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Transportation Research Procedia 10 (2015) 134 – 144

Transportation Research Procedia

www.elsevier.com/locate/procedia

18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015, Delft, The Netherlands

A robust framework for the estimation of dynamic OD trip matrices for reliable traffic management

Jaume Barceló*, Lídia Montero

Barcelona Tech – UPC, Campus Nord, Carrer Jordi Girona 1– 3, 08034 Barcelona, Spain

Abstract

Origin-Destination (OD) trip matrices describe the patterns of traffic behavior across the network and play a key role as primary data input to many traffic models. OD matrices are a critical requirement, either in static or dynamic models for traffic assignment. However, OD matrices are not yet directly observable; thus, the current practice consists of adjusting an initial or a priori matrix from link flow counts, speeds, travel times and other aggregate demand data. This information is provided by an existing layout of traffic counting stations, as the traditional loop detectors. The availability of new traffic measurements provided by ICT applications offers the possibility to formulate and develop more efficient algorithms, especially suited for real-time applications. However, the efficiently strongly depends, among other factor, on the quality of the seed matrix. This paper proposes an integrated computational framework in which an off-line procedure generates the time-sliced OD matrices, which are the input to an on-line estimator. The paper also analyzes the sensitivity of the on-line estimator with respect to the available traffic measurements.

Peer-review under responsibility of Delft University of Technology

Keywords: Dynamic OD Matrices, Matrix Estimation, Kalman filtering, ICT data.

1. Motivation

In the context of estimating passenger-car transport demand, Origin-to-Destination (OD) trip matrices describe the number of trips between each origin-destination pair of transportation zones in a study area. For private vehicles,

* Corresponding author. Tel.: +34 93-401-69-41.
E-mail address: jaume.barcelo@upc.edu

Peer-review under responsibility of Delft University of Technology
doi:10.1016/j.trpro.2015.09.063

route choice models describe how drivers select the available paths between origins and destinations and, as a consequence, the number of trips using a given path (or path flow proportions). The route choice proportions can vary depending on the time-interval in dynamic models, since they depend on traffic states changing over time.

All formulations of static traffic or transit assignment models (Florian and Hearn (1995)) as well as dynamic models involved in ATMS (Advanced Transport Management Systems, Ashok et al. (2000) assume usually that a reliable estimate of an OD matrix is available, and constitutes an essential input for describing the demand to estimate network traffic states and short term predict their evolution. Since OD trips are not yet directly observable, indirect estimation methods have then been proposed. These are the so-called matrix adjustment methods, whose main modeling hypothesis, in the static case, can be stated Cascetta (2001) as follows: if the assignment of an OD matrix to a network defines the number of trips in all network links, then the same OD matrix could be estimated, as the inverse of the assignment problem, as a function of the flows observed on the links of the network. However, since the resulting problem is highly undetermined, additional information is necessary to find suitable solutions and consequently this has been a fertile domain of research (see Lundgren and Peterson (2008) or Bullejos et al (2014).

The estimation of time-dependent OD matrices has been usually based on space-state formulations using Kalman Filtering approaches, Ashok et al (2000), as the most suitable to model dynamic phenomena. What these approaches share with the static ones is that they still require an assignment matrix, whose entries determine the proportion of trips between an OD pair, using a link at a given time interval, with a relevant role for those links where traffic detection stations were located. Chang and Wu (1994) proposed an Extended Kalman-filter approach to deal with the nonlinear relationship between the state variables and the observations. Variants of this approach have been explored by other researchers, using variants of Extended Kalman Filters to deal with the time dependencies of model parameters, which are usually included as state variables in the model formulation. Just to mention a few, Hu et al. (2001) which explicitly take into account temporal issues of traffic dispersion, or Lin and Chang (2007) which also assume that travel time information is available in order to deal with traffic dynamics. Other researchers, Dixon and Rilett (2002), Antoniou et al. (2004) or Work et al. (2008) also included other measurements as for example those supplied by GPS tracking of equipped vehicles or Automatic Vehicle Identification in the model formulation.

However, when real-time measurements from Information and Communications Technologies (ICT) are available, e.g. those supplied by Bluetooth/Wi-Fi devices, hypothesis on non-linear traffic flow propagation to estimate travel-times between pairs of points in the network are no longer necessary, since they can be measured by these technologies, and then state variables can be replaced by measurements and the Extended Kalman formulation can be successfully replaced by an ad hoc linear formulation, Barceló et al. (2013b). which uses deviations of OD path flows as state variables, as suggested by Ashok and Ben-Akiva (2000), and does not require an assignment matrix but instead a subset of the most likely OD path flows identified from a Dynamic User Equilibrium (DUE) assignment.

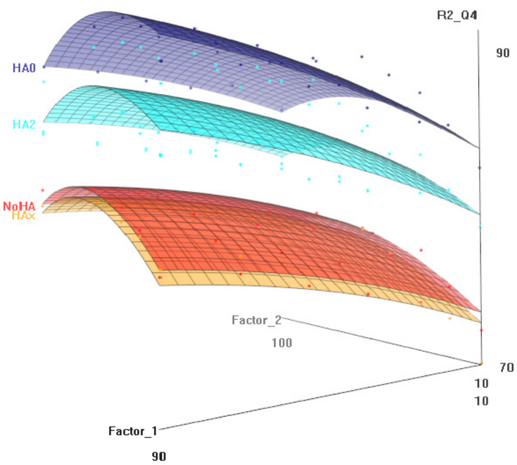

Fig. 1. R^2 Fitted vs Target OD flows (1h 15min) for OD pairs in the 4th quartile (**R2_Q4**) according to #BT Inner Sensors (Factor 1, Detection Layout), %BT Equipped Vehicles (Factor 2, Technology Penetration) and Quality of the OD seed (Factor 3).

A relevant finding of this approach to estimate dynamic OD matrices exploiting ICT data, Barceló et al. (2013a), is that the three key design factors that determine the quality of the estimate are, respectively, the quality of the detection layout, the quality of the historic dynamic OD matrix used as a priori initial estimate, and the percentage of penetration of the technology. This influence can be clearly seen in the graphics in Fig. 1, Barceló et al. (2013a), where the results from a series of computational experiments are represented in terms o response surfaces where each one corresponds to a level of quality of the OD seed used. Clearly the two first factors are controllable design factors while the third one cannot be controlled by the analyst. Assuming that some of the ICT applications (e.g. Bluetooth/Wi-Fi antennas, License Plate Recognition or Electronic ID identifiers, etc.) require fixed locations in the network, the quality of the sensor layout can be guaranteed using an optimized detection layout, purposely