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A model for joint choice of daily activity pattern types of household members

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Abstract. Intra-household interactions constitute an important aspect in modeling activity and travel-related decisions. Recognition of this importance has recently produced a growing body of research on various aspects of modeling intra-household interactions and group decision-making mechanisms as well as first attempts to incorporate intra-household interactions in regional travel demand models. The previously published research works were mostly focused on time allocation aspect and less on generation of activity episodes, trips, and travel tours that are necessary units for compatibility with regional travel demand models. Also, most of the approaches were limited to household heads only and did not consider explicitly the other household members as acting agents in the intra-household decision making. A model is proposed for joint choice of daily activity pattern (DAP) types for all household members that explicitly takes into account added group-wise utilities of joint participation in the same activity. The model is based on the aggregate description of individual DAP types by three main categories – mandatory travel pattern, non-mandatory travel pattern, and at-home pattern. Important intra-household interactions can be captured already at this aggregate level. A choice structure considers all possible combinations of DAPs of all household members as alternatives. Utility function of each alternative includes components corresponding to each individual DAP type as well as group-wise interaction terms that correspond to joint choice of the same pattern by several household members. Statistical analysis of intra-household interactions and estimation results of the choice model are presented. The model estimation has confirmed a strong added utility of joint choice of the same pattern for such person types as non-worker or part time worker in combination with child, two retired persons, two children, and others. The proposed model represents a part of the advanced regional model system being developed for the Atlanta Regional Commission.

Abbreviation: DAP: daily activity pattern type; FW: full-time worker; H: individual staying-at-home daily activity pattern type; HH: jointly chosen staying-at-home daily activity pattern type for two persons; M: individual mandatory daily activity pattern type; MM: jointly chosen mandatory daily activity pattern type for two persons; MMM: jointly chosen mandatory daily activity pattern type for three persons; N: individual non-mandatory-travel daily activity pattern type; NN: jointly chosen non-mandatory-travel daily activity pattern type for two persons; NNN: jointly chosen non-mandatory-travel daily activity pattern type for three persons; NW: non-worker (under 65); PS: preschool child of age (under 6 years); PW: part-time worker; RT: retired person (65 or older); SD: school child of driving age (16 or older); SP: school child of pre-driving age (6–15 years); US: university student.

1. Introduction

Intra-household interactions constitute an important aspect in modeling activity and travel-related decisions. Recognition of this importance has recently produced a growing body of research on various aspects of modeling intra-household interactions and group decision making mechanisms as well as first attempts to incorporate intra-household interactions in regional travel demand models.

The previously published research works were mostly focused on intra-household time allocation between activity types and household members. Much less effort was made on understanding and modeling of generation of activity episodes, trips, and travel tours. In particular, the works of Borgers et al. (2002), Ettema et al. (2004), Fujii et al. (1999), Gliebe and Koppelman (2002), Golob and MacNally (1997), Goulias (2002), Meka et al. (2002), Schwanen et al. (2004), Townsend (1987), Zhang et al. (2002), Zhang et al. (2004), Zhang and Fujiwara (2002) give examples of models for time allocation between various type of activities and household members. Though these works provide valuable insights into the intra-household decision-making mechanism they do not directly address requirements of the structure of travel demand models that are based on discrete units of travel and discrete choice modeling technique.

Most of the approaches including those proposed by Borgers et al. (2002), Ettema et al. (2004), Gliebe and Koppelman (2002), Golob and MacNally (1997), Schwanen et al. (2004), Townsend (1987), Simma and Axhausen (2001), Scott and Kanaroglou (2002), Srinivasan and Bhat (2004) were limited to household heads only and did not consider explicitly the other household members as active agents in the intra-household decision making. In most cases, the model structure was essentially built on the assumption of a "binary" household and could not be easily extended to incorporate more than two interacting agents. This is another limitation that has to be lifted in order to integrate intra-household interactions in the framework of regional travel demand models.

The current paper presents an approach for joint modeling of daily activity pattern types for all household members. This aspect of intra-household interactions relates to the most important aggregate attributes of individual activity/travel behavior. The proposed model represents a part of the model system currently being developed for the Atlanta Regional Commission (ARC). The adopted structure represents a further development of the individual daily activity pattern (DAP) type model applied in the framework of the Mid-Ohio Regional Planning Commission (MORPC) and reported by Vovsha et al. (2004a). The most important advancement of the ARC version of the DAP type choice model compared to the MORPC version is that all household members are modeled simultaneously while the MORPC version was based on the sequential modeling of household members by a predetermined order by person types.

The paper is organized as follows. The next section presents a classification of intra-household interactions where coordination of DAP types is considered as the upper-level interaction. The section that follows presents the choice model structure and supporting statistical analysis of observed individual and joint DAP types based on the recent household travel survey undertaken for ARC. The next section presents the model estimation results. The section that follows explains the placement of the developed model in the framework of the regional models system. The last section contains concluding remarks and directions for further research.

2. Classification of intra-household interactions

According to the general methodological approach adopted for the MORPC and ARC model systems, intra-household coordination mechanism can be stratified by three following principal layers of interactions:

1. *Coordinated principal daily pattern types at the entire-day level*. We consider three principal daily pattern types: (1) *mandatory* (including work, university or school activities, and possibly including additional out-of-home non-mandatory activities); (2) *non-mandatory travel* (including only non-mandatory activities, at least one of which is out of home); and (3) *staying at home* (or absence from town) for the entire day. Statistical evidence shows strong coordination between household members at this principal level, resulting in such decisions as staying home for child care; coordinated work commutes; and household members taking time off together for major shopping trips, family events and vacations.
2. *Episodic joint activity and travel*. Even if household members have chosen different pattern types (for example, one mandatory and the other non-mandatory) they may participate in shared activities and/or joint travel arrangements. We use a classification of typical joint activity and travel types that support the development of operational choice models Vovsha et al. (2004b). In particular, we distinguish fully joint travel tours for shared activities from partially joint tours, in which household members share transportation without participation in the same activity.
3. *Intra-household generation and allocation of maintenance activities*. Many of the routine household maintenance activities (shopping, banking, visit-

ing post office, etc) are implemented and scheduled individually; however, generation of such an activity and its allocation to a particular household member is a function of a household decision-making process (Srinivasan & Bhat 2004). Thus, these activities require an intra-household interaction mechanism to be properly understood and modeled. Maintenance task allocation mechanism may not be observed completely within a 1-day framework since most of the maintenance tasks have cycles longer than 1 day.

It is also assumed that all else being equal, a general hierarchy of intra-household decision-making follows these three layers. Entire-day patterns types are predicted first. Then, conditional upon the chosen daily pattern types for each household member, the decisions regarding joint activities and travel are made, and maintenance activities are generated and allocated to persons. These assumptions provide a schematic and simplified view on the extremely complicated real-world variety of travel behavior of the members of a household and numerous interactions between them. This view, however, has two important features:

- The proposed structure gives a good *coverage for most frequent cases* of intra-household interactions observed in the household travel surveys; also many complicated cases of joint activities and travel arrangement that do not fall directly under one of the proposed categories, still should be only slightly simplified or split in order to be brought in line with the proposed structure.
- The propose structure serves as a constructive framework for derivation of *operational choice models* that can be estimated based on available household travel surveys and applied in a framework of regional travel demand models.

