Assessing the applicability of the Utility-based Dynamic Demand Estimation on large realistic networks

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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 minimises the error between simulated and available traffic data [1-2]. Traditional DODE models solve two optimisation problems, according to a bi-level formulation: in the upper level, time-dependent OD flows are updated, while in the lower level a dynamic traffic assignment problem estimates route fractions and travel times ensuring equilibrium principles.

Since DODE problems are usually underdetermined because of the high number of unknown variables [3], many researchers have dealt with the critical issue of decreasing the number of decision variables in order to (i) obtain a smooth approximation of objective function [4] and (ii) to reduce the overall computational time [5]. Additionally, issues have been addressed, among others, to the nonlinear relation between link and demand flows [6], pointing out how having a reliable a-priori knowledge of the demand (*a-priori seed matrix)* is of paramount relevance in order to achieve good results [7]. Zhou and Mahmassani [8] point out that, in order to provide a robust and accurate estimation, the demand should be considered as a convolution of three functional components: the *"regular pattern"*, the *"structural deviation"* and the *"random fluctuation*". The *regular pattern* can be considered as the systematic component of the demand, the *structural deviation* is the influence of the specific conditions for which we are estimating/updating the OD matrix (weather conditions, road works,…) and, finally, the *random component* takes into account the random fluctuations of the demand. Since having a reliable knowledge of the "*a-priori seed matrix*" is equivalent to know the systematic component of the demand – or *regular pattern* - we can observe that On-line and Off-line DODE are mainly capable of sensing *structural* and *random* deviations from the regular pattern.

A second critical point when estimating the (dynamic) OD demand flows is that this procedure usually assumes a homogeneous population travelling on the network. While different classes of vehicles may be considered [9], conventional models do not explicitly account for the trip purpose. On one hand, this assumption seems reasonable if the *regular pattern* is assumed known *a-priori*, on the other hand, it becomes unrealistic when the modeller wants to estimate the systematic component of the demand.

The main purpose of this paper is to test a new methodology, which aims at estimating the *regular pattern* within the OD matrix. The authors believe that, in order to properly estimate this systematic component of the demand, trip purpose needs to be explicitly included in the DODE model. Based on the empirical findings presented in [10], [11], the authors already formulated a Utility-Based Dynamic OD Estimation (UB-DODE) model, which has been presented in [12], [13]. The previous study evaluated mathematical properties and robustness for the model. However, these properties had been tested on simple networks, with only a few OD pairs. In this work, the new methodology is tested on the network of Luxembourg City, in order to assess its applicability to real-life scenarios.

Methodology:

While for a detailed overview of the model the interested reader can refer to [13], in this section we provide a general overview. The main difference with respect to the standard DODE formulation is in the lower level. We include within lower level DTA procedure a Departure Time Choice (DTC) model that performs the equilibrium through the utility maximisation theory, as proposed in [14]. The advantage of using this approach is twofold.

