A Model of Within-Households Travel Activity Decisions Capturing Interactions between Household Heads

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Abstract: This paper describes a conceptual framework for modeling activity interactions between household heads in conducting out-of-home maintenance activities. It is comprised of several steps; generation of household activities, task allocation of household activities, trip-chaining choices, resource allocation and mode choice. The models are specified for different household types: worker and non-worker households, with or without children. The purpose of this paper is to introduce the modeling framework for household travel activity decision making processes so that it can capture interactions between household heads.

1. INTRODUCTION

The size and spread of urban travel demand is a concern of transportation planners and policy makers in their attempts to alleviate existing transportation problems, in particular, traffic congestion. Travel demand is derived from the activities that individuals need to conduct in space and time. In the past, transportation forecasting models used trips as the unit of analysis. The currently emerging generation of forecasting models is based on activities and considers travel as a derivative of the need to conduct activities on different locations. Focusing on activities allows one to take into account interactions between persons within households and constraints imposed on activity schedules that emerge, for example, from limited

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opening hours of facilities, working times and household needs (e.g., escorting a child to school).

Most studies in activity-based modeling of transport demand use *utility-maximizing*/discrete choice models to describe *individual* travel behavior as will be reviewed in section 2. An exception is Arentze and Timmermans (2000), whose Albatross system is a computational process model based on the decision tree formalism. It was developed for The Dutch Ministry of Transportation, Public Works and Water Management, to explore the possibilities of an activity-based and rule-based approach to develop a travel demand model for policy impact analysis. The latest version of Albatross (Arentze and Timmermans, 2005) is operational for application at the national scale.

This activity-based model of activity-travel behavior is derived from choice heuristics that consumers apply when making decisions in complex environments. The model fits into the activity-based approach which is aimed at predicting which activities are conducted where, when, for how long, with whom, and the transport mode involved. The model takes interactions between individuals within households into account, but does so in a limited way.

We therefore intend to solve this limitation of Albatross by improving some aspects of households' decision making on activity-travel choice. Individual members of a household, particularly the heads of household, often interact and make decisions jointly. Their decisions to engage in out-of-home maintenance activities, for example, often depend on household needs and should take into account the presence of children, if any, accessibility, car availability, etc. Out-of-home maintenance activity may be conducted independently or jointly and household tasks often need to be allocated to household members.

The purpose of this paper is to describe an intended elaboration of Albatross in terms of household level decision making. We introduce a conceptual framework for activity generation, task allocation, trip-chaining choices, resource allocation and mode choice between household heads. All these refer to choice facets embedded in activity-based models of travel demand that should preferably be analyzed at the household level. We briefly sketch key mechanisms in modeling household decision making processes. Given the complexity of such decisions, households may not display perfect choice behavior, but rather use heuristics that are subject to learning over time.

The paper is organized into several sections. After an introduction, the first section briefly reviews existing approaches to modeling within-household interactions in activity-travel choice. Then, against this background, the next sections describe the Albatross system and our conceptual framework. Finally, we summarize the major conclusions.

2. REVIEW OF EXISTING APPROACHES

We will firstly focus on a brief review of existing approaches in modeling within-household interactions in the context of task allocation, joint activity participation, time allocation and household resource allocation. Most of these studies attempt to contribute to the development and improvement of activity-based methods for travel demand modeling that gained momentum over the past couple of decades. Activity-based methods recognize that travel is a consequence of a more fundamental need to participate in activities dispersed over time and space.

In modeling task allocation in households, Vovsha, et al. (2004) implemented a sequence of two linked discrete choice models. The first model relates to the entire household and returns the total daily frequency of individual maintenance tours by purpose. The second model relates to the tour level, and returns the allocation of each generated tour to a particular household member. The model allows important insights into intra-household decision-making mechanisms and improved travel demand forecasts.

