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Dynamic demand estimation and prediction for traffic urban networks adopting new data sources ☆

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ABSTRACT

Nowadays, new mobility information can be derived from advanced traffic surveillance systems that collect updated traffic measurements, both in fixed locations and over specific corridors or paths. Such recent technological developments point to challenging and promising opportunities that academics and practitioners have only partially explored so far.

The paper looks at some of these opportunities within the Dynamic Demand Estimation problem (DDEP). At first, data heterogeneity, accounting for different sets of data providing a wide spatial coverage, has been investigated for the benefit of off-line demand estimation. In an attempt to mimic the current urban networks monitoring, examples of complex real case applications are being reported where route travel times and route choice probabilities from probe vehicles are exploited together with common link traffic measurements.

Subsequently, on-line detection of non-recurrent conditions is being recorded, adopting a sequential approach based on an extension of the Kalman Filter theory called Local Ensemble Transformed Kalman Filter (LETKF).

Both the off-line and the on-line investigations adopt a simulation approach capable of capturing the highly nonlinear dependence between the travel demand and the traffic measurements through the use of dynamic traffic assignment models. Consequently, the possibility of using collected traffic information is enhanced, thus overcoming most of the limitations of current DDEP approaches found in the literature.

1. Introduction

Today modern cities are undergoing social and economic changes that lead to a number of mobility issues related to limited transportation supply. Such issues cannot be addressed properly by adopting strategic planning based on increased capacity only. They must be integrated into a more complex pattern in which solutions can be derived from the adoption of new transport management approaches. In any case, accurate travel demand estimations are key information to be fed to the simulation process required during the evaluation phase.

When long term projects are dealt with, it is expected that proposed scenarios as well as the concurring socio-economic evolution affect travel demand structure in terms of amount, distribution and share among available transport modes; then,

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demand data are usually collected by conducting surveys on a sample of users whose results are used both to directly estimate current demand and to calibrate demand models for future forecasts. Differently, when dealing with short term projects, it is expected that proposed scenarios affect negligibly the demand structure which can be assumed as fixed and, thus, estimated from network observations.

In transport engineering, estimation of travel demand based on direct observations of the network (e.g. from traffic counts and other traffic measurements) is a classical and widely adopted procedure, both in off-line planning and in on-line (real-time) applications. In literature, demand estimation has been initially studied assuming static conditions for the simulation process, that is to say, based on specific assumptions underlying the impact of congestion on route choice. When such conditions do not hold, demand estimates must reflect both time variability and network patterns. This is known in the literature as Dynamic Demand Estimation problem (DDEP).

The off-line DDEP is usually approached as a bi-level problem. The upper-level consists in adjusting the starting demand (previously obtained through a combination of surveys and mathematical models, usually called "a priori" or "seed" demand) using traffic measurements, which are in turn linked to the dynamic demand. This link is generated in the lower level problem where a Dynamic Traffic Assignment (DTA) model is used to load the demand onto the network. It results in a highly undetermined, non-linear, non-convex problem, which was object of relevant research efforts in the last years (Antoniou et al., 2016; Cantelmo et al., 2014).

Several papers can be found in the literature that explore the influence on DDEP, of all the available sources of traffic information. Indeed, the basic information used since the earliest works, i.e. traffic counts, fails to differentiate between congested and uncongested traffic state of a link, because of non-monotone flow-density relationship; thus, employing count data alone can potentially overfit the demand to counts at the expense of accurate depiction of traffic dynamics. Moreover, current technologies can provide a great amount of traffic data: pavement-embedded sensors, roadside radars and cameras provide measurements of flows and speeds at nodes and along links; Advanced Vehicle Identification (AVI), ground-based radio navigation, cellular geo-location and GPS provide a new kind of information about travel times and users' route choices that integrate usual information on traffic flows.

Floating Car Data (FCD) are part of these new data sources. FCD are collected from probe vehicles equipped with on board units, enabling to track the position of specific vehicles along the network. One of the main features of FCD, with respect to data derived by other technologies, is the possibility to obtain information on Origin–Destination (OD) zones of individual trips as well as on their route choices and route travel times. This is fundamental for the calibration of traffic models and even more for the estimation of OD travel demand.

Such a relatively recent technology points to new challenging and promising DDEP opportunities, only partially explored so far, that can improve demand estimation reliability.

The dynamic OD trips resulting from off-line DDEP are usually the starting point of on-line demand estimation and prediction. In on-line applications, the dynamic OD estimation procedure is required to recursively provide fast estimates for recent time slices together with predictions for future time slices. The procedure consists of sequentially updating dynamic OD matrices, previously adjusted off-line, in order to take into account the real-time variability of traffic conditions. In the sequential update the demand components departing in time intervals prior to the one being considered are kept fixed, so reducing computational burden; for this reason it is basically adopted when fast run times are required.

Several papers about on-line demand estimation focus on the adopted solution approach. The Kalman filter (KF) algorithm (Kalman, 1960) has been widely proposed: this algorithm is mainly based on the solution of a least-square cost function, allowing for incremental updating of the OD flows each time additional traffic data are available. However, the application of the KF to on-line estimation and prediction seems to have different drawbacks: its inability to handle a large number of variables, since it requires intensive linear algebra computations, as well as the underlying linearity hypothesis on how OD flows and measurements are related. The latter hypothesis cannot especially be justified if other traffic information sources, highlighting non linearity, are included in the estimation framework.

The present contribution analyses both the off-line and the on-line DDEP in the context of recent technology developments and the related new promising and challenging chances provided by the possibility to collect several heterogeneous traffic data. Firstly, FCD are exploited for off-line demand estimation. Information on users' dynamic route choice behaviour and route travel times have been gathered, coupled with fixed location observations, and included in the DDEP. At the same time, a recent extension of Kalman filter theory, called Local Ensemble Transformed Kalman Filter (LETKF, Hunt et al., 2007), was tested for the on line demand estimation and prediction, with the objective of dealing with the new sources of data. LETKF faces challenges under the common on-line procedures and its applicability is strictly correlated with the current research on dynamic traffic assignment (DTA) models. LETKF works adopting a simulation approach which avoids any linearization of the dependency between OD flows and traffic measurements, as well as it provides a decomposition structure which may permit to divide the problem into sub-problems.

The remainder of the paper is structured as follows. Section 2 deals with the off-line DDEP and the potentialities linked with the adoption of new sources of data from FCD; an application on a real case of study (the district of Eur, Rome, Italy) is presented. Section 3 proposes the new LETKF method for the on-line DDEP and test its reliability both in comparison with other nonlinear KF and in a dynamic environment. Finally, Section 4 provides concluding discussions and statements.