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What about the dynamics in daily travel mode choices? A dynamic discrete choice approach for tour-based mode choice modelling[☆]

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ABSTRACT

The paper presents a heteroskedastic dynamic discrete choice (HDDC) model for tour-based mode choices modelling with an empirical investigation of university students' daily mode choices in Toronto. The reality of connected trips and resulting constrained mode choices are captured through the HDDC framework that is suitable for fitting in an activity-based travel demand modelling system. Data from a web-based travel survey of the students of four universities in Toronto are used. The empirical model highlights the importance of capturing the dynamics in tour-based mode choices modelling. The dynamic model reveals that students' sensitivity to cost vary by trips of the day, while their sensitivity to travel time remains stable. Results of this investigation have policy implications and the proposed methodology has applications in activity-based travel demand modelling.

1. Introduction

From a daily travel demand modelling perspective, two types of approaches to mode choice modelling exist trip–based and tour-based. Trip-based mode choice models have been traditionally used in Four-Stage Models (FSM). However, the need for tour-based mode choice model is obvious for an Activity-Based Model (ABM) of travel demands. A tour refers to a chain of trips that commence from a location and return to the same location at the end (Bowman et al., 1998). A tour-based approach for an ABM is necessary to recognize the dynamics in mode choice behaviour in a tour through the consideration of interdependence among various aspects of mode choices (Ho and Mulley, 2013).

In the ABM framework, the recognition of the time-space constraints shaped by time budget and transportation system performances is the fundamental tenet (Habib et al., 2017). However, this basic tenet is often compromised to fit in the mode choice models. Most ABMs use some sort of a hybrid mix of rules and econometric approaches for modelling activity-travel schedules. Mode choice models are parachuted in to apply in the steps subsequent to the schedule formation (Arentze and Timmermans, 2004; Miller et al., 2005). Thus, many ABM systems rely on either a trip-based or a simplified tour-based mode choice models that in many cases completely overlooks the dynamics of mode choice behaviour.

Efforts of developing tour-based mode choice models for the ABMs are rare in literature. In some cases, where tour-based mode choice modelling is done explicitly, the mode choice model follows the activity scheduling model. This approach considers the predicted schedule as an external input to the mode choice model, which overlooks the endogenous relationship between activity scheduling and travel mode choices (Miller et al., 2005). In fact, there is an insufficient number of modelling techniques available for use in a tour-based mode choice context that can accommodate the dynamics of mode choices in a tour. This is a serious gap in ABM practices. To contribute in filling this gap, this paper proposes a deductive tour-based mode choice modelling structure that uses the classical Dynamic Discrete Choice Modelling (DDCM) approach. The deductive DDCM approach uses a sequential application of discrete choice models with explicit consideration of state dependence and expectation feedback in the mode choices in a tour. The proposed model is developed as a part of the recently proposed dynamic activity-based model, named CUSTOM, which uses the same approach of modelling daily activity scheduling under continuous time and space constraints (Habib et al., 2017). For an empirical application, the proposed DDCM model is applied for a tour-based mode choice model of post-secondary students in Toronto.

The paper is organized as follows. The next section presents a brief literature review on mode choice modelling approaches used by various activity-based models to explain the context of the current investigation. This section is followed by the section explaining the dynamic discrete choice model formulation; data for empirical investigation and results of the empirical modelling. The paper concludes with a summary of key findings and set of recommendations for future studies.

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2. Literature review

Activity-based models (ABMs) have traditionally been using a rule-based approach to develop activity-travel scheduling where mode choice model is accommodated in various ways (Habib, 2011). Some noteworthy rule-based ABMs include: AMOS (Pendyala et al., 1997), PCATS (Kitamura and Fujii, 1998), ALBATROSS (Arentze and Timmermans, 2004), TASHA (Miller and Roorda, 2003), FAMOS (Pendyala et al., 2005), ADAPTS (Auld and Mohammadian, 2012). Mode choice modelling components of these modelling systems are often shaped by the approach used for the activity scheduling process models. In AMOS, the only trip based commuting mode choices are used, overlooking the tour aspects in the mode choice modelling (Pendyala et al., 1997). PCATS uses a two-tier nested logit model for joint destination and mode choices of a trip and considers one model specification for all trips (Kitamura and Fujii, 1998). In ALBATROSS, it is assumed that there are no mode changes between the trips in a tour. As such, one mode for the full tour is assumed in ALBATROSS (Arentze and Timmermans, 2004). Such unimodal tour mode choice is a generalization of the trip-based model.

The tour-based mode choice component of TASHA uses deterministic rules for household level car and task allocations considering the activity schedules of the household members as exogenous inputs. For the choice model formulation of this tour-based mode choice model, an un-orthodox probit approach is used, where random utilities of scheduled activity episodes are independently simulated to derive the tour-level mode choice utility functions (Miller et al., 2005). The result is a non-closed form mode choice probability that may suffer from model identification issue if the intra-household constraints are not properly specified. Moreover, the use of deterministic rules poses concerns over prediction validity when those rules may not remain valid. In FAMOS, discrete trip-based mode and destination choice are modelled jointly for each activity and does not consider a tour-based approach of mode choice modelling (Pendyala et al., 2005). DaySim uses a main mode for the tour-based mode choice, and the trip mode is estimated conditioned on the main tour-mode, origin, destination and start time (Bradley et al., 2010; Bowman et al., 2006). ADAPTS incorporated a mode plan component in its generation-scheduling model framework. However, the mode choice model is estimated as a trip-base model and then added to this system (Auld and Mohammadian, 2012).