For analyzing activity participation and travel-choice interaction in households, Golob and McNally (1996) developed structural equation models of activity duration for household heads. They applied structural equations to simultaneously model the behavior of the male and female heads of household in terms of their activity participation and travel. This study tested hypotheses regarding interactions within households and identified additional interactions as part of an overall model structure which relates to activity participation and travel behavior of household heads. Relationships were established between the amount of time allocated to work, maintenance, and discretionary activities. The interactions between male and female household heads were modeled endogenously; effects due to the presence of other household members were introduced exogenously. The implication of these results was clear: a feedback mechanism should be introduced in trip generation models to represent the effect of travel time on activity frequency and duration decisions. For example, households which have longer commutes should have compensatory reductions in the frequency and duration of participation and travel to other types of activities.

Srinivasan and Bhat (2005) developed a model of time allocation between male and female household heads. They examined household interactions impacting weekday in-home and out-of-home maintenance activity generation in active, nuclear family, households. The in-home maintenance activity generation is modeled by examining the duration invested by the male and female household heads in household chores using a seemingly unrelated regression modeling system. Out-of-home maintenance activity generation was modeled in terms of the decision of the household to undertake shopping, allocation of the task to one or both household heads, and the duration of shopping for the person(s) allocated to the task. They developed and applied a joint mixed-logit hazard-duration model to predict out-of-home maintenance activity generation.

In addition to these models, there are some more papers focusing on intra-household interaction in decision making processes. Scott and Kanaroglou (2002) described an approach for modeling the daily number of non-work, out-of-home activity episodes for household heads for two activity settings, independent and joint activities. They estimated *trivariate ordered probit* models for the heads of three household types: couple, non-worker; couple, one-worker; and couple, two-workers. They found significant interactions between household heads. Gliebe and Koppelman (2005) described the daily activity-travel patterns of individuals in the form of joint activity participation and shared rides. Zhang et al. (2005) reported the development of a household task allocation and time use model based on a multi-linear group utility function. The results indicated that, on weekdays, for nearly half of the households the husband mostly influences task allocation and time use, for one-fifth of the households it is the wife and the remaining households show an equal relative influence for both husband and wife.

Roorda, et al. (2006) developed a more complex household tour-based mode choice model that incorporates household level interactions explicitly, including vehicle allocation within the household, joint travel decisions, and negotiations over ridesharing in the household. All of the decisions are modeled within a clear theoretical framework of household random utility maximization and they used a genetic algorithm for parameter estimation.

Besides this paper, there are more papers about modeling task allocation and time allocation in household within a one-week period (see Lee and McNally (2002) and Ettema & Van Der Lippe (2006)). Ettema and Van der Lippe (2006) tested three hypotheses: If both household heads have traditional role expectations, the male will have a greater opportunity to work; If either male or female has a higher qualified job, he/she also will spend more time to work instead of household tasks; If accessibility to job or store is low, or if young children are part of the household, indicating more severe time constraints, the male will spend more time on work that the woman does.

Another interesting research topic within the context of intra-household decision making concerns vehicle allocation in households. Hunt and Petersen (2004) examined how gender, employment status and household income level influence car allocation by restricting the analysis into households with two or more drivers and fewer vehicles than drivers. Work status and income were more influential to automobile usage than gender.

Even though considerable work has been carried out on the subject of task allocation, activity participation, and vehicle allocation in the context of maintenance activities within households, still many aspects can be improved. We would like to introduce a more refined conceptual framework for activity-based modeling, particularly at the household level, in which we can capture interactions between household heads.

3. ALBATROSS

Albatross is an acronym of *A Learning Based Transportation Oriented Simulation System.* The model considers a particular household and a particular day as given and generates a schedule for maximally two household heads. The presence of children is taken into account as an independent variable in the model, but their activities are not explicitly represented. Mandatory activities are called *fixed* activities, while non-mandatory activities are termed *flexible* activities.

