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A Utility-based Dynamic Demand Estimation Model that Explicitly Accounts for Activity Scheduling and Duration.

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Abstract

This paper proposes a Dynamic Demand Estimation (DODE) framework that explicitly accounts for activity scheduling and duration. By assuming a Utility-Based departure time choice model, the time-dependent OD flow becomes a function, whose parameters are those of the utility function(s) within the departure time choice model. In this way, the DODE is solved using a parametric approach, which, on one hand, has less variables to calibrate with respect to the classical bi-level formulation while, on the other hand, it accounts for different trip purposes. Properties of the model are analytically and numerically discussed, showing that the model is more suited for estimating the systematic component of the demand with respect to the standard GLS formulation. Differently from similar approaches in literature, which rely on agent-based microsimulators and require expensive survey data, the proposed framework is applicable with all those DTA models, which are based on OD matrix, and do not necessarily need any data at user level. This is illustrated by applying the proposed approach with a standard macroscopic realistic Dynamic Traffic Assignment (DTA).

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1. Introduction

Simulation of traffic conditions requires accurate knowledge of the travel demand. In a dynamic context, this entails estimating time-dependent demand matrices, which are a discretized representation of the dynamic origin-destination (OD) flows. This problem, referred to as Dynamic OD Estimation (DODE) in literature, seeks for the best possible approximation of OD flows which minimize the error between simulated and available traffic data (Cascetta, 1984; Cascetta et al., 1993).
Traditional DODE models solve two interconnected optimization problems, according to a bi-level formulation: in the upper level, time-dependent OD matrices are corrected in order to replicate the observations, while the lower level relates OD with path and link flows. For an extensive overview of these models one can refer to (Antoniou et al., 2016; Cascetta et al., 1993).
An important role in DODE problems is assigned to the Dynamic Traffic Assignment (DTA), which has the paramount role of determining the relation between link flows and OD flows. This is typically done by specifying a (dynamic) process for assigning OD flows to the routes connecting each OD pair, and by dynamically propagating the route flows onto the links. The combination of both processes determines the dynamic relation between link and OD flows, which is commonly known as the assignment matrix. Restricting our discussion on only the bi-level approach, the vast majority of the existing works uses a

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deterministic or a stochastic user equilibrium formulation to assign the time-dependent OD flows to the routes (Maher et al., 2001; Zhou et al., 2012). The resulting dynamic OD matrices are therefore assumed to satisfy equilibrium principles at each time period. To guarantee consistency across time periods, sequential and simultaneous estimation approaches have been proposed and compared (Cascetta et al., 1993; Yang et al., 1991). Consistency between the time-dependent route flows and link flows is instead guaranteed by choosing an opportune Dynamic Network Loading (DNL) model. Examples of DNL approaches used in DODE problems are those based on exit flow functions (Cremer and Keller, 1984), on Kinematic Wave Theory (Frederix et al., 2011) or using simulation-based DTA models (Lu, 2013; Tympakianaki et al., 2015). In the last decades many researchers developed utility-based DTA models, which consider both the utility of performing an activity and the disutility of traveling. Microscopic agent-based DTA focus on generating comprehensive activity patterns (Flötteröd et al., 2012), while flow-based models stress the correlation between morning and evening commute, hence their effect on congestion (Li et al., 2014). In this case, DODE research is relatively poor, and only a few works are available for estimating comprehensive demand patterns capable of reproducing realistic traffic conditions (Flötteröd, 2009).

The DODE problem is usually underdetermined because of the high number of unknown variables and their mutual dependencies (Marzano et al., 2009). Spatial dependencies are related to the multiple mapping between OD, route and link variables and therefore depend on the complexity of the network topology, on the chosen route set and on the number and location of sensors (Simonelli et al., 2012; Viti et al., 2008; Yang and Zhou, 1998). Under determinedness can also characterise DODE solutions because of the nonlinear relation between link and demand flows, which is related to congestion propagation phenomena such as spillback (Zhou et al., 2012). Frederix et al. (2013) analyse the effect of congestion, pointing out that, if link flows are assumed to be separable, biased solutions are likely to be found. To deal with these problems, many authors recommend that good starting values of the demand (seed matrices) should be available (Cipriani et al., 2013), and that a distance measure between these values and the estimated OD flows should also be included in the upper level. In existing DODE problems, seed matrices are often coarse adaptations of static matrices, which are derived from socio-demographic data. However, the more the network is complex and congested, the more this condition becomes tight, meaning that the DODE procedure collapses to local adjustments of the demand (Marzano et al., 2009). In addition, static matrices are often calibrated in order to match specific traffic patterns (e.g., the morning rush hour), while empirical evidence shows that spatial and temporal distribution of demand flows changes considerably along the day and in between days. Hence a good static matrix may be suited only for a relatively short evaluation time period.

We argue in this paper that not enough attention is drawn on identifying and estimating reliable time-dependent seed matrices, which should take into account the underlying daily and weekly activity-travel patterns. Our research hypothesis is that incorporating information about daily activity scheduling and duration is of paramount importance to derive dynamic OD flows, which are consistent across time periods. We do so by first formulating the lower level of the traditional bi-level problem as a utility maximisation problem where the departure time choice to perform a certain set of activities is endogenously estimated. Then we extend the proposed model to consider also activity location and duration information.

We demonstrate that, if we extend the bi-level approach by taking into account such information, the number of free parameters in the DODE problem systematically decreases, reducing the under determinedness of the solution. In this paper we demonstrate that the proposed utility-based formulation brings the following scientific and practical contributions:

- By adopting a parametric approach, the number of decision variables is systematically reduced, and a smoother objective function is obtained by exploiting the relation between utility and dynamic user equilibrium (DUE);
- By extending the utility-based approach to account for activity scheduling, location and duration, richer information can be contained in the generated demand matrices;
- By estimating the demand as simultaneous route and departure time choice, the localism of the general DODE formulation is reduced, hence the reliability of the estimated dynamic OD matrices is improved.

We will show how the above contributions are achieved by means of a theoretical analysis and with numerical tests performed on toy networks.

2. Methodology

This work focuses on extending the classical DODE problem to account for the utility of performing different activities. For each considered activity, users are assumed, in this study, to maximize their own utility, which represents the perceived net benefit of performing the activity at some location. Hence, while most of the DODE models consider only the cost of travelling, the utility at the destination represents the main reason for travelling and significantly determines travellers' decisions such as where and when to perform the said activity.

We first formulate the joint route and departure time choice model as a utility maximisation problem within a bi-level formulation. In this paper, we adopt the "classical" Generalised Least Squares (GLS) estimator presented in (Cascetta et al., 1993), which is widely adopted in practice, as the benchmarking model in the next sections. In order to properly extend the bi-