One of the possible ways to consider all household members rather than household heads is to model different persons sequentially by conditioning choice of the DAP of some household members by choices made by the other household members. This approach to sequential modeling of DAP types for all household members was adopted in the MORPC model system (Vovsha et al. (2004a). This approach requires *a priori* fixing of a certain order of processing persons within the household that constitutes a drawback. The current paper represents an attempt to develop a model that treats all household members simultaneously and taking into account all possible cross-impacts of different household members on each other.

A general comparison of sequential and simultaneous choice structures for modeling intra-household interactions was outlined in Vovsha et al. (2004b). In a context of modeling DAP, it was shown that simultaneity is essential only across limited number of aggregate dimensions where intra-household coordination is strong. Numerous other DAP details can be added by the subsequent set of models and either considered individually for each person or as joint activity/travel episodes conditional upon the chosen DAP types for each household member. This opens a way to formulate a simultaneous choice model where the number of alternative DAP types for each person is limited and thus, all possible combinations of them for all household members still result in a manageable choice structure.

3. Coordinated DAP types of household members: choice structure and statistical analysis

Classification of DAP types can be done in many different ways. DAP definition normally includes a list of activities undertaken by the person in the course of entire day with some predetermined hierarchy of the activity types. DAP may also include activity sequencing/scheduling attributes, activity location (at-home versus out-of-home) as well as travel-related characteristics (for example, number and structure of the travel tours).

The definition adopted for the current research is subject to the purpose of joint modeling of DAP types of all household members as well as the overall structure of the model system being developed for ARC. Similar to the model system developed for MORPC (Vovsha et al. 2004a), in the ARC model system the model for joint DAP types plays a role of the leading day-level component that is designed to define the most important aggregate characteristics of the activity/travel behavior as well as capture important intra-household interactions at this level.

Individual DAP is classified by three main types that are mutually exclusive and collectively exhaustive:

- *Mandatory pattern* (M) that includes at least one of the three mandatory activities – work, university, or school implemented out of home. This constitutes either a workday or university/school day, and may include additional non-mandatory activities such as separate home based tours or intermediate stops on the mandatory tours.
- *Non-mandatory pattern* (N) that includes only maintenance and discretionary out-of-home activities and at least one associated travel tour.
- *At-home pattern* (H) that includes only in-home activities. At the current stage of model development, at home patterns are not distinguished by any specific activity (work at home, take care of child, being sick, etc). Also cases with complete absence from town (vacation, business travel) were combined with this category. (There are not enough observations to warrant treating this as a separate pattern type, but it is nevertheless important to include the possibility of absence from town in forecasting models.) The

trinary specification of individual DAP types opens a way to formulate a model of joint choice of DAP types for all household members.

3.1. *Choice structure*

The choice structure adopted for the current research treats all possible combinations of individual DAP types for up to five household members in an explicit way. This covers 98% of the observed households. For larger households with six or more members that constitute 2% of the observed cases, the model refers to the five representative members while the rest of the household members is modeled sequentially and conditional upon the chosen DAP types for the five representatives.

The choice structure formally includes 363 alternatives that correspond to all possible household sizes from 1 to 5:

1. Three alternatives for one-person households,
2. $3 \times 3 = 9$ alternatives for two-person households,
3. $3 \times 3 \times 3 = 27$ alternatives for three-person households,
4. $3 \times 3 \times 3 \times 3 = 81$ alternative for four-person households,
5. $3 \times 3 \times 3 \times 3 \times 3 = 243$ alternatives for five-person households.

Note that with this structure, the size of the model is very sensitive to the number of basic DAP types considered. A model with four basic DAP types – e.g. treating a combination of mandatory and non-mandatory activities as a fourth pattern type – would require $4+16+64+256+1024=1364$ alternatives, almost four times as many alternatives as the model for three DAP types.

3.2. *Observed frequency of individual DAP types*

Table 1 below presents the observed frequency of individual DAP types for different person categories for a regular workday that was tabulated based on the data from the last activity-travel household survey undertaken in the Atlanta region in 2001. The survey scope included 8069 households each surveyed for two consecutive days with respect to all activities and travel undertaken by all household members. After the exclusion of weekends, the survey provided 13,760 valid household-days and 31,243 valid person-days for analysis of DAP types.

For purposes of descriptive analysis and the model specification, all persons were classified into the following eight mutually exclusive and collectively exhaustive person types:

1. *FW – Full-time worker*, including adults who have reported their main occupation as full-time work (35 h or more a week) – 40.8% of the surveyed persons.

Table 1. Observed frequency of individual DAP types.

Person type	Total days	Absolute frequency			Relative frequency (%)		
		M	N	K	M	N	H
1. FW – work full	14,559	11,844	1854	861	81.4	12.7	5.9
2. PW – work part	1792	1000	607	185	55.8	33.9	10.3
3. US – univ stud	1195	729	343	123	61.0	28.7	10.3
4. NW – non-work	4017	158	2681	1178	3.9	66.7	29.3
5. RT – retired	2894	73	1704	1117	2.5	58.9	38.6
6. SD – sch-drive	825	674	104	47	81.7	12.6	5.7
7. SP – sch-predr	3656	2834	600	222	77.5	16.4	6.1
8. PS – preschool	2305	750	753	802	32.5	32.7	34.8
Total	31,243	18,062	8646	4535	57.8	27.7	14.5

2. *PW – Part-time worker*, including adults who have reported their main occupation as part-time work (less than 35 h a week) – 5.3%.
3. *US – University students*, including all adults (18 or older) who have reported their main occupation as full-time studying in university/college even if they also work part time – 3.3%.
4. *NW – Non-working adult*, including persons who have not reported any regular work or studying activity (homemakers or temporarily unemployed) and under 65 years old – 12.9%.
5. *RT – "Retired"*, including any non-working adult of 65 years or older – 7.5%.
6. *SD – Schoolchild of driving age* (16+), distinguished from younger school children because access to a car has a significant impact on the activity/travel behavior – 3.2%.
7. *SP – Schoolchild of pre-driving age* (6–15) – 10.1%.
8. *PS – Pre-school age child* of 0 to 5 years old – 7.4%.

The relative frequency of the DAP types is a strong function of the person type. In particular person types non-workers (NW) and retired (RT) are logically characterized by a very low percentage of mandatory patterns and high percentage of non-mandatory and at-home patterns. In the opposite way, person types FW (full-time workers) and SD and SP (school children) are characterized by a very high percentage of mandatory patterns and low percentage of non-mandatory and at-home patterns.

Since mandatory activities included all work, school, and university/college activities, every person type is characterized by a certain non-zero percentage of observed mandatory DAPs. School activities included day care for preschool children. Mandatory activity is of course a different category for preschool children, but it still preserves many features of conventional work/school activities – fixed schedule, predetermined location, long duration, normally chronologically first position in the DAP, etc.