Albatross consists of two major components that together define a schedule for each individual and each day. The first component generates an activity skeleton consisting of fixed activities and their exact start time and duration. As an important distinct feature, the skeleton model component determines activity patterns on a continuous time scale. It consists of several sub processes including:

1. Determining the pattern of sleep activities
2. Determining the pattern of the primary work/school activity
3. Determining the pattern of secondary, fixed activities
4. Determining the location of each fixed activity episode

The second component determines the part of the schedule related to flexible activities to be conducted that day, their travel party, duration, time-of-day and travel characteristics, as follows:

1. Choice of transport mode for the primary work tour(s)
2. Determining selection, travel party and duration of flexible activities
3. Determining start time and trip chaining of activities

4. Determining the transport mode of each tour in the schedule
5. Determining the location of each flexible activity

Central to the developed approach was the use of the decision tree formalism for representing choice heuristics of individuals and deriving these heuristics from activity travel data. Each decision tree is derived from corresponding observations in the activity diary data set using a CHAID based induction method.

Albatross does take into account interactions between individuals. In Albatross, scheduling decision steps are made alternately between the household heads whereby the state of the schedule after each last decision step of one person is used as condition information in the next decision step of the other person, and vice versa. Although Albatross, especially compared to other activity-based models of that generation, already includes several mechanisms to deal with household level decision making, the system can be further improved. In particular, the following elements will be addressed:

1. Allocation of activities to persons is not an explicit decision step in Albatross. Rather the selection of activities in a person's schedules emerges from a series of yes/no decision by that person.
2. The choice between joint or independent participation in activities is not modeled in the sense that the required synchronization in case of joint activities is not imposed as a constraint.
3. Car allocation to persons is not an explicit decision. That is Albatross does take into account that a same car cannot be allocated to two persons at the same time if they are at different locations. Also, Albatross takes into account the travel demands of one person in the mode choice (car, etc) of tours of the other person, and vice versa. However, it is not modeled as an allocation decision.

We therefore intend to alleviate these potential shortcomings of Albatross by improving some aspects in households' decision making on travel activity. We introduce a conceptual framework for activity generation, task allocation, trip-chaining, resource allocation and mode choice between household heads. These are choice facets embedded in activity-based models of travel demands that should preferably be modeled at the household level. In addition, we will briefly sketch key mechanisms in modeling household decision making process. Given the complexity of such decisions, households may not display perfect choice behavior, but rather use heuristics that are subject to learning over time. We will apply the same approach as developed in Albatross to extract such rules: i.e. a CHAID based induction method.

4. CONCEPTUALIZATION

As we explained above, this project is intended to solve the deficiency of the Albatross system related to aspects of household-level decision making. In the following sections, we will explain our conceptual framework in household travel activity decision making proposed to refine the Albatross model.

4.1 Classification of Activities

In transportation research, it has been widely acknowledged that travel is derived from household decision making under spatial and temporal constraints. It is commonly assumed in travel demand research that work and school activities constitute compulsory or mandatory activities that are conducted by individuals independently. In addition, activities such as daily shopping, non-daily shopping, bring/get children/other persons, etc constitute maintenance activities, and in principle it may suffice that a single household member performs these activities, implying that these activities are subject to task allocation. Finally, activities such recreation, social visits, and other leisure activities are typically conceptualized as discretionary activities, and may be conducted jointly or not.

We emphasize that joint/independent and household/individual are two independent dimensions of activities, in the sense that, in principle, every combination of choices is possible. For example, an individual-level activity could be conducted jointly (e.g., eating out together with the partner) and a household-level activity may be conducted independently (e.g., one person doing shopping). Nevertheless, mandatory activities are often individual-level activities and are mostly performed independently. Maintenance and discretionary activities can be either individual or household activities. Individual activities generally serve individual-level needs, and will typically but not necessarily be carried out independently. Household activities are derived from household needs and may be performed either independently or jointly.

