has the most effect on females and males in families, where we see a reduction in secondary on-tour maintenance on leisure days. Adult children, those with higher relative workloads and disabled persons are all less likely to conduct secondary on-tour maintenance. Homeowners are more likely to attach maintenance stops to subsistence patterns, and less likely to attach them to maintenance patterns.

Overall, the parameter estimates for secondary on-tour maintenance activity match expectations very closely and are statistically significant.

Table 12 Secondary on-tour maintenance activity lifestyle variables

	Subsistence patterns		**Maint. Patterns**		**Leisure patterns**	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Constant, male	-.3156E+1	.35E+0	-.1611E+1	.61E+0	-.2220E+1	.14E+1
Constant, female	-.3012E+1	.34E+0	-.1737E+1	.61E+0	-.1333E+0	.21E+0
# children 0-17 plus # disabled, male	.5584E-1	.34E-1	.1094E+0	.76E-1	.1969E+0	.10E+0
# children 0-17 plus # disabled, female	.2566E+0	.37E-1	.1927E+0	.37E-1	.3146E+0	.63E-1
Nonfamily with 2+ adults	.4443E-2	.13E+0	-.2539E-1	.19E+0	.1291E+0	.32E+0
Family with 2+ adults, male	.8699E-1	.10E+0	-.7628E-1	.13E+0	-.3077E+0	.21E+0
Family with 2+ adults, female	-.1133E+0	.84E-1	.1319E+0	.98E-1	-.2619E+0	.18E+0
Adult child	-.5246E+0	.11E+0	-.3006E+0	.20E+0	-.2817E+0	.39E+0
Relative workload	-.4719E-2	.30E-2	-.5125E-2	.25E-2	-.4349E-2	.48E-2
Disabled	-.7440E+0	.28E+0	-.3855E+0	.14E+0	-.8603E+0	.31E+0
per capita income ($10K)	.7212E-1	.25E-1	.1334E-1	.30E-1	-.2649E-1	.54E-1
Homeowner	.1734E+0	.64E-1	-.1236E+0	.79E-1	-.4031E-1	.15E+0
Workforce participation rate	-.1688E+0	.14E+0				
1+ cars are in HH	.6411E+0	.29E+0	.4143E+0	.17E+0	.8059E+0	.42E+0
1+ cars per adult	.1666E+0	.97E-1	-.3509E-1	.88E-1	.2272E+0	.17E+0

Table 13 shows the parameter estimates for secondary at-home maintenance. A very strong tendency is present among females to attach at-home activities to an on-tour maintenance pattern, and an even greater tendency among men on leisure patterns to avoid at-home maintenance activity. Children increase at-home maintenance activity of working parents, but only for mothers if the pattern is maintenance or leisure. Additional household adults have a small but clear effect to reduce at-home maintenance on subsistence patterns, but the effects are less consistent and significant on other patterns. Persons with high relative workloads are relieved of at-home maintenance tasks in all pattern types. High per capita income reduces at-home maintenance on subsistence patterns, and home ownership increases at-home maintenance on all pattern types. In summary, most of the estimates for secondary at-home maintenance activity are as expected and statistically significant.

Table 13 Secondary at-home maintenance activity lifestyle variables

	Subsistence patterns		**Maint. patterns**		**Leisure patterns**	
	Coeff.	Std Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
constant, male	-.3439E-1	.41E+0	-.1101E+0	.25E+0	-.1251E+1	.28E+0
constant, female	.1302E+0	.40E+0	.8582E+0	.22E+0	.3135E+0	.24E+0
# children 0-17 plus # disabled, male	.1738E+0	.54E-1	-.5966E-1	.13E+0	-.2397E+0	.15E+0
# children 0-17 plus # disabled, female	.3857E+0	.61E-1	.4185E+0	.10E+0	.1718E+0	.98E-1
nonfamily with 2+ adults	-.2944E+0	.12E+0	-.5180E-1	.34E+0	.3641E+0	.34E+0
family with 2+ adults, male	-.2436E+0	.84E-1	.3065E+0	.23E+0	-.7424E-1	.24E+0
family with 2+ adults, female	-.1423E+0	.76E-1	-.4783E+0	.19E+0	.3450E-1	.20E+0
adult child	-.7575E+0	.17E+0	-.1037E+1	.36E+0	-.7022E+0	.43E+0
relative workload	-.6702E-2	.36E-2	-.8577E-2	.55E-2	-.9475E-2	.55E-2
disabled	-.1202E+1	.44E+0	-.1003E+1	.23E+0	-.4730E+0	.24E+0
per capita income	-.1011E+0	.37E-1	-.3026E-1	.51E-1	-.3407E-1	.58E-1
homeowner	.2111E+0	.99E-1	.4054E+0	.16E+0	.2389E+0	.16E+0

Secondary leisure activity

The secondary leisure constant represents a baseline level of demand for on-tour leisure activity relative to remaining at home. We expect to see gender differences in this baseline, perhaps with males being more leisure oriented, even after controlling for level of work participation, which probably dampens leisure participation, especially when work hours exceed 40 hours per week. Members of non-family households may conduct more leisure activities on-tour, satisfying social needs that family members satisfy at home. People with young children and/or disabled family members probably have lower demand for on-tour leisure, due to greater costs and less opportunities for on-tour participation. Higher income may induce greater demand for on-tour leisure, especially among those who have available time because they are not full-time workers. Persons with travel related disabilities may have lower demand for on-tour leisure. Finally, the availability of a car for every adult in the household may increase demand for on-tour secondary leisure activity.