The obvious strong dependence of the choice probability of the particular DAP on the person type leads to the forming the entire-household choice utility as a composition of person type-specific utility components. However, the previously implemented analysis and estimation of the sequential DAP choice model for MORPC has shown that there are strong interactions between household members and preferences to implement certain patterns jointly (Vovsha et al. 2004a). This means that the entire-household DAP choice utility should have interaction terms, i.e. added utility of joint activity participation on the top of the individual DAP choice utilities. In order to understand better the structure of intra-household interactions at the level of DAP type choices we analyze below the observed frequencies of pair-wise and triple-wise combinations of individual DAP types.

3.3. *Observed frequency of pair-wise DAP combinations*

Table 2 below presents the observed frequency of pair-wise DAP combinations by person types. There are $3 \times 3 = 9$ possible DAP combinations for each of the 36 ordered pairs of eight person types. In order to reduce the number of statistics to analyze we focus on two joint DAP types in particular – *joint non-mandatory DAP (NN)* and *joint staying at home (HH)* – where we expect the added utility of joint participation in the same activity should manifest itself in that the relative frequency of joint patterns would be higher than just a product of the correspondent relative individual frequencies shown in Table 1.

Table 2 is organized in the following way: For each pair of person types it shows the absolute and relative frequency of the joint patterns NN and HH. Then the expected relative frequency of the joint patterns NN and HH is calculated as a product of individual frequencies (from Table 1). Then the bias (observed versus expected relative frequency) is calculated. Finally, the person type pairs are sorted by NN bias in order to highlight the most frequent and strongest intra-household interactions.

Joint DAP means a coordinated choice of the same DAP type by two household members, but it is not necessarily joint in the sense that the whole activity-travel pattern or some of its components are pursued together. It does not necessarily imply shared activities or joint travel arrangements, though probability of shared activities and joint travel arrangements is much higher for coordinated patterns; that is captured by the subsequent models in the model system hierarchy.

Table 2. Observed frequency of pair-wise DAP combinations.

Person types		Absolute frequency			Relative frequency (%)		Expected frequency (%)		Bias (%)	
		Total	NN	HH	NN	HH	NN	HH	NN	HH
NW	PS	1207	450	309	37.3	25.6	21.8	10.2	15.5	15.4
RT	RT	715	351	175	49.1	24.5	34.7	14.9	14.4	9.6
PW	PS	406	98	45	24.1	11.1	11.1	3.6	13.0	7.5
PS	PS	699	164	215	23.5	30.8	10.7	12.1	12.8	18.7
SP	SP	1426	139	57	9.7	4.0	2.7	0.4	7.0	3.6
PW	SP	839	89	17	10.6	2.0	5.6	0.6	5.0	1.4
SP	PS	1071	107	66	10.0	6.2	5.4	2.1	4.6	4.1
SD	SP	458	29	8	6.3	1.7	2.1	0.3	4.2	1.4
NW	SP	1308	184	49	14.1	3.7	10.9	1.8	3.2	1.9
FW	PS	2802	195	109	7.0	3.9	4.2	2.1	2.8	1.8
FW	FW	4592	181	62	3.9	1.4	1.6	0.3	2.3	1.1
FW	PW	1279	84	13	6.6	1.0	4.3	0.6	2.3	0.4
FW	SP	4557	178	60	3.9	1.3	2.1	0.4	1.8	0.9
NW	NW	443	204	116	46.0	26.2	44.5	8.6	1.5	17.6
FW	US	910	45	12	4.9	1.3	3.6	0.6	1.3	0.7
FW	SD	1080	23	18	2.1	1.7	1.6	0.3	0.5	1.4
FW	RT	693	53	48	7.6	6.9	7.5	2.3	0.1	4.6
FW	NW	2702	227	106	8.4	3.9	8.5	1.7	−0.1	2.2

Shaded areas corresponds to the most frequent intra-household interactions in both absolute and relative terms. Table includes all two-way person-type combinations with 400+ observations.

In general, it should be noted that absolute majority of person type pairs with only few exceptions are characterized by positive added utility of joint DAP types. There are several person type pairs where intra-household interactions are especially strong both in terms of the absolute number of the observed joint patterns and significance of the relative positive biases. The following important interactions should be mentioned:

- Joint non-mandatory and at-home patterns for person types NW and pre-school child (PS). This is a logical reflection on the presence of a young child and caretaking parent (most frequently, female) who is (most frequently, temporary) unemployed.
- Joint non-mandatory and at-home patterns for two persons of type RT (retired). This is also a logical combination of activities of two retired persons in (most frequently) the framework of a household at the last lifecycle stage. They normally do not have mandatory activities and tend to coordinate both out-of-home and in-home non-mandatory activities.
- Joint non-mandatory and at-home patterns for person types PW and PS. This represents a caretaking intra-household mechanism similar to the "non-worker – preschool child" mechanism described above with a strong

gender bias towards female PWs. However, in this case, the caretaking parent traded her/his work activity only partially.

- Joint non-mandatory and at-home patterns for two persons of type PS. In households with two or more PS, the corresponding arrangements regarding their day care, staying at home, or taking on tour for some other activity are frequently coordinated and made by the same adult household member. These person type pairs as well as other numerous but less significant interactions, represent potential interaction terms that should be included into the joint choice utility function and tested statistically during the model estimation.

3.4. *Observed frequency of three-way DAP combinations*

Table 3 below presents the observed frequency of three-way DAP combinations by person type combinations. There are $3 \times 3 \times 3 = 27$ possible DAP combinations for each of the 120 ordered three-way combinations of eight person types. We again focus on two particular joint DAP types – *joint non-mandatory DAP (NNN)* and *joint staying at home (HHH)*.

Table 3 is organized in the way similar to the Table 2. For each three-way combination of person types, it shows the absolute and relative frequency of the joint patterns NNN and HHH, the expected relative frequency of the joint patterns NNN and HHH calculated as a product of individual frequencies, and the bias of the observed versus expected relative frequency. Finally, the person type combinations are sorted by the absolute HHH frequency and only the first 20 triples are shown in order to highlight the most frequent and strongest intra-household interactions.

Similar to the previously discussed pair-wise interactions, most of the triple-wise interactions are also characterized with positive biases that are manifestations of the added utility of participation in joint activities and intra-household coordination. It should be noted that many of the person type triples are characterized by a high value of some of the biases but a very low absolute frequency because the sub-sample of households that actually contains this triple of person types is small. Several other triple-wise combinations like combinations of non-working adult types NW and RT can be logically explained as a composition of pair-wise effects since each person type triple can be broken into three pairs.

There are however several person type triples that are characterized by significant absolute frequency of both joint patterns (NNN and HHH), significant positive biases in relative terms, as well as can be better explained logically as a group-wise effect than just a composition of pair-wise effects. Among them combinations of the most frequent child caretaker of type NW

Table 3. Observed frequency of triple-wise DAP combinations.

