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Short-term traffic forecasting: Where we are and where we're going

Eleni I. Vlahogianni *, Matthew G. Karlaftis, John C. Golias

Department of Transportation Planning and Engineering, School of Civil Engineering, National Technical University of Athens, 5, Iroon Polytechniou Str., Athens 15773, Greece

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ABSTRACT

Since the early 1980s, short-term traffic forecasting has been an integral part of most Intelligent Transportation Systems (ITS) research and applications; most effort has gone into developing methodologies that can be used to model traffic characteristics and produce anticipated traffic conditions. Existing literature is voluminous, and has largely used single point data from motorways and has employed univariate mathematical models to predict traffic volumes or travel times. Recent developments in technology and the widespread use of powerful computers and mathematical models allow researchers an unprecedented opportunity to expand horizons and direct work in 10 challenging, yet relatively under researched, directions. It is these existing challenges that we review in this paper and offer suggestions for future work.

1. Introduction

Short term traffic forecasting has been a very important consideration in many areas of transportation research for more than 3 decades. This interest is the direct result of an increasing need for developing user friendly applications which can both provide accurate information to drivers and be used for signal optimization. The ability to provide such information is the result of phenomenal technological and computational advances that have enabled researchers to collect data and subsequently predict at very high temporal resolutions.

Both the technological aspects of this analysis (ITS Technology) and the analytical (data analysis), have been the focus of countless research papers over the past few years (Adeli, 2001; Vlahogianni et al. 2004; Van Lint and Van Hinsbergen, 2012). The combination of unprecedented data availability and the ability to rapidly process these data has brought on immense development and acceptance of ITS technologies. At the same time, a novel research area, based on data driven empirical algorithms, has been systematically growing in parallel to the well-founded mathematical models that are based on macroscopic and microscopic theories of traffic flow (Wang and Papageorgiou, 2005; Yuan et al., 2012; Treiber and Kesting, 2012; Fowe and Chan, 2013; Kerner et al., 2013). This significant leap from analytical to data driven modeling has been marked by an overwhelming increase of Computational Intelligence (CI) – Data Mining (DM) approaches to analyzing the data. Researchers have moved from what can be considered as a classical statistical perspective (the ARIMA Family of models), to Neural and evolutionary computational approaches (Karlaftis and Vlahogianni, 2011).

Short-term traffic forecasting based on data driven methods is one of the most dynamic and developing research arenas with enormous published literature. Interestingly, however, most of the research has concentrated on 'testing' alternative

* Corresponding author. Tel.: +30 2107721369; fax: +30 2107721454.
E-mail addresses: elenivl@central.ntua.gr (E.I. Vlahogianni), mgk@central.ntua.gr (M.G. Karlaftis), igolias@central.ntua.gr (J.C. Golias).

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modeling approaches on short-term traffic data, possibly because of the data's ready availability and the relative ease of applying many of the available analytical approaches. This concentration leaves a number of important questions and challenges unaddressed or, relatively to the rest of the literature, under researched. In this paper we review existing research with an explicit focus on identifying, briefly discussing, and offering information on 10 areas where we believe that the technological and analytical challenges lie for the next generation of short term forecasting research.

2. Short term traffic forecasting: a brief overview

Since the early 1980s, short-term traffic forecasting has been an integral part of most Intelligent Transportation Systems (ITS) and related research. It concerns predictions made from few seconds to possibly few hours into the future based on current and past traffic information. Most of the interest has focused on developing methodologies that can be used to model traffic characteristics such as volume, density and speed, or travel times, and produce anticipated traffic conditions. The field of short-term traffic forecasting has a life of 35 years (Ahmed and Cook, 1979); in the first part of its development, most – if not all – of the research employed 'classical' statistical approaches to predicting traffic at a single point. Later, applications of data driven approaches were the focal point in the literature, where a rich variety of algorithmic specifications – most times creatively applied – were proposed. The weight placed recently on empirical computational intelligence-based approaches, including Neural and Bayesian Networks, Fuzzy and Evolutionary techniques, can be considered as inevitable, particularly as most classical approaches have been shown to be 'weak' or inadequate under unstable traffic conditions, complex road settings, as well as when faced with extensive datasets with both structured and unstructured data.

Existing literature has been studied in 3 papers; the first, by Vlahogianni et al. (2004) provided a critical review of the entire spectrum of the short-term traffic forecasting literature up to 2003, and underlined the complexities of several conceptual, design and methodological issues involved in developing forecasting applications. The second and third, by Adeli (2001) and van Lint and Van Hisbergen (2012), reviewed Neural Network and Artificial Intelligence (AI) applications to short-term traffic forecasting, collecting and analyzing the literature using such approaches. To avoid overlaps with already published work, in Tables 1–4 we summarize the available literature for the periods 2004–2006, 2007–2009, 2010–2011, 2012–2013 respectively, and categorize papers based on certain criteria that can give a good sense of where most research effort has concentrated over the past decade.

From the overview it becomes clear that most effort has gone into: i. using data from motorways and freeways, ii. employing univariate statistical models, iii. predicting traffic volume or travel time, and iv. using data collected from single point sources. Recent developments in technology and the widespread use of powerful computers and mathematical models allow researchers an unprecedented opportunity to expand horizons and direct work in 10 challenging directions. These are presented following a top-down approach; the first and second challenges refer to the system's characteristics (responsiveness and location of interest), that will integrate prediction models. The third challenge is dedicated to the problem of forecasting traffic and variable choice. Challenges 4 to 5 focus on data issues and the manner in which new technologies have altered the available prediction datasets. Next, Challenges 6 to 9 refer to the methodological and modeling issues that are involved with developing novel prediction algorithms. Finally, challenge 10 deals with the role of artificial intelligence models and on the manner of integrating such models into prediction schemes. These 10 challenges are reviewed and summarized in Table 5.

3. The challenges

3.1. Challenge 1. Developing responsive algorithms and prediction schemes

Transportation agencies require forecasts that are robust to short and longer term changes in traffic conditions. In cases where these changes are unexpected – accidents, and adverse weather conditions for example – traffic management systems should optimize management and advisory strategies. Responsive predictions are very important, yet difficult to construct, as the relationship between non recurrent (unexpected) events and short term traffic conditions is complex and several times unclear (even the effects of weather on short-term traffic flow remains elusive). Forecasting algorithms that can incorporate the effect of non-recurrent conditions and provide accurate predictions will enhance the decision making capabilities of traffic management systems, improve coordination between authorities, and help maintain a sustainable level of service.

Research on responsive traffic prediction schemes has focused on developing multi-regime models to account for the shifts of traffic between congested and uncongested conditions (Vlahogianni, 2009; Kamarianakis et al., 2010). These models have been also extended to incorporate the effect of accidents or adverse weather on predictions (van Lint and van Zuylen, 2005; Castro-Neto et al., 2009; Fei et al., 2011; Min and Wynter, 2011), yet with no straightforward results particularly with respect to the effects of weather. Li and Chen (2012) and Li and Rose (2011) reported that the inclusion of rainfall (5 min data) on the short-term travel time predictions may reduce forecasting inaccuracies and improve the model robustness. Innamaa (2009) reported similar prediction performance for 5 min data – based on average relative metrics – for both 'normal' and adverse weather and road conditions. Tsirigotis et al. (2012) emphasized the marginal effect of rainfall on short-term (10 min step) freeway speed predictability. Vlahogianni and Karlaftis (2012), using recurrence-based complexity measures,