The estimation results for secondary on-tour leisure activity, listed in Table 14, differ somewhat from our expectations, but are plausible. Working over 40 hours per week does not significantly alter demand for secondary on-tour leisure activity. The effect of children is in most cases small and insignificant, and the most important effects are the tendency to reduce on-tour leisure for working females and increase it for females already on leisure patterns, with the latter effect potentially representing mothers at play with their children. The effect of income is to increase secondary on-tour leisure activity, and not surprisingly it occurs on subsistence patterns for full-time workers and on maintenance patterns for others. Disability increases the likelihood of secondary on-tour leisure activity attached to subsistence patterns, probably because disabled people on subsistence patterns have made their transportation arrangements and the marginal cost of an extra stop for leisure is much lower than on at-home patterns; associating a disability parameter for secondary on-tour activities on on-tour patterns may be more appropriate. Finally, the effect of the first car in the household is more important than the effect of additional cars, enabling persons to attach leisure stops to maintenance and leisure patterns.

Table 14 Secondary on-tour leisure activity lifestyle variables

	Subsistence patterns		**Maint. patterns**		**Leisure patterns**	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Constant, male	-.3070E+1	.33E+0	-.2566E+1	.62E+0	-.1852E+1	.14E+1
Constant, female	-.3104E+1	.34E+0	-.2571E+1	.62E+0	-.2094E+1	.13E+0
Children 0-12 are in HH, male	-.3373E-1	.12E+0	.1316E+0	.24E+0	-.2103E+0	.43E+0
Children 0-12 are in HH, female	-.2476E+0	.15E+0	.1107E+0	.13E+0	.2927E+0	.23E+0
Nonfamily	.1588E+0	.78E-1	.2198E+0	.90E-1	.3965E+0	.14E+0
Disabled	.8747E+0	.23E+0	-.2960E+0	.17E+0	-.3844E+0	.30E+0
per capita income, full time worker	.8586E-1	.53E-1	-.6387E-1	.61E-1	-.1196E-1	.11E+0
per capita income, not full-time worker	.1478E-1	.24E+0	.5138E-1	.35E-1	-.1532E-1	.53E-1
Usual weekly work hours	-.1131E-1	.40E-2	-.2326E-2	.37E-2	-.5950E-2	.66E-2
# work hours over 40	.8876E-2	.61E-2				
1+ cars are in HH	-.2569E+0	.18E+0	.3156E+0	.19E+0	.6609E+0	.37E+0
1+ cars per adult	.6443E-1	.33E-1	.4051E-1	.11E+0	.6516E-1	.18E+0

Pattern components

Now turn attention to the pattern utility components associated with the pattern in which the activities are conducted. The utility in these components is not inherent in the activity itself, but rather comes from scheduling cost, synergy, fatigue or opportunity cost of the pattern—in particular, lost opportunity for at-home leisure activity. These components implicitly capture the effect of the 24-hour time constraint restricting the number of activities in the schedule. The model includes three categories of pattern component—placement, primary tour activity combinations and inter-tour combinations—all of which are directly observed in the pattern and together comprise the component $\tilde{V}_p$.

Secondary activity placement components

Secondary activity placement components differentiate utility of secondary activities that share a common purpose but occur at different places in the pattern or in different pattern types. The utility comes from the activity's placement relative to the primary activity. For example, in subsistence patterns the on-tour secondary maintenance activities differ in utility, depending on whether they occur on an at-home subsistence pattern, on the primary tour—either before, as a subtour or after the primary stop—or on a separate secondary tour. In the model, one placement must serve as a base for each purpose, with utility of other placements measured relative to the base. We arbitrarily identify a secondary stop after the primary stop as the base case.

Secondary maintenance on on-tour subsistence patterns. For secondary maintenance activities on on-tour subsistence patterns, usual workload probably affects placement utility; as the workday gets longer separate maintenance tours should decrease relative to stops after, while subtours and stops before might increase. For family members, especially those with children, family ties may make work-based subtours less appealing because they preclude coupling with other family members. Higher income may alter the utility of chained primary tours relative to separate secondary tours, inducing convenience shopping activity attached to the subsistence tour, and also to allowing unplanned secondary tours with less concern for travel costs. The availability of cars will tend to increase freedom to attach maintenance stops to primary tours, reducing the relative attractiveness of separate maintenance tours. Apart from the lifestyle and mobility effects on placement, stops after work may be the most attractive of the placement options because of the convenience of chaining stops with the primary stop, and the greater schedule flexibility of stops after work. This is in contrast to stops before work and on subtours where a timely arrival at work may be important. Since stop after work is the base case for placement utility, we expect negative constants on all other alternatives.

The parameter estimates for secondary stop placement on subsistence tours, in Table 15, show a few differences from our expectations. Although having children does tend to eliminate the work-based subtour for women, other family connections do not. Also, when usual work hours are very small, the model indicates a preference for separate maintenance tours, with maintenance stops after subsistence surpassing a separate tour only when usual work hours exceed about 30 hours.

When the primary subsistence activity is conducted at home, higher work hours probably reduces utility of secondary maintenance tours, relative to the utility of maintenance stops after work on on-tour patterns, because of the inconvenience of leaving home. Presence of children and disabled may keep home-based workers from making maintenance tours, and the availability of cars may not hurt the attractiveness of secondary tours for at-home workers as much as for on-tour workers. Overall, however, we expect the schedule flexibility of working at home, and the associated unavailability of chaining opportunities, to make the utility of secondary tours higher for subsistence at home patterns than for subsistence on tour patterns. We see all these effects in the Table 15 estimation results.

