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An optimization model to measure utility of joint and solo activities

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ABSTRACT

The choice of 'dining out with friends' or 'wrapping up unfinished tasks at work' depends on the utility/satisfaction gained from performing each activity while being constrained by time and physical resources. In fact, such parameters as 'type', 'time of day', 'duration', 'location', 'companionship', and etc. are defining factors in quantifying the utility of activities - a challenging problem which has been the focus of research for many years. This paper proposes a methodology to estimate the parameters of utility distributions for joint and solo activities, along with the penalty values associated with the deviation of activity start time and duration from their modal values. The study utilizes travel survey data collected in Frauenfeld, Switzerland, over the period of six weeks in 2003. The proposed model is a bi-level optimization model, where the upper level maximizes the accuracy of the activity scheduling on the aggregate level and is measured using the outputs of lower level optimization models. Each lower level model is a variation of pickup and delivery problem and schedules activities for each individual in the population using the parameters of utility distribution and penalty values generated by the Genetic Algorithm. The results indicate that travelers are trying to be more consistent with their arrival time to work, school and pickup/drop off activities: the associated penalty values for deviation from the modal value for arrival time to work and school activities are high. Additionally, significant differences in the parameters of the estimated utility distribution for joint and solo activities are observed, reflecting the fact that utility gained from joint and solo activities are different and needs more in-depth investigation. The proposed methodology has the potential to be applied to any multiday travel survey data, which due to advances made in handheld smart devices and mobile applications are becoming more convenient to collect.

1. Introduction

Activity type, sequence, location, duration, start time, mode and companionship are defining factors of mobility patterns. A thorough and complete analysis of activity patterns demands consideration of all possible interactions among these parameters, a task which comes with many computational complexities and has been the focus of research for a good number of years. Sometimes even a small variation in one attribute of individual's activity pattern can change the compositions of activity patterns for a group of individuals - e.g. cancellation of going to gym after work might alter individual's preferences

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over the mode of transportation, also he/she might spend more time with other family members, resulting in changes in the activity patterns of other household members. Inferring which attributes of activities are more resilient to change (and which are not) is important in the estimation of the overall demand for transportation systems. In travel behavior literature, a wide spectrum of utility-based choice models has been developed to measure the utility associated with any of these attributes in the execution of activity plan by individuals. Among those, quantifying the utility gained from participation in activities is the most important one, as in most models, the decision to participate in an activity is assumed to be made prior to mode choice or scheduling (Arentze et al., 2000; Bhat et al., 2004). On activity choice models, many questions have been investigated. Do individuals participate in activities to fulfill commitments or do they participate for the satisfaction (Arentze and Timmermans, 2009; Nijland et al., 2012) or utility gained from them (Becker, 1965)? Does the utility of an activity depend on with whom it is performed and if yes, how can it be measured (Allahviranloo et al., 2017; Zhang et al., 2005)? How do social interactions play a role in daily activity patterns and choices made by travelers? These questions and many other similar ones have prepared the ground for conducting a significant amount of research in travel behavior studies mainly focusing on modeling group decision-making behavior, household interactions, social networks, and joint activity participations.

In his paper ‘A theory of the allocation of time’, Becker quantifies the utility gained from different activities based on the number of hours spent working and the wage rate of individuals (Becker, 1965). In the proposed model, where the objective function is maximizing the utility gained from participation in a set of activities, the constraints are the time and cost budget. During the past half a century, a wide range of utility-based models in different forms and structures has been proposed and applied in practice. Regardless of the scope - whether they evaluate mode choice behavior or agenda formation and scheduling, or activity location selection – these models share the same premise of maximizing total utility.

In the work presented here, we focus on quantifying the parameters of the utility distributions associated with activity companionship attributes and scheduling preferences of travelers. According to Ho and Mulley, mode choice and shift from one mode of travel to another highly depends on the companionship during the trips. Travelers are more likely to use cars for their joint trips, however, it is more likely for solo trips to be conducted by public transportation if enough motivation is provided (Ho and Mulley, 2015). From a policy perspective, measuring the utility of joint versus solo activities is beneficial for better decision making and planning. Our analysis is based on a detailed six-week long travel diary survey data. We propose a bi-level optimization model consisting of upper level and lower level models. The upper-level model finds the best set of weights for terms of the objective function using a Genetic Algorithm, and the lower level models are in the form of Pickup and Delivery problems with Time Windows. The objective function for the lower level model has multiple terms including minimizing disutility of deviations from the desired start time for the activities, deviations from the desired duration of the activities, minimizing total time spent on traveling, and maximizing the utility gained from participation in the activities.

The combination of facets being of interest here has to our knowledge not been addressed by others. The inclusion of non-household participants in our approach makes the use of the standard household-based choice models irrelevant (e.g. Zhang and his interesting work over the decades Zhang et al., 2002, 2005). The social-network based approach proposed by Dubernet and Axhausen would be able to address this (Dubernet and Axhausen, 2015), but they have not explored the issue of the estimation of the underlying utility functions yet. The methods presented here will benefit travel behavior literature through their potential application to panel data. Access to long-term mobility data generated from the ubiquitous use of smart devices will enable us to learn modalities and temporal preferences of individuals to perform their activities, which are inputs to our proposed methodology. Additionally, network structure used in this paper makes it possible to incorporate different dimensions such as mode, variable travel time, and accessibility constraints. Lastly, we should point out three potential extensions of the current work that can be incorporated into the proposed model but were not pursued due to the limited size of our data. *First*, execution of separate sets of analysis for different segments of the population, as taste and preferences might vary by the socio-demographic attributes of individuals. *Second*, the inclusion of travel time fluctuations in decisions related to the start time and duration of activities. Clearly, the value of the penalty associated with the deviation of activity start time during rush hour is expected to be different from the penalty of deviation from activity start time during off-peak hours. And *third*, adjusting the model to include different modes of transportation would add to the value of analysis. Implementation of these extensions would cause identification issues for our analysis given the fact that our data is limited to a total of 36,761 trips recorded from the travel patterns of 230 individuals, therefore these analyses were not pursued here.

In the remaining sections of the paper, we first review some of the most relevant and recent works in Section 2, it is followed by the problem statement and presenting the model formulations in Section 3. In Section 4, a discussion on the data used for the analysis along with the results of the estimation will be provided and conclusions are presented in Section 5.

2. Literature review

Depending on the type of the activity, individuals have different preferences in the way they participate in activities, some activities are preferred to be conducted solo versus some that are ranked higher when they are performed jointly with others. As pointed out by Srinivasan and Bhat, the result of a study with American Time Use Survey data shows statistically