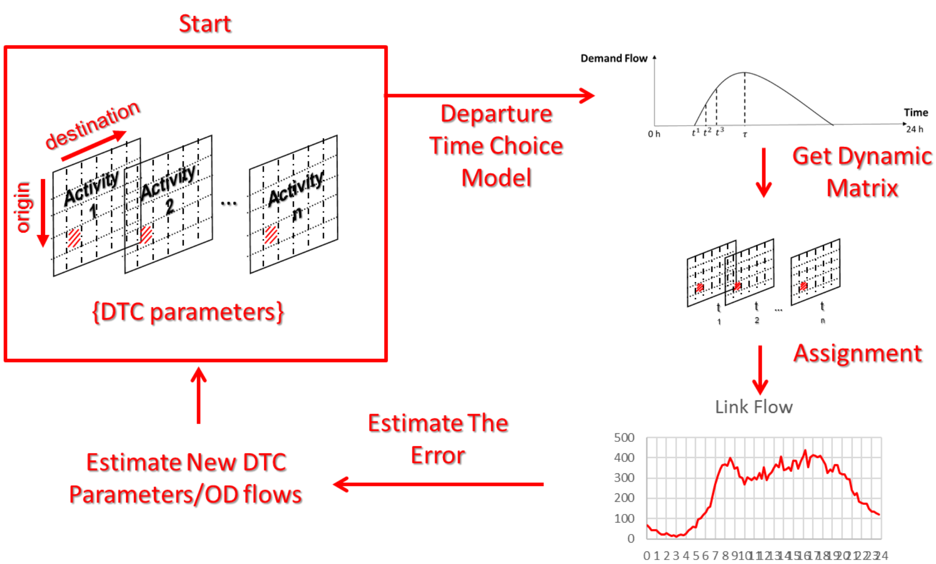

Figure 1: Illustrative representation of the UB-DODE model;

Firstly, this formulation automatically decreases the number of decision variables. The reason is that the parameters of the departure time choice model become the decision variables of the model. As a consequence, the UB-DODE becomes a parametric approach in which, for each OD pair, the model estimates the average departure time and its variance. The second advantage is that the DTC model can include different parameters for different activities, thus it explicitly accounts for the trip purpose within the DODE. Lastly, since each parameter directly affects a large number of time-dependent OD flows, the locality of the optimization problem strongly decreases. Figure 1 shows the main steps for the proposed UB-DODE model.

Experiment and results:

The aim of this paper is to assess the applicability of the novel procedure in practice, by applying the procedure to the network of Luxembourg City. This network, shown in Figure 1, consists of more than 3400 links and 1400 nodes and represents the typical middle-sized European city in terms of network size. Moreover, Luxembourg City has the typical structure of a metropolitan area, composed of a city centre, ring, and suburb areas.

Lastly, to support the claim that the model is ready for practical implementations, the simulation environment employed is PTV Visum [15], which is one of the most widely adopted software packages for traffic analysis.

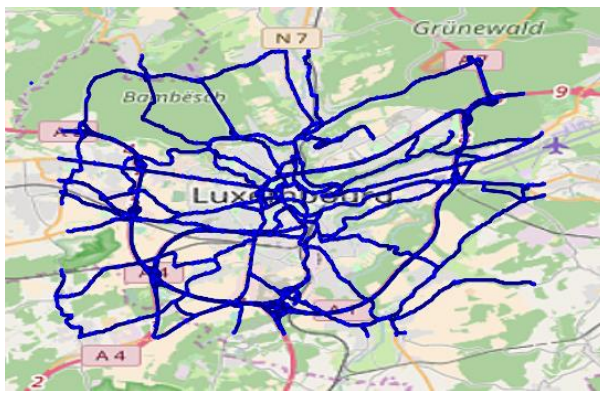

Figure 2: Network of Luxembourg City

After generating a realistic matrix through the conventional 4-Step model, employing socio-demographic data, we performed the DODE on the network shown in Figure 2, comparing the results obtained through the proposed UB-DODE and a conventional DODE procedure with the realistic matrix, which represents our target demand matrix. Both methods use the well-established SPSA to estimate the gradient [16], and the traffic counts within the GLS-type goal function [2].

The preliminary results, reported in Figure 3, show that the proposed model outperforms the standard DODE approach in inferring the OD demand. Although both models fail in estimating the real demand, an expected issue when including solely link flows in the objective function, the standard approach creates an unrealistic demand pattern, that can be hardly combined with any on-line prediction model. On the other hand, the demand profile obtained through the proposed approach is smoother and, in general, more realistic. This suggests that the model is more suited for estimating the systematic component of the demand, or "*regular pattern*".