Secondary leisure on on-tour subsistence patterns. For secondary leisure on-tour activities, placement lifestyle effects related to usual workload and presence of children are probably different than for maintenance activities. People with heavy workloads may find increased utility in a leisure subtour, providing a recuperative break in a long workday. People with children or disabled in the household may be inclined to avoid a second tour for leisure, instead chaining leisure activities with their subsistence tour. Car availability and income may have effects similar to those with maintenance patterns. On subsistence-at-home patterns, nonfamily persons may take secondary leisure tours more often than family members, satisfying social needs.

Estimation results for secondary leisure activity placement in subsistence patterns are also shown in Table 15. Unexpected results include a rather strong effect of car availability to decrease work-based leisure subtours relative to stops after work, and of nonfamily status to decrease secondary leisure tours on at-home subsistence patterns. Otherwise, the results are as expected.

Table 15 Placement of secondary maintenance and leisure activities in subsistence patterns

Component	Variable	Coeff.	Std. Err.
Secondary maintenance stop after	Base case for secondary on-tour maintenance activity		
Secondary maintenance stop before	constant	-.6762E+0	.20E+0
	usual weekly work hours	.5109E-2	.47E-2
Secondary maintenance subtour	constant	-.9690E+0	.30E+0
	Family	-.2999E-1	.16E+0
	children 0-12 are in HH, female	-.8172E+0	.30E+0
	usual weekly work hours	.1248E-1	.62E-2
Secondary maintenance tour on on-tour subsistence patterns	Constant	.1885E+1	.54E+0
	usual weekly work hours	-.6237E-2	.37E-2
	per capita income	-.8682E-1	.39E-1
	1+ cars in HH	-.4123E+0	.37E+0
	1+ cars per adult	-.4115E+0	.14E+0
Secondary maintenance tour on at-home subsistence patterns	Constant	.3001E+1	.71E+0
	# children 0-17 plus # disabled, female	-.3019E+0	.12E+0
	usual weekly work hours	-.5627E-2	.57E-2
	1+ cars in HH	-.4422E+0	.52E+0
	1+ cars per adult	-.7181E-1	.22E+0
Secondary leisure stop after	Base case for secondary on-tour leisure activity		
Secondary leisure stop before	Constant	-.4185E+0	.36E+0
	1+ cars per adult	-.6591E+0	.38E+0
Secondary leisure subtour	Constant	.4321E+0	.34E+0
	usual weekly work hours	.1944E-1	.49E-2
	1+ cars per adult	-.6085E+0	.28E+0
Secondary leisure tour on on-tour subsistence patterns	Constant	.2981E+0	.78E+0
	family w children 0-12 or disabled	-.1074E+0	.17E+0
	female in family w children 0-12 or disabled	.1029E+0	.20E+0
	per capita income	-.1596E+0	.50E-1
	1+ cars per adult	-.3819E+0	.26E+0
Secondary leisure tour on at-home subsistence patterns	Constant	.1815E+1	.80E+0
	Nonfamily	-.6694E+0	.29E+0
	per capita income	.2116E+0	.77E-1
	1+ cars per adult	-.1467E+1	.32E+0

Maintenance and leisure patterns. On maintenance and leisure patterns, the distinction between primary and secondary activities is not as clear as on subsistence patterns, and these patterns lack lifestyle information to indicate the usual duration of the primary activity. Thus it is more difficult to establish a rich set of expectations and estimated parameters explaining secondary stop placement. We expect to see a preference for combining secondary maintenance stops with primary maintenance tours, but otherwise to conduct secondary activities on separate tours. In contrast to subsistence patterns, if the primary activity is at home there is probably less tendency to conduct secondary activities on-tour, for the same reasons that keep the primary activity at home, with the effect softened by the presence of one or more cars per adult.

Estimation results for secondary activity placement in maintenance patterns are in Table 16, and for leisure patterns are in Table 17. In maintenance patterns with secondary on-tour leisure activity there is an unexpected but plausible strong tendency to attach the leisure activity to the maintenance tour. There is also an extremely strong tendency to avoid secondary on-tour activities when the primary activity is at home, especially for secondary leisure activities. People on leisure patterns have a strong tendency to avoid a second leisure tour, preferring to attach the second leisure stop to the primary. There is an even stronger tendency to avoid a leisure tour altogether when the primary leisure activity is at home.

Table 16 Placement of secondary maintenance and leisure activities in maintenance patterns

Component	Variable	Coeff.	Std. Err.
Secondary maintenance stop after	Base case for secondary on-tour maintenance activity		
Secondary maintenance stop before	constant	-.2992E+0	.14E+0
Secondary maintenance tour on maintenance tour patterns	constant	-.2145E+0	.67E+0
Secondary maintenance tour on maintenance at home patterns	constant	-.1718E+1	.71E+0
	1+ cars per adult	.6167E+0	.23E+0
Secondary leisure stop after	Base case for secondary on-tour leisure activity		
Secondary leisure stop before	constant	.4151E-3	.17E+0
Secondary leisure tour on maintenance tour patterns	constant	-.2180E+1	.90E+0
Secondary leisure tour on maintenance at home patterns	constant	-.5505E+1	.11E+1
	1+ cars per adult	.5187E+0	.76E+0

Table 17 Placement of secondary maintenance and leisure activities in leisure patterns

Component	Variable	Coeff.	Std. Err.
Secondary maintenance stop after	Base case for secondary on-tour maintenance activity		
Secondary maintenance stop before	constant	.1352E+0	.23E+0
Secondary maintenance tour on leisure tour patterns	constant	-.6385E+0	.14E+1
Secondary maintenance tour on leisure at home patterns	constant	-.1598E+1	.14E+1
Secondary leisure stop after	Base case for secondary on-tour leisure activity		
Secondary leisure stop before	constant	-.2832E+0	.22E+0
Secondary leisure tour on leisure tour patterns	constant	-.3435E+1	.15E+1
Secondary leisure tour on leisure at home patterns	constant	-.6419E+1	.16E+1

Primary tour combinations

These components capture the utility effects of having multiple secondary stop placements on primary tours. Certain combinations may bring synergy or inconvenience, apart from the implicit time constraint, fatigue and opportunity costs captured by the inter-tour parameters of the next section. For instance, it may be necessary for many people with pre-school children to drop off and pick up their children at daycare locations, increasing the need for maintenance stops before and after work.

