# Estimating Household-Level Time-Use within a Week Activity Scheduling Framework – Application of the MDCEV Model

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## SHORT SUMMARY

Activity-based approaches have become state-of-the-art in travel demand modelling due to their behavioural realism. While there have been great advances in modelling techniques, most studies do not consider the household context, and almost all are limited to the generation of single-day activity schedules. Therefore, we propose an activity generation and scheduling approach for one week, considering the household context. This study provides a general overview over the proposed framework, and further details the model used to generate household-level activity time-use for the period of one week.

The proposed model contributes to the current state of activity-based models as it goes beyond individual, single-day travel demand and allows for analysis of household-level decisions for the modelling period of one week.

**Keywords:** activity-based model, MDCEV, week activity schedules, time-use

## 1. INTRODUCTION

Activity-based approaches have become state-of-the-art in travel demand modelling due to their behavioural realism. While there have been great advances in modelling techniques, most studies do not consider the household context, and almost all are limited to the generation of single-day activity schedules. Therefore, we propose an activity generation and scheduling approach for one week, considering the household context. This study provides a general overview over the proposed framework, and further details the model used to generate household-level activity time-use for the period of one week.

Activity-based approaches can be categorised into rule-based and econometric models. Rule-based models rely on hard-coded rules and heuristics, which make them easier to implement. However, this limits their behavioural realism and the ability to generalise model results.

Econometric approaches mitigate these limitations by modelling individual decisions, not through rules and heuristics, but based on the principle of utility maximisation. Bowman and Ben-Akiva (Bowman & Ben-Akiva, 2001) presented the first disaggregate activity-based approach, which generates activity schedules by sequentially modelling individual decisions through (nested) logit models. Although the sequential model of decisions remains a popular approach in activity-based travel demand models, the method has some limitations. The sequence in which the analyst considers the decisions in the model claims that there is an order among the individual decisions. This possibly arbitrary order does not allow for consideration of trade-offs between all choices. This limitation has given rise to the development and application of the multiple discrete-continuous extreme value (MDCEV) model ((Bhat, 2005, 2008)). In this approach, individuals do not consider alternatives as perfect substitutes for each other but simultaneously as a

combination of different activities and the time allocated to them, subject to a time budget constraint. While the first formulation of the model only allowed for modelling aggregated time allocation to each activity type, more recent studies show that the model can also consider activity episodes (Palma et al., 2021) and their order (Saxena et al., 2022) .
Another approach to overcome some of the limitations of sequential models is to consider trade-offs between daily scheduling choices by formulating an optimisation problem ((Manser et al., 2022; Pougala et al., 2022)). In this approach, the objective is to maximise the utility of an individual's schedule through a mixed-integer linear program.
Although the presented approaches all improve state-of-the-art activity-based models, some limitations are worth noting. First, they only consider activities and their schedules for one day. However, past studies highlight the importance of considering multiple days for a more realistic simulation of travel behaviour within travel demand models ((Hilgert et al., 2017; Mallig & Vortisch, 2017)). Furthermore, all choices are considered on an individual level and disregard the context of the household. While this is sensible for some activities like work or work-related activities, the household context influences who conducts certain activities, such as shopping or escorting activities.
However, the proposed approaches cannot simply be transferred from the single-day to the 7-day context. Considering 7-day schedules and household context significantly increases the dimensions of the models, which will likely render the currently defined optimisation problems too large to find a solution within a sensible timespan. Furthermore, we challenge that the underlying assumptions regarding the choice situations of scheduling activities still hold in the 7-day context. In utility theory, we assume that individuals know all possible alternatives within a choice set and choose the one that maximises their utility. Manser et al. (Manser et al., 2022) elaborate on the issue concerning this assumption regarding modelling activity schedules and present a method to generate a feasible choice set. Although the authors propose a sensible approach for single-day activity schedules, it is arguable whether activity schedules of one week actually result from individuals comparing and choosing among a set of alternative schedules or rather from scheduling activities such that they meet a set of constraints.
In this study we combine the idea of activity generation through an MDCEV model and the scheduling using an optimisation approach. The rest of this paper is structured as follows. We will first provide an overview over the activity generation and scheduling framework. Subsequently, we describe the data used in our study and detail the model specification of the MDCEV model. We go on to present the estimation results and conclude our paper with future work and final remarks.

## 2. MATERIALS AND METHODS

Although the scope of this paper is focusing on the estimation of parameters to model household-level time-use, the motivation for the chosen model specification is rooted within the framework of modelling week activity schedules. This section, therefore, first provides an overview over the proposed framework. We subsequently provide a brief overview over the data used in this study, and finally specify the model.

### *Activity Generation Scheduling Framework*

We propose an activity generation and scheduling approach for one week, considering the household context through a combination of the MDCEV model and a constraint satisfaction optimisation approach. The framework for activity generation and scheduling is illustrated in figure 1. The input data can consist of either 7-day travel diary data or time-use data. Additionally, multiday data generated through pattern sampling based on single-day data (as proposed by Zhang et al. (Zhang et al., 2018)) is also possible.