As mentioned in Vovsha, et al. (2004), household maintenance activities can be further split into three categories: shopping, escorting, and other maintenance activities. Shopping is important to fulfill household needs for foods, clothing, house appliances, etc. Escorting, which is termed a bring/get activity in this paper, is also essential, particularly in households with young children, to drop-off or pick-up them to/from school or daycare. Subsequently, other maintenance activities, such as, banking, are grouped together with other activities into a single activity. The need for such other maintenance activities will occur less frequently.

4.2 Conceptual Framework

4.2.1 Activity Generation

Household heads are faced with the decisions which mandatory, maintenance or discretionary activities to conduct on the day concerned. In this paper, we focus on maintenance activities and related travel. Other, non-maintenance activities are taken into account as well, but are taken as given.

Initially, the model predicts the maintenance activities conducted in a household for a given day. Let n be the number of maintenance activities generated on the day considered. Then, the set of maintenance activities can be denoted as $M = \{m_1, m_2,\ldots,m_n\}$. The maintenance activities can be classified into specific categories such as daily shopping, non-daily shopping, bring/get person, etc.

In this step, who performs which maintenance activity is not known yet. The result of this step is just a description of activities performed at the household level for a particular day. The number and types of maintenance activities carried out on a certain day may be similar or may be different from another day. In fact, household and individual activities are dynamic and vary from day to day. As a result, the activities are a selection of an exhaustive list of maintenance activities that are considered by households.

The number and kind of maintenance activities conducted strongly relies on household characteristics, such as household size, presence of school-age children, work status, income, and car(s) ownership. Household size is important because larger households tend to generate more out-of-home, non-work activities, particularly maintenance activities. Similarly, households with school-age children need to become involved in dropping-off or picking-up children from school, whereas other household types will not be involved in this activity. Work status may also play a major role in generating maintenance activities. A distinction can be made between full time and part time jobs for each adult member of the household. The work status of each head will have an impact on income of the household and time available for other activities. For example, households with higher income/more time might be carrying out out-of-home maintenance activities more than those with lower incomes/less time.

Accessibility and the possession of vehicles in a household, particularly car, are taken as important variables to be considered as well in generating activities. Possibilities for out-of-home maintenance activities become much broader if locations are nearby and cars are available.

4.2.2 Task Allocation

In this step, the model identifies the allocation of maintenance activities to household heads, i.e. how these tasks are allocated across the male and female heads. An activity is either allocated to a single person or to both persons. In the latter case the activity is conducted together.

To describe this formally, we define an allocation variable a_{ij}, where i= 1,2 denotes the person, and j =1,2,…,n denotes the maintenance activities as follows:

$$a_{ij} = \begin{cases} 1 & \text{if person } i \text{ conducts activity } j \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Table 1. Matrix representation of task allocation pattern example.

	m_1	m_2	m_3	m_4	Σ
P_1	1	0	1	0	2
P_2	0	1	0	1	2
Σ	1	1	1	1	4

As an example, Table 1 shows the allocation pattern of a household involving two persons and four maintenance activities. In this example, person P_1 conducts activities m_1 and m_3 and person P_2 is responsible for activities m_2 and m_4. Hence, in this case, there are four maintenance activities distributed across two adult people in the household.

In the example of Table 1 each person conducts the one or more maintenance activities allocated to him/her alone. However, there is a possibility that maintenance activities are performed together. In general, the following constraint applies to the set of allocation variables:

$$\sum_i a_{ij} \geq 1, \quad j = 1, 2, \ldots, n \quad (2)$$

With regard to allocating the tasks to household heads, time constraints, time-budgets and time allocation have to be taken into consideration. Time constraints relate to opening hours of facilities, such as shop, school, office, etc. It is not possible to conduct shopping activities when the shops are closed. Likewise, it is not possible to go to work during office closing time. In addition, the time spent on other, especially mandatory activities by each person should be taken into account.