Estimation results are shown in Table 18 for all subsistence, maintenance and leisure patterns. We find the anticipated effect of pre-school children, which is marginally stronger for mothers than fathers. We also see a general tendency to combine before and after stops to the subsistence pattern, but almost none whatsoever for maintenance and leisure patterns.

Inter-tour effects

These components capture the effects on pattern utility of activity combinations beyond the primary tour, capturing trade-offs among secondary at-home maintenance, extra stops on the primary tour, and secondary tour participation. Primarily they capture disutility arising from time constraints, fatigue and lost opportunity for at-home leisure. This disutility would increase with number of activities and tours, with leisure activity combinations causing greater disutility than maintenance combinations because of synergy in combining maintenance activities. As with the other pattern categories, inter-tour combination utility must be identified relative to base cases. We choose the simplest combinations as base cases, resulting in the expectation of negative values for all constants. The only lifestyle effects we identify for work patterns are for workload and occupation. Those who regularly work longer hours may prefer simple patterns, that is, patterns with no on-tour secondary stops or tours. Nonprofessionals may have less interests and commitments that take them places other than work on their workdays. Lifestyle effects on maintenance patterns are included for parents of children, who may be more likely to conduct multiple tours, and people over 65, who may be less likely to conduct multiple tours.

Table 18 Secondary activity combinations on primary tour

Component	Variable	Coeff.	Std. Err.
Primary subsistence tours			
Maintenance stops before & after	constant	.1144E+1	.17E+0
	children 0-4 are in household	.5700E+0	.31E+0
	female w children 0-4 in household	.3934E+0	.39E+0
other before and after stop combinations	constant	.3012E+0	.20E+0
stops before & after with subtour	constant	.3667E+0	.21E+0
Primary maintenance tours			
stops before and after	constant	.6154E-1	.61E+0
	per capita income	-.8293E-2	.84E-1
	1+ cars per adult	.3018E+0	.26E+0
leisure stops before & after	constant	.6803E-1	.35E+0
maint & leisure stops, before & after	constant	.1731E-1	.21E+0
Primary leisure tours			
stops before and after	constant	.2247E-1	.12E+1

The estimation results for inter-tour effects are listed in Tables 19 through 21. We see the anticipated effects, although the specification does not distinguish secondary activity purpose. A specification that makes this distinction may significantly improve the model fit. Disutility of multiple tours increases nonlinearly; the addition of a third tour hurts utility much more than the addition of a second tour. In most cases adding at-home maintenance to a pattern also reduces its attractiveness; the effect is that people trade at-home maintenance for extra tours.

Table 19 Subsistence pattern inter-tour combinations

	Coeff.	Std. Err.
Constants for patterns with no secondary at-home maintenance:		
Subsistence at home with 0 secondary tours —base for subsistence at home patterns		
Subsistence at home with 1 secondary tour—base for subsistence at home w secondary tour(s)		
Subsistence at home with 2+ secondary tours	-.1365E+1	.47E+0
Simple subsistence tour with 0 secondary tours —base for subsistence on tour patterns		
Simple subsistence tour w 1 secondary tour—base for simple subsistence tours w sec. tour(s)		
Simple subsistence tour with 2+ secondary tours	-.1679E+1	.26E+0
Complex subsistence tour with 0 secondary tours	.8683E+0	.59E+0
Complex subsistence tour with 1 secondary tour	.2707E+0	.60E+0
Complex subsistence tour with 2+ secondary tours	-.1457E+1	.70E+0
Constants for patterns with secondary at-home maintenance:		
Subsistence at home w 0 secondary tours—base for subsistence patterns w at-home maint.		
Subsistence at home with 1 secondary tour	-.4825E+0	.44E+0
Subsistence at home with 2+ secondary tours	-.1611E+1	.71E+0
Simple subsistence tour w 0 secondary tours	-.7428E+0	.36E+0
Simple subsistence tour with 1 secondary tour	-.7386E+0	.36E+0
Simple subsistence tour with 2+ secondary tours	-.1147E+1	.43E+0
Complex subsistence tour with 0 secondary tours	.1343E+0	.69E+0
Complex subsistence tour with 1 secondary tour	-.4990E+0	.71E+0
Complex subsistence tour with 2+ secondary tours	-.1826E+1	.81E+0
Lifestyle effects		
Usual weekly work hours: simple subsistence tour w no secondary tours	.4077E-2	.37E-2
Nonprofessional: simple subsistence tour w no secondary tours	.2676E+0	.73E-1