Person types			Absolute frequency			Relative frequency (%)		Expected frequency (%)		Bias (%)	
			Total	NNN	HHH	NNN	HHH	NNN	HHH	NNN	HHH
NW	PS	PS	444	121	99	27.3	22.3	7.1	3.5	20.2	18.8
NW	SP	PS	539	49	37	9.1	6.9	3.6	0.6	5.5	6.3
FW	NW	PS	1101	63	32	5.7	2.9	2.8	0.6	2.9	2.3
NW	NW	PS	73	9	27	12.3	37.0	14.5	3.0	−2.2	34.0
SP	PS	PS	241	10	26	4.1	10.8	1.8	0.7	2.3	10.1
FW	SP	SP	1704	49	26	2.9	1.5	0.3	0.0	2.6	1.5
FW	PS	PS	757	39	21	5.2	2.8	1.4	0.7	3.8	2.1
PS	PS	PS	88	16	19	18.2	21.6	3.5	4.2	14.7	17.4
PW	PS	PS	122	20	19	16.4	15.6	3.6	1.2	12.8	14.4
SP	SP	SP	288	10	17	3.5	5.9	0.4	0.0	3.1	5.9
PW	SP	PS	213	23	16	10.8	7.5	1.8	0.2	9.0	7.3
PW	NW	PS	71	7	13	9.9	18.3	7.4	1.1	2.5	17.2
FW	NW	NW	146	7	11	4.8	7.5	5.7	0.5	−0.9	7.0
SP	SP	PS	307	31	8	10.1	2.6	0.9	0.1	9.2	2.5
FW	NW	SP	1126	33	8	2.9	0.7	1.4	0.1	1.5	0.6
...	...	...	...	...	...	...	...	...	...	...	...

Shaded areas corresponds to the most frequent intra-household interactions in both absolute and relative terms.

or PT with two children of types PS (preschool) and SP (school pre-driving) should be noted. In particular, this includes the most frequent joint patterns of NW with two preschool children (NW PS PS). Such combinations indicate potential components of the choice utility function that should be tested statistically.

3.5. *Choice utility construction*

Alternatives of the joint DAP type choice model correspond to all possible combinations of all individual trinary choices of DAP types $i = 1,2,3$. All household person are numbered from 1 to H, where H corresponds to the household size. Every person has a unique number $h = 1,2,...,H$ within the household and the corresponding person type p_h. The set of the entire-household DAP alternatives is specific to the household size and denoted as $\Omega_H = \{i_1,i_2,...,i_h,...,i_H\}_H$. The observed part of the function for each alternative is specified to have the following general form:

$$U_{i_1 \ldots i_H} = \sum_{h=1}^{H} V_{i_h p_h} + \sum_{h_1=1}^{H} \sum_{h_2=h_1+1}^{H} W_{(i_{h_1}=i_{h_2})p_{h_1}p_{h_2}} + \sum_{h_1=1}^{H} \sum_{h_2=h_1+1}^{H} \sum_{h_3=h_2+1}^{H} Z_{(i_{h_1}=i_{h_2}=i_{h_3})p_{h_1}p_{h_2}p_{h_3}} + \ldots$$

where $V_{i_h p_h}$ is the individual component of choice of the DAP type i by the household member h of the person type p, $W_{(i_{h_1}=i_{h_2})p_{h_1}p_{h_2}}$ the pair-wise component of joint choice of DAP type i by household members h_1 and h_2 of the person types p_1 and p_2 consequently, $Z_{(i_{h_1}=i_{h_2}=i_{h_3})p_{h_1}p_{h_2}p_{h_3}}$ the triple-wise component of joint choice of DAP i by household members h_1, h_2, and h_3 of the person types p_1, p_2, and p_3 consequently.

The individual choice utility component is specified to have the following form:

$$V_{i_h p_h} = \sum_{k \in K} c_{kip} x_{kh} \tag{2}$$

where $k \in K$ is the a set of individual, household, and zonal attributes, x_{kh} the value of the k attribute for the h person, c_{kip} the coefficient for the k attribute in the i alternative utility that is assumed to be specific to the person type p but generic across persons h.

The pair-wise choice utility component is specified as:

$$W_{(i_{h_1}=i_{h_2})p_{h_1}p_{h_2}} = w_{ip_1p_2} \times \begin{cases} 1, & \text{if } i_{h_1} = i_{h_2} = i,\ p_{h_1} = p_1,\ p_{h_2} = p_2 \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where $w_{ip_1p_2}$ is the coefficient (added utility) for a dummy variable that corresponds to joint choice of the DAP type i by two household members of types p_1 and p_2. The triple-wise choice utility component is assumed to have the following form:

$$Z_{(i_{h_1}=i_{h_2}=i_{h_3})p_{h_1}p_{h_2}p_{h_3}} = z_{ip_1p_2p_3} \times \begin{cases} 1, & \text{if } i_{h_1}=i_{h_2}=i_{h_3}=i, p_{h_1}=p_1, p_{h_2}=p_2, p_{h_3}=p \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

where $z_{ip_1p_2p_3}$ is the coefficient (added utility) for a dummy variable that corresponds to joint choice of the DAP type i by three household members of types p_1, p_2, and p_3.

The model overall has only 24 individual utility components of the form (2) to estimate for three individual DAP types and eight person types. Thus, most of the person variables (like age or gender), household variables (like income or car ownership) and zonal variables (like area type or accessibility to certain land uses) were tested in the individual utility component.

The number of potential pair-wise and triple-wise components is much higher. For pair-wise components we have three joint DAP types (MM, NN, HH) by 36 ordered person type pairs that comes to 108. For triple-wise components we have three joint DAP types (MMM, NNN, HHH) by 120 ordered person type triples that comes to 360. Thus, it was decided at the current stage of the model development that all group-wise components would be estimated as alternative and person type specific dummies, without interacting them with the other person, household, or zonal attributes.

In the adopted structure, the individual DAP utility component is specified to account for most of the exogenous variables, while group-wise components are intended to capture intra-household interactions that are specified to be person-type specific and generic across other dimensions. This limitation was adopted in order to make the choice model technically manageable in estimation and application.

Any attempt to parameterize interaction terms with the other variables, for example making intra-household interactions differential by three residential urban types (urban, suburban, and rural) would triple the number of constants to estimate and also number of terms in all utility expressions. In several attempts we ran out of the ALOGIT limits. In some other cases we found that the sub-samples of actually chosen cases wore too thin.

In future research, this limitation will be lifted. In particular, several published research works indicate on dependence of intensity of intra-household interactions on spatial environment of the residential place (Ettema et al. 2004; Schwanen et al. 2004). This effect can be explored with the proposed choice model structure. It will require introduction of area type and accessibility variables in the interaction terms (3) and (4). This represents an interesting avenue for future research.

The choice utility expression (1) can also include higher-order terms (like quadruple-wise combinations, etc) that are relevant for households of size four or larger. For this terms, even making them person-type specific like pair-wise and triple-wise expressions (3) and (4), would require thousands of potential combinations to consider. For this reason, these terms are kept completely generic in a form of household-size specific dummies that indicate on the choice of the same DAP types by all household members. For each household with four or more members, three dummy variables were tested that corresponded to three uniform choices of all household members (MMMM..., NNNN..., and HHHH...)