Therefore, household heads must allocate their time properly, particularly in two-worker households with pre-school and school-age children. In the

Netherlands, the elementary schools are typically open from 08.30-15.30, and much shorter on Wednesday, from 08.30-12.45. As a result, the worker parents should spend time for picking-up children, because the office hours are from 09.00-17.00 or even until 18.00, which is much longer than school hours. Therefore, they should organize, who will pick-up children during work time. Otherwise, they have to allow the day-care institution to take care of the children and then (one of) the parents will pick-up their children on the way to home after work.

In households in which one parent works out-of-home and one works at home, the latter may have more (flexible) time to conduct household tasks. In particular if pre-school and school-age children are present, the bring/get children activity is likely conducted by the person who works at home.

In sum, task allocation will be influenced by such factors as time spent on mandatory activity, flexibility of working at home, accessibility to facilities, and gender. The less time a person spends on work, the more time is left for conducting maintenance activities. Recently, due to policy measures in traveling, more and more people who commute to work everyday have a chance to work at home on a particular day of the week. Indeed, it depends on the company they work for. The person who has the flexibility to work at home will have the opportunity to pick-up children or do other household tasks. It probably means his/her work duration will be smaller on a certain day, for instance on Wednesday (in Netherlands).

A further factor that should be mentioned is accessibility to schools, shops, and office. For example, those household heads with better access to pick-up children from the office or from home, will be more responsible for the household tasks.

Finally, the traditional gender role in household is likely to play a role as well. Most female workers spend more time at home than male workers during their children's school-age. They even have a tendency to do part-time job rather than a full-time job during that period. However, in case both male and female work, the work status and the flexibility of working at home between both household heads should be taken into account as well.

4.2.3 Trip Chaining Choices

We model a trip-chaining decision as a choice between *yes/no* linking a given pair of activities. In addition to maintenance activities, the existence of other (mandatory and discretionary, if any) activities should be taken into account here too. We denote other activities as O, and the total number of other activities scheduled on the day considered as c. To describe trip-chaining choices formally, we define a variable c_{ij}, where $i= 1,\ldots,n+c$ and $j= 1,\ldots,n+c$, are indexes of activities, such that:

$$c_{ij} = \begin{cases} 0 & \text{if } i \text{ is not linked with } j \\ 1 & \text{otherwise} \end{cases} \qquad (5)$$

Two activities are linked if they are conducted during the same tour. We illustrate the principle using the same example as used earlier. Table 2 shows for this example the matrix of trip-chaining choices where (as before) four maintenance activities are performed and three others activities are conducted.

Table 2. Matrix activities performed in a household.

	m_1	m_2	m_3	m_4	O_1	O_2	O_3
m_1	1	0	0	0	1	0	0
m_2		1	0	1	0	0	1
m_3			1	0	0	0	0
m_4				1	0	0	1
O_1					1	0	0
O_2						1	0
O_3							1

Linked = 1 (conduct on the same tour)

Not-linked = 0 (conduct on a separate tour)

m=maintenance activities

O=other-maintenance activities (mandatory and discretionary activities)

Every *ij* pair of trip-chaining variables must meet the following logical constraints:

1. $c_{ij} = c_{ji}$
2. If $c_{ij} = 1$ and $c_{jk} = 1$ then $c_{ik} = 1$ (for every third activity *k*)
3. If $c_{ij} = 0$ and $c_{jk} = 0$ then $c_{ik} = 0$ (for every third activity *k*)

From matrix, c_{ij}, we can derive the number and activity compositions of tours of the household on the day considered. We use the example to explain the procedure by which the tours can be derived. First, we need to fill out the empty cells on the left side of the diagonal (gray cells in Table 3).