Table 20 Maintenance pattern inter-tour combinations

	Coeff.	Std.Err.
Constants for patterns with no secondary at-home maintenance:		
Maintenance at home with 0 secondary tours—base for maint at home patterns		
Maint at home w 1 secondary tour—base for maint at home w secondary tour(s)		
Maintenance at home with 2+ secondary tours	.1413E+1	.35E+0
Simple maint tour w 0 secondary tours —base for maintenance on tour patterns		
Simple maintenance tour with 1 sec. tour—base for simple maint. tours w secondary tour(s)		
Simple maintenance tour with 2+ secondary tours	-.2057E+0	.34E+0
Complex maint. tour w 0 sec. tours —base for maint-on-tour patterns w complex primary tour		
Complex maintenance tour with 1 secondary tour	-.9401E-2	.23E+0
Complex maintenance tour with 2+ secondary tours	.8617E-1	.40E+0
Constants for patterns with secondary at-home maintenance:		
Simple maint. tour w 0 sec. tours —base for maint-on-tour patterns w at-home sec. maint.		
Simple maintenance tour with 1 secondary tour	-.1803E-2	.17E+0
Simple maintenance tour with 2+ secondary tours	.3643E+0	.35E+0
Complex maintenance tour with 0 secondary tours	.5771E-2	.17E+0
Complex maintenance tour with 1 secondary tour	.8976E-1	.27E+0
Complex maintenance tour with 2+ secondary tours	-.5358E-1	.44E+0
Lifestyle effects		
Simple maint tour with 1+ sec tours, male w kids 0-17 in hh	.4846E+0	.27E+0
Simple maint tour with 1+ sec tours, female with kids 0-17 in hh	.1317E+0	.18E+0
Simple maint tour with 1+ sec tours, age is over 65	-.4517E+0	.14E+0
Complex maint tour with 1+ sec tours, male w kids 0-17 in hh	-.1432E+0	.39E+0
Complex maint tour with 1+ sec tours, female with kids 0-17 in hh	.1038E+0	.21E+0
Complex maint tour with 1+ sec tours, age is over 65	-.4539E+0	.16E+0

Table 21 Leisure pattern inter-tour combinations

	Coeff.	Std. Err.
Constants for patterns with no secondary at-home maintenance:		
Leisure at home with 0 secondary tours—base for leisure at home patterns		
Leisure at home with 1 secondary tour—base for leisure at home w secondary tour(s)		
Leisure at home with 2+ secondary tours	.1922E+1	.71E+0
Simple leisure tour with 0 secondary tours—base for leisure on tour patterns		
Simple leisure tour with 1 secondary tour—base for simple leisure tours with secondary tour(s)		
Simple leisure tour with 2+ secondary tours	.1741E+0	.43E+0
Complex leisure tour w 0 secondary tours —base for complex leis. tour patterns		
Complex leisure tour with 1 secondary tour	-.3387E+0	.31E+0
Complex leisure tour with 2+ secondary tours	-.1055E+1	.70E+0
Constants for patterns with secondary at-home maintenance:		
Leisure at home with 0 secondary tours—base for leisure patterns with at-home maintenance		
Leisure at home with 1 secondary tour	.1096E+0	.44E+0
Leisure at home with 2+ secondary tours	.2507E+1	.77E+0
Simple leisure tour with 0 secondary tour	.1514E+1	.18E+0
Simple leisure tour with 1 secondary tour	.9532E+0	.24E+0
Simple leisure tour with 2+ secondary tours	.1681E+1	.41E+0
Complex leisure tour with 0 secondary tours	.9243E+0	.23E+0
Complex leisure tour with 1 secondary tour	.1168E+1	.31E+0
Complex leisure tour with 2+ secondary tours	.5163E+0	.60E+0

Tours accessibility

The final component in the pattern utility function is the composite measure of expected utility arising from the tours in the pattern, comprising the terms $\sum_{t \in T_p} V_t$.

This component of the utility is a pattern attribute that can only be measured as a composite of tour and activity attributes among the conditional tour alternatives available for the given pattern. In a standard nested logit model it is the expected utility among the available conditional alternatives, as measured by the conditional logit choice model. Its value only has meaning relative to the alternatives and other expected utility measures derived from the same conditional model. Standard nested logit models have been proven generally to be consistent with random utility theory when the parameter values are in the range zero to one. If the parameters exceed the value 1, then consistency with random utility theory depends on the values of the data.

In the day activity schedule model a pure nested logit form is compromised for the sake of tractability by making conditional independence assumptions among tours. This precludes use of the standard single valued logsum expected utility measure of the nested logit form. Instead, a composite measure is used, derived from the logsums of the tours in the pattern. In the composition, it is important to account for (a) the difference in scale of the component logsums and (b) the different importance to the pattern choice of expected utility for different tour priorities and purposes. This is handled by estimating separate coefficients for each type of logsum in the composite measure. It is difficult to anticipate the relative size of these parameters, because the scale and importance effects cannot be separately identified. Negative values will certainly produce counterintuitive results, predicting an increase in utility of a pattern if the expected utility of a component tour drops.

The tour accessibility parameter estimates are listed in Table 22. Each pattern purpose has its own set of parameters because of expected purpose-specific differences of accessibility importance in pattern choice. Primary and secondary tours have separate parameters for the same reason, and also to accommodate potential scale differences between primary and secondary tour utilities. Primary tours with secondary stops have different parameters than those without, for two reasons. First, people may place different weight on expected primary tour utility if it includes multiple activity stops. Second, due to the simplifying compromises made in the Portland tour models, in which expected secondary stop utility is not used to explain tour choices, the measure used for expected tour utility of tours with secondary stops provides only an estimate of the desired expected tour utility measure. As it turns out, the parameter estimates for primary tours with and without extra stops are not significantly different from each other and could be constrained to be equal.