In the estimation procedure, pair-wise terms were tested on the top of the statistically successful individual terms, triple-wise terms were tested on the top of statistically successful individual and pair-wise terms, and so forth, whatever best explains intra-household interactions both statistically and meaningfully. All else being equal, the lower-level terms were given a first priority since they are simple in the model estimation and application. Higher-level terms were adopted only if they had added significant explanatory power on the top of the successful lower-level terms.

The proposed utility form resulted in a quite parsimonious structure to estimate despite a large set of alternatives. The model does not have alternative-specific variables *per se*. It has 24 basic individual utility expressions with stratified constants, 36 pair-wise person type interaction terms, and several additional triple-wise and high order terms that proved to be significant. In terms of the number of coefficients to estimate, it is not fundamentally different from many other activity-based models. It was successfully estimated on data from the ARC regional travel survey that is of a usual size for metropolitan areas.

4. Estimation results

The logit estimation results for the model specification described above are shown in Table 4. The coefficients are shown in three columns, related to mandatory, non-mandatory and home day patterns. The first page of the table and the top of the second page show the variables included in the individual utility component. Some of the key findings are:

- **Person type**: The person-type-specific constants indicate that, all else equal, FW and students are most likely to carry out mandatory patterns, while NWs, retired and preschoolers are least likely to carry out either mandatory or non-mandatory travel patterns.
- **Gender**: The interactions of person-type with gender show that among full time and PWs, females are less likely than males to go to work on a given day, while among retired persons, females are more likely than males to stay home.
- **Age**: Among very young children under age 6, the likelihood of going to (pre)school increases with age. Among children age 6–15, the likelihood of going to school is somewhat lower in the age categories 6–9 and 13–15, relative to age 10–12. There are several reasons why school children may miss school on a normal weekday. First of all, it can be sickness with staying at home (or visiting doctor, or being hospitalized). Statistical analysis has shown that there is an age impact on frequency of missing school because of sickness – younger kids just get sick more frequently. Another reason for missing school can be participation in (frequently not official) work/non-work activity or just skipping classes. That is more frequent for

Table 4. Model estimation results.

Utility terms for three pattern types	M – mandatory		N – non-mandatory		H – home all day	
	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
Constants						
FW – full-time worker	1.809	6.8	0.9652	17.2		
PW – part-time worker	−0.2456	−0.4	0.9854	6.6		
US – university student	1.683	13.0	0.3354	1.0		
NW – non-working adult	−4.352	−3.8	−0.6639	−2.0		
RT – retired	−7.499	−3.7	−0.5391	−1.5		
SD – driving age schoolchild	2.689	7.8	−0.03897	−0.1		
SP – pre-driving age schoolchild	3.105	20.5	0.5628	1.4		
PS – pre-school child	−0.2948	−1.8	−1.646	−4.1		
Age						
PS – age 0–1	−0.4515	−3.3				
PS – age 4–5	0.6107	4.9				
SP – age 6–9	−0.2943	−2.7				
SP – age 13–15	−0.7141	−4.1	−0.672	−3.7		
FW – age under 40	0.2091	4.9				
RT – age over 80					0.7666	8.1
Gender						
FW – female	−0.1259	−2.9				
NW – female	−0.743	−4.5				
RT – female					0.4769	5.0
Car ownership						
NW – more cars than workers	0.6515	2.7	0.8168	8.4		
RT – more cars than workers	2.992	3.0	1.056	8.2		
PS – more cars than workers			0.2991	2.8		
FW – fewer cars than workers					0.5039	4.5
NW – fewer cars than workers					0.8965	3.1
RT – fewer cars than workers					0.5496	1.3
SD – fewer cars than workers					0.6475	1.2
SP – fewer cars than workers					0.5862	2.8
PS – fewer cars than workers					0.5061	3.0
Household income						
FW – income < $20,000					0.5313	4.3
RT – income < $20,000					0.533	5.7
PW – income < $20,000					0.3232	1.3
PW – income $50–100,000					−0.4032	−2.1
PW – income > $100,000			0.4207	3.0	−0.3534	−1.3
NW – income $50–100,000					−0.5602	−6.8
NW – income > $100,000					−0.7188	−5.6
SD – income < $20,000					1.307	3.0
SD – income $50–100,000					−0.5031	−1.2
SD – income > $100,000					−2.046	−2.0
PS – income $50–100,000					−0.5708	−5.9
PS – income > $100,000					−0.6186	−4.3
Accessibility						
FW – peak accessibility to employment	0.1212	4.9				

Table 4. Continued.

Utility terms for three pattern types	M – mandatory		N – non-mandatory		H – home all day	
	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
PW – peak accessibility to employment	0.2004	3.4				
NW – peak accessibility to employment	0.2314	2.3				
RT – peak accessibility to employment	0.2792	1.8				
NW/RT/US – off-peak accessibility to retail			0.07207	2.4		
SD/SP/PS – off-peak accessibility to retail			0.08233	2.3		
FW/PW – usual work location is home	−1.758	−23.1			0.1813	1.9
FW/PW – no usual work location	−0.5935	−11.5				
SD/SP – no usual school location	−0.866	−10.2				
Two way interactions						
Full time × full time	0.141	2.5	1.123	12.3	1.626	11.2
Full time × part time	0.08845	1.0	0.4947	3.7	0.7407	2.4
Full time × university	0.4273	4.9	0.5523	3.4	1.183	3.9
Full time × NW			0.02186	0.2	0.9436	6.7
Full time × retired			0.3115	2.2	1.298	8.0
Full time × driving child	0.3842	3.9	0.4095	1.8	2.064	7.3
Full time × pre-driving child	0.2623	4.1	0.6008	5.1	1.501	9.7
Full time × PS	0.5118	5.9	0.751	6.6	0.9912	7.7
Part time × part time	1.135	5.0	1.032	3.0	0.8911	1.3
Part time × university	0.173	0.8	0.3355	1.0	1.642	2.8
Part time × NW			0.7477	3.8	0.7057	2.2
Part time × retired			0.09831	0.5	0.463	1.3
Part time × driving child	1.103	5.1	0.495	0.9	3.057	6.0
Part time × pre-driving child	0.3079	3.4	0.8984	6.8	0.7685	2.3
Part time × PS	0.5074	3.5	1.452	9.9	1.07	5.2
University × university	0.8726	6.0	1.054	5.3	1.018	1.4
University × NW			0.193	0.9	1.781	6.3
University × retired			0.4065	1.6	0.4835	0.8
University × driving child	−0.0021	−0.1	1.62	4.0	1.546	1.5
University × pre-driving child	0.2975	2.1	0.5165	1.8	1.552	3.4
University × PS	0.2254	1.1	0.8973	4.1	1.34	5.2
NW × NW			0.6984	5.1	1.352	7.9
NW × retired			0.1864	1.4	1.209	8.2
NW × driving child			0.6801	3.2	0.5243	1.2
NW × pre-driving child			0.5646	5.1	0.8112	4.1
NW × PS			1.164	10.5	1.167	8.8
Retired × retired			0.7291	7.0	1.407	11.7
Retired × child (all ages)			0.2919	1.2	0.8632	3.2
Driving child × driving child	0.4794	1.4	1.512	2.2	2.198	2.5
Driving child × pre-driving child	0.5151	3.8	1.422	5.9	0.977	1.4
Driving child × PS	0.5516	1.4	1.273	2.4	1.467	2.7
Pre-driving child × pre-driving child	0.9731	8.8	1.553	11.3	2.8	15.8
Pre-driving child × PS	0.5961	5.0	0.6184	4.3	1.434	8.2
PS × PS	1.651	11.1	0.8771	5.7	1.378	9.5
*Three way interactions****						
FW × FW × FW	0.3133	3.4				

Table 4. Continued.