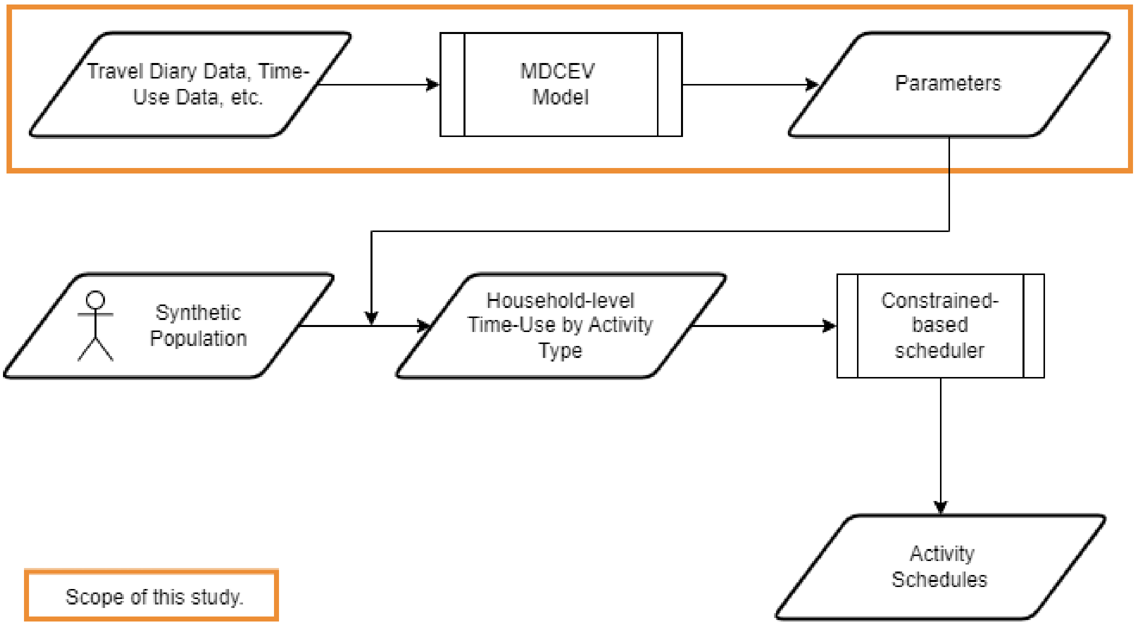


**Figure 1 - Activity Generation and Scheduling Framework**

Based on this data, we estimate an MDCEV model. The estimated parameters are then applied to the synthetic population of the model region. At this stage, we define the model according to Bhat's (Bhat, 2005) original formulation such that activities and the time allocated to them are predicted at an aggregate level. The model specification and results are scope of this study and detailed in the following sections.

Given the household-level activity types and times, the activity scheduler then considers each time slice of the activities and allocates it to a time slice within a household member's schedule. Similar to Pougala et al. (Pougala et al., 2022) and Manser et al. (Manser et al., 2022), we propose to define an optimisation problem to generate these schedules. However, instead of defining an objective function that needs to be maximised, we propose to solve a constraint satisfaction problem (CSP). In this case, no objective function is necessary. The objective of a CSP is to find a feasible solution subject to previously defined constraints. These constraints can either be defined as hard (hc) or soft constraints (sc). If a hard constraint is violated, the solution is rejected, whereas the violation of a soft constraint results in a penalty. We propose to use constraints that apply to household members and those that apply to the timing of activities:

- Work activities can only be assigned to employed household members (hc)
- Education activities can only be assigned to household members in education (hc)
- Shopping and escorting activities can only be assigned to household members over the age of 16 (hc) and should ideally be conducted by adult household members (sc)
- Work activities are subject to regional employment law, which constrains the total work time per week, the work time per day and required breaks (hc). Soft constraints could be added to, e.g. account for flextime or different durations for lunch breaks.
- Education activities can only be conducted during reasonable times (e.g. secondary school times start between 7:30 and 8 am and finish at the latest at 5:30 pm).
- Shopping can only be conducted during shop opening hours.

Additionally, we include constraints that ensure all activities have a reasonable minimal duration and that frequent switches between short activities are avoided.

### *Data*

The data used in this study stems from the German Mobility Panel (MOP), a longitudinal survey that has been conducted annually since 1994. In the survey, participants report their trips in a 7-day travel diary in addition to providing personal and household information.

For this study, we used data from 2017 to 2019, which includes data on 4.564 households. As the data is collected using a travel diary and not a time-use diary, we had to prepare the data such that it reflects activity time-use. We set the start of each diary to midnight of the first survey period and assigned the time until the first trip to "home". We repeated the same for the activity of the last trip of the week, setting the end of the diary to midnight on the last assigned survey day. We then determined the time-use for each activity per person and subsequently summarized the values at the household-level.

We differentiate eight alternative activities: home, work, business or work-related (meaning work activity outside the workplace), shopping, escorting someone, education, leisure, ad other activities. Further, we have included parameters to account for household information on income (high vs. low), number of children in the household (yes/no), and household size.