As opposed to rule-based approach, there are some ABMs that use the fully econometric approach of activity-scheduling. However, the mode choice model is often accommodated in the same way it is done in the rule-based models. Such models include model by Bowman and Ben-Akiva (2001), CEMDAP (Bhat et al., 2004), etc. Bowman and Ben-Akiva (2001) use a discrete choice modelling system to model activity scheduling, and mode choice is considered endogenous to that system. They use a tour-based approach of mode choice modelling, but only mode-specific tours are specified. This unimodal tour approach does not allow combinations of different modes within a single tour. For example, if someone dropped-off a household member at a transit station, and then the household member took transit to the end station, and then returned to the origin using a taxi, this model will not model these mode choices jointly.

The econometric ABM, CEMDAP considers a tour-based approach for mode choice modelling (Bhat et al., 2004). It allows to model the tour-level mode choices, but the tour patterns are defined in simplified ways. Such as home-work-home, and home or work-based sub tours, etc.

In terms of model formulation, Bhat (1995, 1998) showed that by adopting advanced modelling techniques it is possible to relax independence of irrelevant alternatives' (IIA) property in the trip-based mode choice modelling context. A similar approach can be adopted for modelling tour-based mode choices. In a different paper, Bhat and Sardesai (2006) estimated a mixed logit model to estimate joint revealed preference and stated preference mode choice models which can capture preference heterogeneity.

Vovsha, Bradley, and Davidson (2004, 2005 and 2010) developed an activity-based model named CT-RAMP, which uses a hybrid mix of econometric models and rules for activity scheduling. It uses a nested logit model to model tour-based mode choices, where trip-level mode choice models define the lower level and that feeds into the upper level of tour-based mode combinations. This approach explicitly considers inter-dependence of the mode choice between consecutive trips in a tour, but the tour-based mode choice modelling structure becomes fixed as it is estimated. The flexibility of the tour-based mode choice model can be an issue for general applicability of the model.

Besides these, many operational travel demand models use tour-based mode choice approach. However, in most of the cases, tour-based mode choice is defined as the choice of a particular mode for a sequence of trips in a tour. That said, a combination of modes in a single tour is not considered (Bowman et al., 1998; Freedman et al., 2006; Cambridge Systematics, 2002). The limitation of such approach is that single mode-specific tour-based approach is nothing different from a trip-based mode choice model. Cirillo and Axhausen (2002) proposed such a trip-based model by using the mixed logit approach to capture the implicit correlations between modes choices of a sequence of trips made in a day. However, it still overlooks the dynamic aspects of tour-based mode choices. Another recent paper uses a recursive logit model to model tour-mode choice where a forward-thinking term is added to the utility equation. However, this forward-thinking term is approximated using generalized cost function for shortest path (Vovsha et al., 2017).

In reality, the choices of travel modes for the day's activity-travel schedules are dynamic in nature. So, a dynamic discrete choice model (DDCM) is promising in this case. As proposed by Heckman (1978, 1981), a DDCM can be formulated in a way that the choice of a mode for any specific trip of a day considers state dependence, and expectations of next trips' mode choice. To our knowledge, nobody investigated the application of a DDCM for modelling mode choices of an activity-based travel demand model. In fact, application of DDCM in transportation is very rare with few exceptions of modelling social interactions (Kuwano et al., 2011) and car ownership choice modelling (Cirillo et al., 2015).

This paper proposed a noble approach of using DDCM for the tour-based mode choice modelling. The objective is to develop a flexible modelling system that can capture the dynamic nature of tour formations and allow investigating multimodal behaviour within a single tour. The proposed model is developed for the mode choice modelling component of a recently proposed activity-based travel demand modelling system, CUSTOM, which uses a dynamic econometric approach to activity scheduling (Habib et al., 2017). The next section presents the econometric formulation of the proposed DDCM for tour-based mode choice modelling.

3. Econometric model

According to Heckman's general formulation (1978) of DDCM the total utility U_{imt} of an individual (i) of an alternative (m) at timethe (t) can be written as follows:

$$U_{imt} = \beta X_{imt} + \sum_{k=1}^{t-1} \rho_{(k)} y_{im(t-k)} + \Omega \sum_{n=1}^{t-1} \sum_{k=1}^{n} y_{im(t-k)} + \varepsilon_{imt} \tag{1}$$

β = is the parameter vector

X_{imt} = attributes associated to modes

$\sum_{k=1}^{t-1} \rho_{(k)} y_{im(t-k)}$ = this term captures the effect of state dependence.

$\rho_{(k)}$ = time dependent parameter which captures the effect of the event occurred t periods ago on current values of total utility

$y_{im(t-k)} = 1$ if person i choose a certain mode at time t-k and zero otherwise

Ω is coefficient to capture the cumulative effect

ε_{imt} is random utility component with zero mean and variance σ^2_{imt}