Table 3. Matrix activities performed to identify the number of tours.

	m_1	m_2	m_3	m_4	O_1	O_2	O_3
m_1	1	0	0	0	1	0	0
m_2	0	1	0	1	0	0	1
m_3	0	0	1	0	0	0	0
m_4	0	1	0	1	0	0	1
O_1	1	0	0	0	1	0	0
O_2	0	0	0	0	0	1	0
O_3	0	1	0	1	0	0	1

This based on the knowledge (i.e. constraint 1) that $c_{ij} = c_{ji}$, for each i and j. Next, we identify the activity combinations performed together within tours. In this example, the rows of the matrix represent the following activity combinations:

1. m_1, O_1
2. m_2, m_4, O_3
3. m_3
4. m_2, m_4, O_3
5. O_1, m_1
6. O_2
7. m_2, m_4, O_3

There is not a one-to-one correspondence between these activity combinations and tours because the same combinations occur multiple times while they refer to a same tour. In this example, number 1 and number 5 relate to the same tour, namely the tour on which activities m_1 and O_1 are conducted. Similarly, number 2, number 4 and number 7 refer to the same tour, namely the tour where activities m_2, m_4, and O_3 take place. Thus, to identify the tours implied by this list, we must merge those combinations that include the same set of activities. Hence, the tours performed in the household and day considered in this example, can be described as:

1. m_1, O_1
2. m_2, m_4, O_3
3. m_3
4. O_2

Apparently, there are four tours performed in this household-day conducted by both male and female head.

If we combine this result with the allocation pattern of this example (Table 1) we can identify the person(s) involved in each tour. Tour 1 and tour 3 are conducted by person 1, and tour 2 is conducted by person 2. However, given its focus on maintenance activities, the model does not predict who conducts tour number 4.

In sum, at this stage of the decision process the tours for the household-day are known regarding the activities and persons involved. In the example, we have:

- Tour 1: P_1: (m_1, O_1)
- Tour 2: P_2: (m_2, m_4, O_3)
- Tour 3: P_1: (m_3)
- Tour 4: P_1 or P_2: (O_2)

4.2.4 Resource Allocation and Mode Choice

Travel demand models have rarely addressed household car allocation decisions. However, car allocation decisions in households affect individual travel behavior, in particular in a household in which fewer cars than drivers exist. There is only a small number of published works on models that explain how vehicle allocation decisions are made within households, such as Hunt and Petersen (2004).

Households with car(s) can be grouped into: two or more drivers and fewer cars, balance between drivers and cars, more cars and fewer drivers in the household. The first group can be defined as car/vehicle insufficient households. These are households in which at least one vehicle is present but fewer vehicles than workers or fewer vehicles than drivers. Then, trade offs must be made between using the car for the commute trip, if any, and for satisfying household maintenance activities.

Among the three groups above, only the first group has to be taken into consideration seriously with regard to household resource allocation. There are some variables that should be considered in making a decision which person should use car, such as gender role, work status, income and complexity of the activity agenda.

In the case of conducting purely independent maintenance activities, there will be vehicle allocation to either male or female. One will use the car, while the other should use another mode during the time the other person uses the car. If only one person performs out-of-home activities, the car is possibly used by him/her. Of course, it is also possible that both people choose not to use the car.

For those households who do not have a car, the choice set for predicting transport mode does not include the car.

Having allocated the car, the mode choice for each person in the household will be predicted. The choice set of modes (*V*) generally includes car as driver, car as passenger, slow modes (walking, bike) and public transport. If z is the number of tours scheduled for the household-day, then the result of this step can be written as $V = \{v_1, v_2, ..., v_z\}$, where v_i is the element of the mode choice set assigned to tour *i*.

5. CONCLUSIONS

In this paper, we have briefly discussed some principles of modeling within-household interaction in building activity-based models of transport demand in general and improving the Albatross system in particular. We have argued that especially activity generation, task allocation, trip-chaining choice, resource allocation and mode choice requires household level decisions. The system then explicitly describes who performs which task. Another aspect concerns the organization of activities in trip chains resulting in the number and activity composition of tours that each male and female head carries out during the day. Modeling resource allocation allows a better integration of various facets in activity-travel decisions. It is expected that dynamic decision making process in a household can be implemented as well. The elaboration of joint activity participation and empirical estimation for the model will be explored in future research.

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