Utility terms for three pattern types	M – mandatory		N – non-mandatory		H – home all day	
	Coefficient	T-stat	Coefficient	T-stat	Coefficient	T-stat
FW × FW × PW/NW	0.3495	2.4	0.4637	1.8		
FW × FW × SP/PS						
FW × PW/NW × PW/NW			0.3491	1.0	0.9573	2.8
FW × PW/NW × SP/PS					0.2939	1.4
FW × SP/PS × SP/PS			0.3553	2.3		
PW/NW × PW/NW × PW/NW			−1.386	−1.7	0.9881	2.9
PW/NW × PW/NW × SP/PS			−0.8571	−3.8	0.4374	1.9
PW/NW × SP/PS × SP/PS					0.4747	2.4
SP/PS × SP/PS × SP/PS	−0.3906	−2.1				
Interaction across all household members						
Three person household – all same patterns	−0.0671	−0.7	−0.3653	−2.5	−1.181	−6.0
Four person household – all same patterns	−0.6104	−2.6	−1.346	−4.0	−3.733	−7.5
Five person household – all same patterns	−1.528	−3.4	−3.453	−5.0	−8.621	−7.0
Estimation statistics						
Observations 13677						
Alternatives 363						
Final log-likelihood −19404.3						
$Rho^2(0)$ 0.422						
$Rho^2(c)$ 0.264						

older kids. A combination of these two factors may explain the result that 10–12 years old are the most frequent school attendees. Full time workers under age 40 are more likely than older workers to go to work, while retired persons age 80 or older are more likely to stay at home than younger retirees.

- **Car ownership and competition**: Non-working and retired adults are more likely to attend a mandatory activity (typically school) or travel for non-mandatory activities if there are more cars than there are workers in the household. If on the other hand, there are *fewer* cars than workers in the household, most person-types are more likely to stay at home all day, with the strongest effect being found for non-working adults. Thus, non-working adults are the most severely influenced by car competition.
- **Household income**: FWs, PWs, retirees and driving age students are all more likely to stay home if they are in low income households (under \$20,000). PWs, non-working adults, driving age children and pre-school children are all less likely to remain at home all day if they are in high income households, with the effects generally stronger for incomes over \$100,000 than for incomes in the \$50,000 to \$100,000 range.
- **Accessibility**: All categories of adults are more likely to travel to mandatory activities if the peak hour accessibility to employment from the residence

zone is high. (Accessibility is measured using a function of attraction and travel impedance to all possible destinations, approximating the logsum from a joint mode and destination choice model.) All person types except full time and PWs are more likely to have non-mandatory travel patterns if the off-peak accessibility to retail employment from the residence zone is high.
- **Usual work and school locations**: Workers, not surprisingly, are much less likely to travel for mandatory activities if their usual workplace is at home. They are also somewhat more likely to stay at home all day. Workers who reported not having a usual workplace – e.g. construction workers with variable work location – are less likely to have mandatory travel.

The second page of Table 4 shows the estimated two-way interactions terms for each person-type combination, applied to alternatives where both perform the same type of pattern (MM, NN or HH). The entire half-matrix of 36 interaction terms was estimated for each pattern type, except for mandatory patterns, where no interactions were estimated for NWs and retirees who rarely choose such patterns. Some results worth noting include:

- All of the estimated two-way interactions are positive, except for a slightly negative result for a combination of university student and driving age child. The majority of the positive interactions are significantly different from zero.
- For mandatory (M) patterns, the largest interaction is between two PS: If one goes to pre-school, the other is likely to go also. There is also a large interaction between two PWs, indicating that part-timers in the same household tend to coordinate their schedules to work on the same days (unless one needs to stay home to take care of children, which is captured by other interaction terms). Other large positive interactions are between two children of age 6–15, and between PWs and driving age children.
- For non-mandatory (N) travel patterns, the largest positive interactions are among pairs of children, particularly children age 6 and older. There are also large interactions between children under age 6 with PWs and non-working adults: such young children often go everywhere with their caretaker, and thus have the same DAP. The interactions between two FW or two PWs are also fairly high: one is more likely to stay home from work and do something else instead if the other does the same. Note that the interactions between retired and all other person types are quite low. Retired persons tend to interact mainly with other retired persons in the household. Presence of two retired person indicate on an older household with the corresponding changes in the life style.
- The interactions for stay at home (H) patterns are similar in many ways to those for non-mandatory (N) patterns. The interactions are generally

highest for children, particular with other children and with NWs and part-timers. Retirees tend to have smaller interactions. Students of driving age (16+) show particularly strong interactions with working adults and with other children in the same age group.

The final page of Table 4 shows the interactions terms for three-way person type combinations and for all persons in households of three or more people all choosing the same pattern. Because there are too many possible three-way combinations to estimate all terms, we looked at interactions between three specific groups of person types that seem to have similar behavior in the descriptive analysis (see Table 3 above). These groups are:

- FW – Full time workers
- PW/NW – Part time workers plus Non-workers
- SP/PS – All children under age 16

In general, three-way interactions were only kept in the model if they were significantly different from 0. The results are discussed below. In this discussion, "non-workers" includes both PWs and non-working adults:

- Combinations of three adults including at least two FWs show strong positive interactions for mandatory (MMM) patterns. If two of them go to work, the third one will tend to go to work/school as well.
- Combinations of three children show a negative interaction for MMM patterns. This may offset somewhat the positive interactions found for pairs of children. (Note that each three-way interaction term is added in the utility to three 2-way interactions – persons 1 and 2, persons 2 and 3, and persons 1 and 3.)
- For non-mandatory (NNN) patterns, there are negative interactions for 3 "non-workers", and for 2 "non-workers" and a child. This may indicate allocation of out-of-home maintenance activities across non-working adults.
- Combinations of three adults that are a mix of FW and "non-workers" show a positive interaction for NNN. If two of them choose a non-mandatory pattern, the third is also more likely to.
- All three-way combinations that include 2 or more "non-workers" or at least 1 "non-worker" and a child, are more likely than others to all choose the stay at home pattern (HHH). These are the strongest three-way interactions that were estimated, indicating that two-person interactions alone are not sufficient to capture the phenomenon that certain types of household members tend to stay at home with each other.