### *Household-Level Time-Use Estimation*

The household-level time use is estimated using a MDCEV model approach as it was first presented by Chandra Bhat (Bhat, 2005). The model is specified such that home activities are treated as an outside good. Integrating an outside good ensures the positive consumption of that alternative; in this case the specification results in all individuals conducting a home activity. The problem is defined by:

$$Max \sum_{k=1}^{K} \frac{\gamma_k}{\alpha} \Psi_k \left( \left( \frac{x_k}{\gamma_k} + 1 \right)^{\alpha} - 1 \right) \tag{1}$$

Subject to the budget constraint B

$$B = \sum_{k=1}^{K} \mathrm{x}_k \tag{2}$$

where K is the number of considered activities, $x_k$ is the amount of time spent on activity k. The budget of a household is the number of minutes per week (10.080) times the number of household members. The α and γ parameters determine the satiation. In our model, we specified α such that it does not vary over alternatives, while different γ parameters are determined for each alternative. The probability of an observed combination of activities including their duration is given by:

$$P(x_1^*, x_2^*, \ldots, x_M^*, 0, \ldots, 0) = \frac{1}{\sigma^{M-1}} \left( \prod_{m=1}^{M} f_m \right) \left( \sum_{m=1}^{M} \frac{p_m}{f_m} \right) \left( \frac{\prod_{m=1}^{M} e^{Vi/\sigma}}{\left(\sum_{k=1}^{K} e^{Wk/\sigma}\right)^M} \right) (M-1)! \tag{3}$$

We estimated several models accounting for different parameters. The final model is the one in which all parameters were statistically significant.

## 3. RESULTS AND DISCUSSION

Table 1 provides the estimated parameters of the MDCEV model on household-level activity time use.

**Table 1: Parameter Estimates of MDCEV model**

| | δ-coefficient (utility) | γ-coefficient (satiation) |
|---|---|---|
| Work | | 21.149 |
| Intercept | -5.400 | |
| High Income | 0.378 | |
| Business/work-related | | 5.157 |
| Intercept | -6.546 | |
| High Income | 0.503 | |
| Shopping | | 0.279 |
| Intercept | -2.806 | |
| Household size | -0.137 | |
| Escorting someone | | 0.489 |
| Intercept | -5.793 | |
| Children under 10 y/0 in the household (yes/no) | 1.335 | |
| Education | -6.887 | 20.988 |
| Leisure | | 3.470 |
| Intercept | -3.767 | |
| High Income | 0.021 | |
| Travel | 3.293 | 0.00288 |

The results show that travelling has largest the δ parameter indicating that this is the most popular activity. This is not surprising as in our case, all activities (except home) are bound to travelling to a different location. On the other hand, considering the satiation parameter of travel, we can see that the least time is invested in travel. Escorting someone is the least popular activity, but the utility is increased when children under the age of 10 are living in the household. This is sensible, as smaller children are more likely to be escorted e.g., to childcare or school. The satiation parameter is, again, comparatively low meaning that not a lot of time is invested into the activity. Both work and work-related have similar coefficients, albeit work-related activities are slightly less popular. The utilities of both alternatives are increased in households with higher income. The two activities differ considerably regarding their satiation. Work activities have the highest overall satiation parameter indicating that most time is spent working. Although the satiation parameter for work-related activities is still relatively large, it is much smaller compared to the one for work activities at the workplace.

Compared to the other activities, shopping is rather popular. This reasonable, as almost all households conduct some shopping activity throughout the week. Interestingly, the utility of shopping decreases with increased household size indicating that larger households actually conduct fewer

shopping activities per week. While this seems counterintuitive at first, this can be explained by the fact that smaller households are less likely to buy in bulk and, thus, have to go shopping more frequently. The satiation parameter for shopping shows that time spent is rather small.
Leisure activities are less popular than shopping activities, indicating that households conduct fewer leisure activities compared to shopping, however, the satiation parameter shows that a comparatively large amount of time is invested.
There are few comparable studies that allow for a discussion of the model results in relation to other research. Our model is most similar to the aggregated time-use model presented by Palma et al. (Palma et al., 2021). In this study, the authors also find that travelling is considered the most popular activity, whereas work and escorting activities are less popular.

## 4. CONCLUSIONS

This study presents a household-level activity generation and scheduling framework with a focus on model estimation for the generation of activity time-use. We propose a combined MDCEV model and constrained satisfaction approach as a realistic representation of household level activity time-use and scheduling decisions.
The presented results of the MDCEV model are sensible and show that e.g. shopping activities need to be considered in the household context. It is somewhat difficult to relate the model results to the literature as there are only few studies conducted applying an MDCEV model to activity time use and especially because activities are often defined differently. In future work, we will relate the entire modelling framework to other published work as this allows for a more comprehensive discussion of our results.
At the current stage of the model, we only consider aggregate household-level activity time-use. In further modelling work, we will test to see if the consideration of some activities on the individual level (such as work activities) by specifying the activities as individual alternatives leads to better results.
The proposed model contributes to the current state of activity-based models as it goes beyond individual, single-day travel demand and allows for analysis of household-level decisions for the modelling period of one week.

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