In all cases the estimated parameters are less than one. In only one case is the estimate less than zero, and then with almost no significance. For subsistence patterns, primary tour accessibility carries more weight relative to the secondary tours than it does in maintenance and leisure patterns. Primary tour accessibility is also less significantly different from zero for maintenance and leisure patterns, although three of the four estimates exceed zero by approximately one standard error and should be retained in the model. For all pattern purposes, accessibility is more important for secondary leisure tours than it is for secondary maintenance tours.

Table 22 Tour accessibility logsums

	Subsistence patterns		**Maint. patterns**		**Leisure patterns**	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
primary tour with no extra stops	.8103E+0	.18E+0	.1709E+0	.19E+0	.2260E+0	.26E+0
primary tour with extra stops	.6539E+0	.19E+0	.1349E+0	.19E+0	-.6022E-1	.38E+0
secondary maintenance tour*	.1223E+0	.16E+0	.2187E+0	.13E+0	.2187E+0	.13E+0
secondary leisure tour*	.5173E+0	.20E+0	.9845E+0	.20E+0	.9845E+0	.20E+0

*estimated jointly for maintenance and leisure patterns

Specification tests

Several statistical tests on groups of parameters test various aspects of the model specification. In each test the collective significance of a group of variables is tested by estimating a model in which their coefficient values are restricted to zero, and then conducting a likelihood ratio test. Table 23 reports the number of restrictions, restricted loglikelihood, likelihood ratio statistic and p-values for each test. The p-value represents the probability under the null hypothesis—insignificance of the parameter group—of observing data at least as adverse to the hypothesis as is actually observed. Thus, a value near zero, coupled with well-reasoned *a priori* belief that the group belongs, gives a strong indication of the importance of the group in the specification.

Table 23 Statistical tests of pattern model restrictions

Test number	Variables removed (parameters restricted to 0)	number of restrictions (n)	Restricted loglikelihood LL(R)	Likelihood ratio statistic*	p-value**
	Lifestyle variables				
1	all lifestyle, except gender	152	-24512	958	0+
2	HH structure	14	-24049	32	0.004
3	role	70	-24227	388	0+
4	capabilities	38	-24160	254	0+
5	activity commitments	30	-24125	184	0+
6	**Mobility commitments**	27	-24087	108	0+
	Activity components				
7	subsistence pattern at-home maintenance	12	-24129	192.8	0+
8	leisure pattern at-home maintenance	11	-24054	42.8	0+
	Secondary activity placement components				
9	maintenance in subsistence patterns	16	-24094	122.8	0+
10	leisure in subsistence patterns	14	-24152	238.8	0+
11	maintenance in maintenance patterns	3	-24054	42.8	0+
12	leisure in maintenance patterns	3	-24095	124.8	0+
13	maintenance in leisure patterns	3	-24038.2	11.2	.01
14	leisure in leisure patterns	3	-24067	72.2	0+
	Primary tour combinations				
15	in subsistence patterns	5	-24075	84.8	0+
16	in maintenance patterns	5	-24034	2.8	.7
17	in leisure patterns	1	-24032.6	0	1-
18	**Expected tour utility**	10	-24060	54.8	0+

* -2(LL(R)-LL(U)), where U is full model and R is restricted model of current column, testing significance of removed parameters. Unrestricted loglikelihood, LL(U), equals –24032.6.
** given the true restricted model, under which the likelihood ratio statistic is asymptotically distributed chi squared with n degrees of freedom, the probability of a statistic at least as adverse to the model as the observed statistic

Tests 1 through 5 support the importance of the four lifestyle categories collectively, and individually, and test 6 achieves the same result for the mobility commitments category.

Tests 7 and 8 support the importance of the secondary at-home maintenance activity parameters in subsistence and leisure patterns. In this case, the test result lends support not only to the parameters as a group, but also to the hypothesis that the identification of secondary at-home maintenance is important in the pattern choice set definition.

Tests 9 through 14 test the importance of the parameters that differentiate attractiveness of alternative positions within the pattern for secondary activity participation. In the parameters, and in the tests, the placement of secondary activities is distinguished by pattern purpose—that is, purpose of the pattern's primary activity—and secondary activity purpose. In all cases, the parameters are significant as a group. Formal tests were not conducted to test whether the placement parameters are significantly different by pattern purpose or secondary activity purpose, but examination of the individual parameters reveals differences that indicate the importance of these distinctions. These results lend support for a pattern choice set definition that distinguishes pattern placement for secondary activities, specific to pattern and secondary activity purpose.

Tests 15 through 17 examine the importance of primary tour combinations for subsistence, maintenance and leisure patterns. Of the few parameters in this category, we see that they are supported as a group only for subsistence patterns. That is, only for subsistence patterns have we found evidence of utility associated with particular combinations of two or more secondary activities on the primary tour, distinct from any utility or disutility the combination may cause in the pattern as a whole.

Test 18 supports the importance of the tour expected maximum utility parameters as a group, reconfirming the conclusion of Ben-Akiva and Bowman (1999) that it is important to represent travel demand in the context of the day activity schedule. With the expected maximum utility variables, changes in tour utility, caused by changes in the transport system performance or in spatial activity opportunities, have a significant effect on the choice of pattern. Such effects cannot be captured by tour or trip-based travel demand models.

It would be possible to conduct more tests that might lead to refinement of the model structure, utility function structure or model variables. Testing of the pattern model's multinomial logit assumption, with the likely introduction of nesting structure to accommodate correlation among subsets of pattern alternatives, remains as a high priority research objective. The need probably exists for nesting, and perhaps more complex correlation structures, because of the multidimensional nature of the pattern choice. For example, strong random utility correlation probably exists among patterns that share primary purpose.