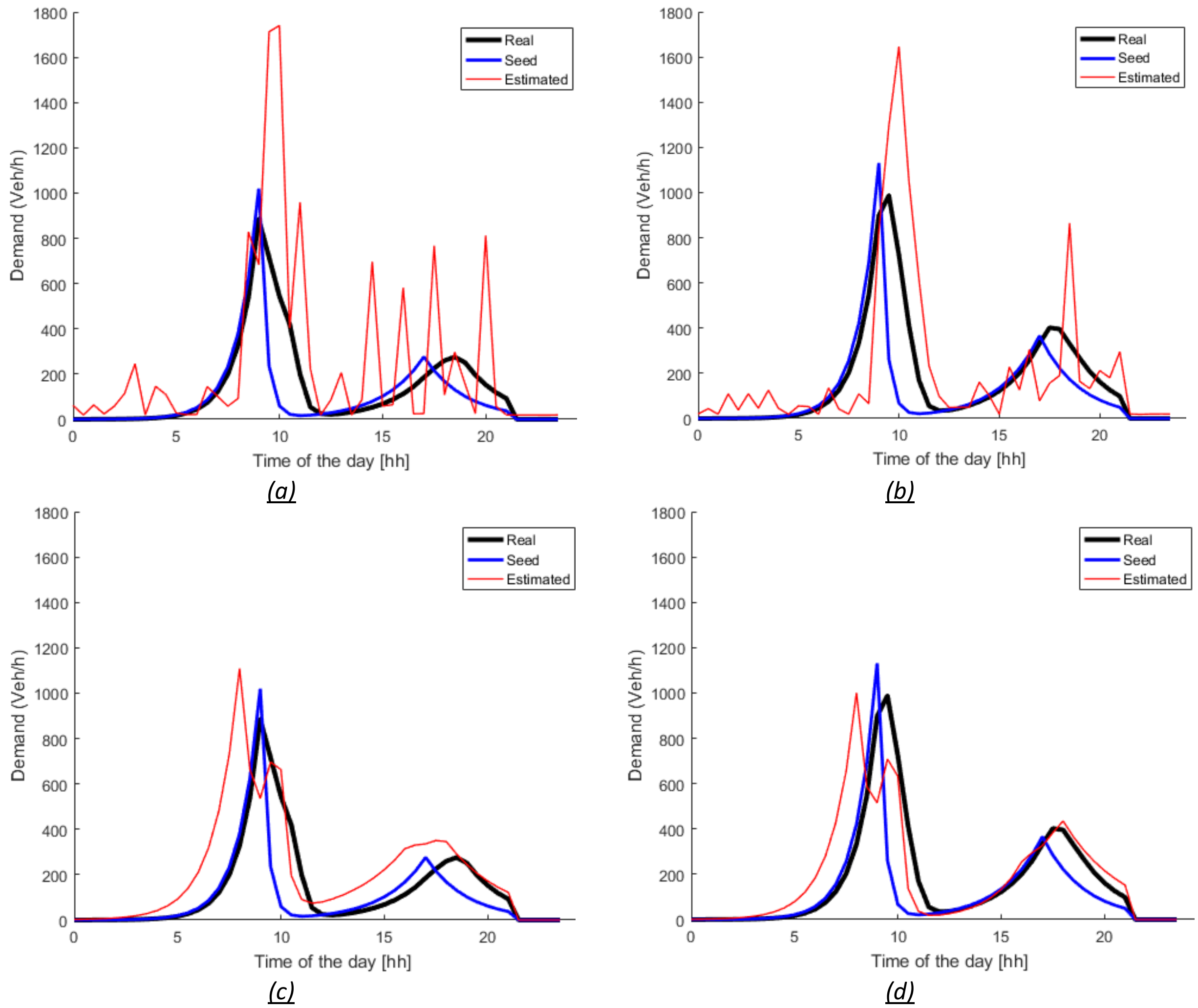

Figure 3: (a) Generated Demand For Traffic Zone 12 (Bridel) according to the standard DODE; (b) Generated Demand For Traffic Zone 17 (France-Longwy) according to the standard DODE; (c) Generated Demand For Traffic Zone 12 (Bridel) according to the UB-DODE; (d) Generated Demand For Traffic Zone 17 (France-Longwy) according to the UB-DODE;

The final goal of this study is to replicate the same experiment under several conditions, in order to verify the robustness of the UB-DODE approach: congested/uncongested scenarios, different sources of information and different solution algorithms. This will furthermore allow to assess the conditions under which the proposed model is capable of estimating a reasonable demand profile, compatible with existing on-line/off-line DODE models.

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