The final estimates in Table 4 are for combinations where everyone in households of 3, 4 and 5 people choose the same pattern. The estimates are all negative and increase in strength with household size and going from M to N to H. These coefficients will tend to offset the positive two-way interactions, which are additive across all household members and may become somewhat redundant in the larger households. (Note that a three-person household has 3 two-way interactions, while a four-person household has 6 and a five-person household has 10.)

Numerous statistical trials were implemented to capture a nested structure along such dimensions as dominant DAP types (for example, presence of at least one mandatory DAP in the household versus the households without a mandatory DAP) or joint DAP combinations (for example, presence of at least one pair-wise joint DAP of types MM, NN, or HH versus the households without joint patterns), etc. In all tests the nesting coefficients proved to be not significantly different from 1.0. As a result, a multinomial logit structure was finally adopted.

Additionally, attempts to capture scaling effects by introducing dummy nodes with coefficients scaling each utility were implemented. In particular, scaling by household size was tested, since in large households there are more combinatorial opportunities to form joint pairs and triples of DAP types. The scaling coefficients proved to be very close to 1.0 indicating that the pair-wise and triple-wise components of the added utility of joint DAP types are stable over the household sizes and generally exhibit an "additive" nature in large households.

Some discussion of the behavioral validity of the resulted multinomial logit structure with numerous alternatives is needed since one can reasonably argue that human decision-making probably does not proceed in this manner. This is a very interesting aspect that relates to the fundamental view on the choice model – is it a representation of a decision-making process or just an analytical tool for predicting most probable outcomes? We are rather inclined to consider the proposed model in the second sense and do not claim that this structure fully captures the underlying decision-making process. However, some process-based behavioral aspects can be associated with the proposed model structure.

For example, though the choice structure includes hundreds of alternatives, many of the utility components are individual with a limited addition of interaction terms. Thus, in reality no one evaluate hundreds of utilities to choose a joint pattern, but rather each person first evaluate three individual-pattern-type utilities and has a preliminary choice, but then, the household members interact and adjust their choices based on what the other members choose. In this interpretation the model can even be applied iteratively rather then simultaneously.

Another possible interpretation (in some sense, opposite to the first one) is that persons in the household first make joint decisions (like going on vacations together) and then make their individual choices conditional upon the joint decisions made at the entire-household level. Following this behavioral interpretation, we can view the current model as a hierarchical choice structure where interactions occur at the upper level while individual choice relate to the lower level.

Both approaches and the corresponding modifications of the model represent interesting avenues for future research.

5. Placement in the travel demand model system

The proposed model for joint choice of DAP types for household members represents a part of the advanced regional travel demand model system being currently developed for the Atlanta Regional Commission (ARC) by PB Consult with participation of M. Bradley and J. Bowman. It has not been applied at the time of writing, but will eventually be applied in the framework of the ARC regional model system.

A general structure of the ARC model system is presented in Figure 1. It represents a sequence of choice models applied in a conditional micro-simulation fashion with numerous feedbacks between them. It is similar in many respects to the structure of the previously developed MORPC model system (Vovsha et al. 2004a), but it has several additional advanced features that the MORPC system does not have.

The limited framework of the current paper allows for only a brief description of the whole model system with the purpose of putting the joint DAP in the general modeling context. The model system starts with the synthesis of population by traffic analysis zones. The adopted population synthesis technique allows for adjustment of multidimensional household distributions to any set of zonal targets or marginal distributions as well as adding any household-composition or person variables by matching the synthesized households to observed households in PUMS. Then for each household, a set of longer-term choices is modeled that includes location of regular workplace/school for each worker/student, as well as car-ownership choice as a function of the household composition and residential location, as well as the auto, walk and transit accessibility to the modeled work and school locations of all household members.

The next sequence of models within the dotted lines refers to the operative day-level. The first two models relate to the most important aggregate determinants of activity and travel behavior. This includes joint DAP type choice for all household members that is described in the current paper in

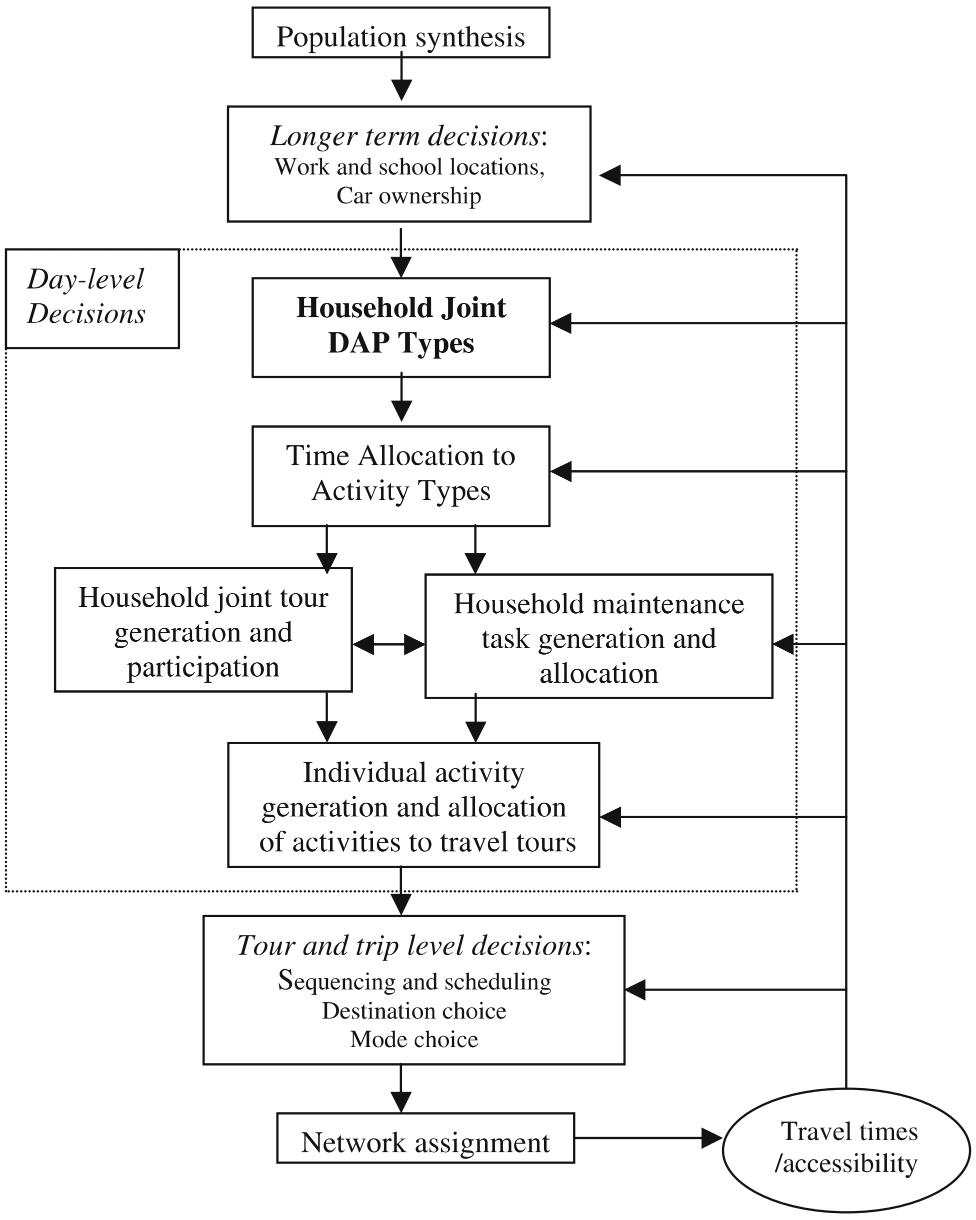

Figure 1. ARC model system structure.