Nevertheless, the tests described here provide evidence, in addition to the individual parameter tests, in support of the basic model structure, utility function structure and lifestyle variable categories of the model.

MODEL APPLICATION

Pattern effects of a peak period auto toll

The empirical model is tested in application using a simplified application procedure in which it is applied to the estimation sample without network assignment and reiteration. Therefore, the predictions represent the sample instead of the Portland population, and do not take into account secondary demand adjustments resulting from changed traffic conditions.

We apply the day activity schedule model to the estimation sample under the estimation conditions and with a $.50 per mile toll levied on all auto travel occurring during the morning and evening peak periods. Aggregate results Table 24 show pattern shifts captured by the model that would be ignored or confounded with other effects in trip and tour-based models. Increased travel costs for peak period auto tours in the tour models reduces expected maximum tour utility in the pattern choice model, where patterns with tours that rely most heavily on peak period auto travel become relatively less attractive. In the tour models, subsistence tours rely heavily on peak period travel, as do secondary tours on subsistence patterns. Thus, there is a shift away from patterns of these types. This is accompanied by a shift toward other pattern types, including nonwork patterns, at-home patterns, those with no secondary tours, and those with at-home maintenance tasks.

Table 24 Day activity pattern adjustments for $.50 per mile peak period toll

Pattern type	Pattern's predicted percent in sample without toll	Pattern's predicted percent in sample with toll	Percent change in predicted number of patterns, with toll
Subtotals by primary purpose			
subsistence	56.1	55.4	-1.3
maintenance	28.9	29.3	1.5
leisure	15.0	15.3	1.9
Subtotals by Primary tour complexity			
at home	15.6	16.1	3.3
simple	51.1	50.6	-0.9
complex	33.3	33.3	-0.1
Subtotals by secondary tours			
0 sec tours	65.4	65.6	0.3
1+ sec tours	34.6	34.4	-0.6
Subtotals by home maintenance			
no at-home maintenance	55.5	55.2	-0.5
at-home maintenance	44.5	44.8	0.6
Total all patterns	100.0	100.0	

These pattern shifts combine with time and mode change effects in the conditional tour models to yield travel predictions. Although tour model application results are not available for this pattern model, Figure 3(b) shows results from a very similar, but somewhat simpler version. It provides a graphical summary by tour purpose and priority, showing that primary maintenance and leisure tours replace primary subsistence tours under the toll. A compensating drop occurs in secondary maintenance tours, but this compensating drop does not occur in leisure tours. Thus, the model predicts a net increase in leisure travel demand induced by the toll policy.

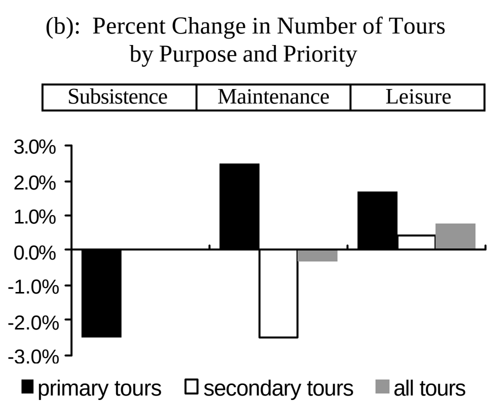

Figure 3 (a) Activity pattern effects, and (b) travel effects of $.50 per mile peak period toll policy

Heterogeneity of activity patterns and pattern effects

The previous analysis ignores the lifestyle and mobility effects in schedule choice and the associated potential heterogeneity of response to the toll policy. Table 25 examines two dimensions of the activity pattern, secondary tour participation and participation in at-home maintenance activity, predicting shifts in these activity pattern dimensions for 22 population segments, defined by household structure and role, capabilities, activity commitments and mobility decisions.

Figure 4 highlights 4 of the many results contained in the table. Figure 4(a) shows that part-time workers are much more likely than others to include secondary tours in their activity pattern.

Income has little effect on secondary tour participation, but Figure 4(b) shows that the toll has a greater tendency to simplify the patterns of lower income persons.

Turning to participation in at-home maintenance activity, Figure 4(c) shows a strong gender-based role specialization that is heightened in the presence of children. The toll policy has only a small effect on at-home maintenance, but the model predicts that workers (presumably those predicted to work less because of the toll) pick up some of the at-home maintenance responsibilities from their nonworking counterparts (Figure 4(d)). In summary, the model captures much heterogeneity in both pattern choice and predicted response to the toll policy. The results, none of which is surprising, clearly demonstrate the importance of explicitly modeling heterogeneity in the pattern choice.

Table 25 Predicted toll response of 22 population segments—secondary tours and at-home maintenance

	with secondary tours		with at-home maintenance	
Population segment	Pattern's predicted percent in segment without toll	Percent change with toll	Pattern's predicted percent in segment without toll	Percent change with toll
Household structure and role				
Nonfamilies	34.1	-0.5	36.0	0.3
families with no children, males	31.7	-0.7	31.6	0.2
families with no children females	33.3	-0.7	41.8	0.2
families with children, males	32.8	-0.2	29.0	0.4
families with children, females	42.6	-0.7	53.8	0.1
Household annual income ($1000s)				
under 15	32.0	-1.0	42.0	-0.1
15 to 29	34.3	-0.9	41.1	0.1
30 to 44	35.1	-0.7	38.7	0.2
45 to 59	35.2	-0.5	37.1	0.4
over 60	35.0	-0.2	34.5	0.5
Disability limits independent travel				
No	35.2	-0.8	38.6	0.2
Yes	22.7	-0.7	31.1	-0.1
Usual weekly work hours				
Nonworkers	35.3	-1.5	52.2	-0.3
1 to 19	41.5	-0.4	43.1	0.3
20 to 34	37.3	-0.6	37.3	0.5
35 to 44	33.0	-0.1	30.5	0.8
45 to 54	32.2	0.2	27.9	0.7
55 or more	30.1	0.2	27.1	0.7
Students without other employment	41.5	-0.6	35.8	0.2
Vehicles per adult				
0	24.7	-0.1	35.5	-0.1
Under 1	32.3	-0.7	36.5	0.0
1 or more	35.8	-0.8	38.9	0.3
Total	34.6	-0.7	38.3	0.2

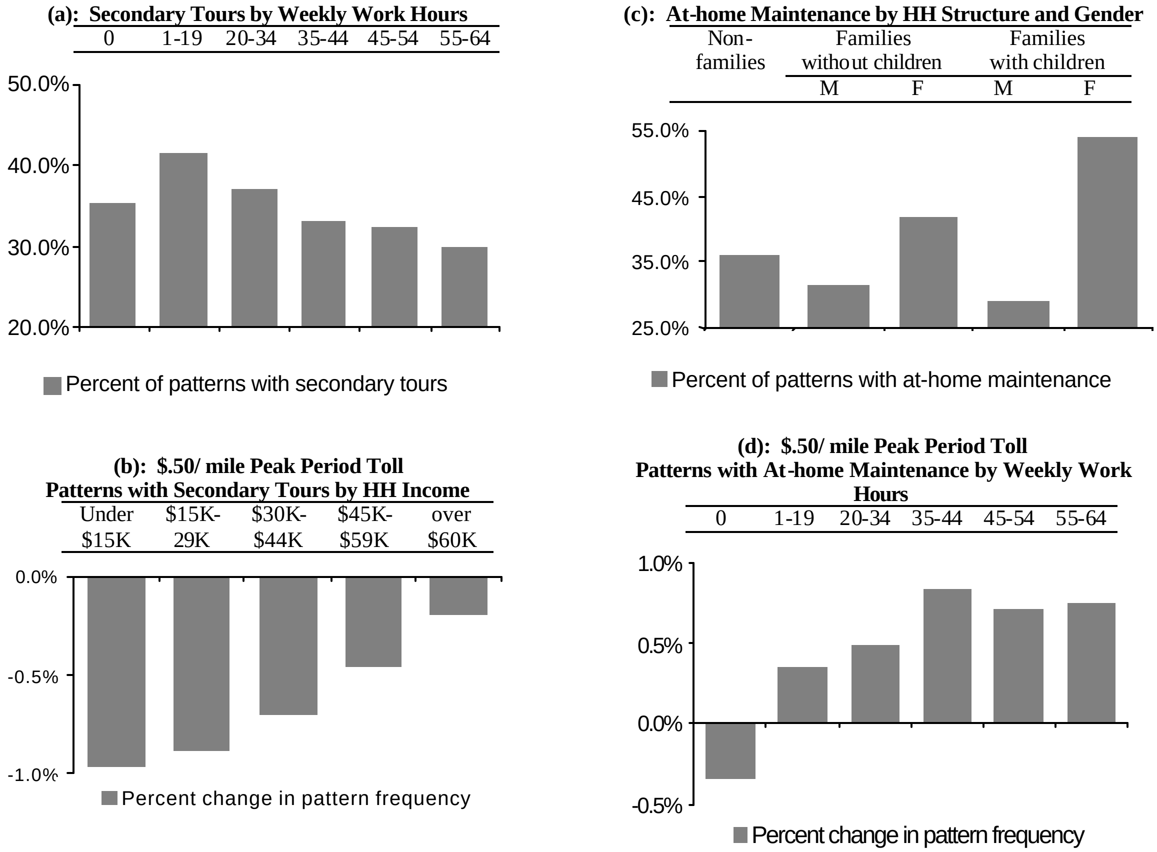

Figure 4: Lifestyle heterogeneity in the day activity schedule model: (a) Part-time workers are more inclined to conduct secondary tours, (b) The toll reduces secondary tours more for low income persons, (c) Role specialization in families gives more at-home maintenance to females, and especially mothers, and (d) workers pick up at-home maintenance responsibilities under the peak period toll.

SUMMARY AND CONCLUSIONS

In this paper we enhance in three important ways the specification of the activity pattern component of the activity schedule model system presented earlier (Ben-Akiva and Bowman, 1999), statistically test the significance of these enhancements, and demonstrate the effects in prediction. First, the choice set is expanded to provide a more detailed account of activity participation, including at-home activities and identifying the purpose of all modeled activities. Second, the utility function is enhanced to associate utility directly with each activity in the pattern, in addition to that which is related to expected tour utility and the pattern as a whole. These two changes should reduce the occurrence of missing variable bias and improve prediction when utility changes for particular types of activities, such as at-home activities or activities of a particular purpose. The third change is a systematic treatment of lifestyle and mobility heterogeneity effects on pattern choice. This should also improve model prediction, especially when the population's lifestyle profile changes, and should allow for a more accurate assessment of welfare effects on population subgroups. These enhancements are made to an integrated activity schedule model in which pattern choice depends on expected tour utility. This enables the model to predict all within-day aspects of travel—including at-home and on-tour activity participation, multiple tourmaking and trip chaining—with sensitivity to activity opportunities and travel conditions.

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