detail. This model is complemented by a time allocation model between four basic activity types – mandatory, non-mandatory out-of-home, non-mandatory in-home, and travel – for each household member. These two models create an aggregate skeleton of the DAP for each household member. The subsequent set of models is strongly conditional upon the outcomes of these two models and gradually adds details to each individual DAP.

Conditional upon the time windows remaining for the household members after mandatory activities, a model that generates joint non-mandatory tours and associated activities as well as modeled person participation in these tours, is applied. This model is applied simultaneously with a linked model that generates household maintenance tasks and allocates them to household members based on the previously made decision regarding each person DAP type and already assigned mandatory activities. Then a model that forms the rest of the DAP (individual discretionary activities, and activity/task/episode distribution by mandatory and non-mandatory tours) is applied for each person.

The choice utility structure of the proposed joint DAP type model assumes that additional utility is derived only by multiple household members choosing to undertake the same DAP. At this stage it is still unknown if the household members will actually share activities or household tasks.

Effects of joint activity episodes are modeled further in the model system conditional upon the outcome of the current model and there is an additional joint participation utility captured at the episode level. Joint episodes may occur between persons with different DAP types. However, the probability of joint episodes is much higher for persons with coordinated patterns, than for persons with different patterns. This is captured by conditional linkages between the current model and the subsequent model for joint episodes.

The purpose of the current model is not to produce a detailed structure of all episodic intra-household interactions but rather to account for most important entire-day interactions that have an impact on the whole DAP type, like having all-day vacation together, or staying at home because of child sickness, etc.

The next model system components refer to the tour-level and trip-level (stop-level) decision models. The tour-level models include primary destination choice for non-mandatory tours, scheduling of departure from home and arrival back home for all tours, as well as entire-tour mode combination choice. Further on, the location of each stop for the secondary activity episodes is modeled for each tour, detailed mode choice for each associated trip, and the trip departure and arrival time.

Finally, highway network assignments and skims are performed, allowing re-calculation of travel times for each trip. These travel times are fed back to the DAP type and time allocation stage for each household and person. Changing travel times affect the structure of time budget of each person through the allocation procedure that will finally generate a different set of activities and DAP structures. Feeding-back through individual DAP types and time budgets is different from conventional upward feeding-back.

6. Conclusions and directions for further research

In this paper, we have demonstrated that modeling the DAP types of all household members simultaneously captures much of the interaction between people that cannot be captured by modeling them independently or even sequentially. The estimates of the interactions between pairs and triads of household members are generally significant and positive, indicating that members of various types are prone to change their activities to match those of other household members.

We have mentioned a number of ways that a model of this type could be extended as part of further investigation. These include:

- Estimating the household interaction terms as function of other person and household variables (such as age, gender, household size and composition, income, car ownership) and zonal variables (urban density, accessibility to destinations). For example, the interactions between the patterns of adults and children may be found to be stronger for females than for males. The urban travel environment may also have an impact on the structure of interactions. Pair-wise and triple-wise interaction structure may be specific to certain household size and composition.
- Expanding the model beyond three basic activity types. For example, the mandatory pattern could be subdivided into those who only perform mandatory activities out of home during the day versus those who carry out both out of home mandatory and non-mandatory activities. Non-mandatory activities could also be divided into maintenance and discretionary activities (although this distinction is generally less clear from survey data than is the distinction between mandatory and non-mandatory).
- Integrating an activity time allocation model with this model. This would require a combination discrete/continuous model with many linked endogenous variables. It would be quite a challenge to estimate such a model and still retain all of the discrete information on intra-household interactions that is contained in the model presented here.
- Adding behavioral realism to the multi-dimensional choice structure by meaningful nesting levels corresponding to entire-household joint decisions

As we integrate this model with other models in the ARC model system, and possibly in other similar model systems, it will become more clear how such a model can best support the entire household travel/activity forecasting process. A particular area of focus will be how the model can best provide inputs to other models of intra-household interactions, including not only fully joint tours and allocated maintenance activities, but also possibly including partially joint travel and activities such as picking up or dropping off other household members.

It is important to recognize to what extent the number and type of activities predicted by this model is different than that produced by an DAP model without intra-household interactions, using the same input variables. Independent models for each person with a full set of alternative-specific constants will give probably the same average number of activity patterns of each type as the model with interactions since both models should replicate the observed shares. However, independent individual models tend to produce unrealistic entire-household patterns (like cases where preschool child stays at home while all adults go to work) while the model with intra-household interactions not only guarantees replication of the average observed individual patterns but also their proper linkage within each household.

The difference between model structures can produce very different model elasticities with respect to exogenous variables and this is the major reason for explicit modeling of intra-household interactions. For example, if we consider a scenario where a day care for preschool children is supposed to be significantly improved, thus resulting in a lower percentage of preschool children staying at home and higher percentage having a mandatory pattern, a model with interactions would show an additional percentage of workdays for workers and consequently, additional traffic in the peak period because of the growing amount of home-work trips. A model without interactions would probably be quite insensitive to this factor showing only an isolated effect on preschool children's choices.

In a similar way, independent models for two full-time working spouses with 80% of workdays and 20% of non-mandatory and staying at home for each of them will result only in 64% of coordinated workdays, while 36% of cases would correspond to a situation where at least one of the workers does not go to work. If we take a segment of households with one car as an example, it will be a competition for this car with inevitable captivity for one of the workers to transit for 64% of days only. Contrary to that, a model with joint choice of daily patterns will create 70–75% joint workdays out of the same individual probabilities. It means that the transit captivity for one of the workers will by 10% higher. This can have a significant impact on the mode choice predictions.

These considerations in favor of the joint modeling approach should however be supported by the model application and validation. This represents another important avenue for further research.

Finally, it is worth noting that incorporating intra-household interactions in a forecasting model requires that the population synthesis method that is used to generate the households will provide a realistic distribution of household compositions within each zone. In addition to variables which are typically used to control the sampling of a synthetic population – namely distributions along household size, number of workers, and income – it may also be necessary to control explicitly for the presence of senior citizens and children in households. As part of the ARC model development, we are undertaking detailed testing of the accuracy of synthetic household sampling using different combinations of zonal control variables.

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