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Transportation Research Procedia 17 (2016) 452 – 459

Transportation Research Procedia

www.elsevier.com/locate/procedia

11th Transportation Planning and Implementation Methodologies for Developing Countries, TPMDC 2014, 10-12 December 2014, Mumbai, India

Freeway travel time prediction based on seamless spatio-temporal data fusion: case study of the freeway in Taiwan

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Abstract

Travel time prediction has been the fundamental brick for developing both Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS). The problem of travel time prediction is primarily shaped by the data available for model development and the needs from the perspectives of both travelers and operators. A distance-based Electronic Toll Collection (ETC) system over the freeway system in Taiwan has been fully implemented since December 2013, which provides more comprehensive online data acquisition of freeway traffic conditions, thereby enabling the capability to more reliably predict of travel time over freeway segments. Based on the data from both the ETC system and traditional Vehicle Detectors (VDs), this research proposes a travel time prediction approach whose core technique of data fusion seeks to seamlessly capture the spatio-temporal pattern of freeway traffic flows by matching traffic dynamics revealed from the ETC and VD data. Further, prediction models are constructed thereupon, where the Kalman filter is employed for short-term prediction and the Fourier transform for long-term prediction based on the continuous parameterized modeling of spot travel speed. The proposed approach is implemented as an online deployable system using Java, together with real-world data collected from the freeway in Taiwan, for the numerical experiments. The prediction errors are no greater than 10% in most cases, which illustrates the high accuracy of prediction capability of the model. The encouraging results also highlight the benefits of the pre-processing of data and data fusion in improving data quality and applicability.

Peer-review under responsibility of the Department of Civil Engineering, Indian Institute of Technology Bombay

Keywords: freeway travel time prediction; data fusion; spatio-temporal traffic pattern; Kalman filter; Fourier transform

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Peer-review under responsibility of the Department of Civil Engineering, Indian Institute of Technology Bombay
doi:10.1016/j.trpro.2016.11.087

1. Introduction

To know freeway traffic conditions or even to foresee them to a certain extent can be a matter of great concern from the perspectives of both freeway operators and travelers, in regard with transport efficiency and reliability. They facilitate freeway operators to more effectively respond to traffic congestion or to mitigate its potential by applying preventive strategies, such as ramp metering and routing guidance dissemination. Also, travelers may be enabled to re-plan their trips and routes accordingly to circumvent congested freeway segments and the associated travel delays. To describe freeway traffic conditions, travel time is one intuitively perceivable and generally used measurement, and substantial research efforts have been made for online freeway travel time prediction, which in the aforementioned contexts plays a critical role to address the needs of both perspectives, as the underlying development aspects of Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS).

The foundation of travel time prediction along a freeway lies in the traffic dynamics unfolding over a spatio-temporal pattern, which results in the intricacy of traffic flow interaction and propagation. The travel time of each freeway segment varies over time. Hence, to predict the travel time of a trip for a specific Origin-Destination (O-D) pair needs the capturing of the inferred trajectory with a given starting time of the trip, which can be subjected to the randomness and of short-term flow fluctuation and vulnerable to prediction errors accumulated along the trajectory, especially for the real-time applications.

The problem of travel time prediction is largely shaped by data availability, which presents another major methodological challenge: how to abstract the spatio-temporal pattern of freeway traffic and effectively utilize it to project future dynamics. The prediction accuracy can be highly conditioned on data quality, as measurement errors seem inevitable to different degrees for various data acquisition techniques and mechanisms. Data fusion has been one of the related focuses to leverage the characteristics of data obtained from different sources to enhance data quality for the development of prediction models. Conventionally, the monitoring of the freeway system in Taiwan relies on traditional Vehicle Detectors (VDs) and few Closed-Circuit Televisions (CCTVs). An Electronic Toll Collection (ETC) system, shifting from a manual one and starting its operation in 2006, has enriched data acquisition over the freeway system in Taiwan, where more detailed data of vehicular flows are available. Since December 2013, a distance-based pricing scheme using the ETC system has been fully implemented, which allows more comprehensive inspection of freeway traffic conditions in accordance with the further subdivided freeway toll segments. This provides potential capability for the operators to attain higher accuracy and reliability for freeway travel time prediction.

Motivated by the described current problem states and the advanced data acquisition environment, this research uses the case study of the freeway in Taiwan and proposes a travel time prediction approach whose core technique of data fusion seeks to seamlessly capture the spatio-temporal pattern of freeway traffic flows, primarily with respect to the data collected from the ETC system and traditional VDs. Based on the output of data fusion, the prediction models of freeway travel time are then developed for the inquiries of different locations and time dimensions.

The remainder of the paper is organized as follows. In the next section, the problem of freeway travel time prediction in an ETC environment is first described with more details regarding the freeway system in Taiwan; it is followed by the review of relevant literature. The travel time prediction approach is proposed in Section 3, including the discussion and justification of the related methodological aspects. Then, the proposed approach is validated and analyzed by numerical experiments based on the real traffic data of the Freeway in Taiwan. The last section concludes research findings and highlights the contributions of this study**.**

2. Freeway travel time prediction in an ETC environment

2.1. Problem description

For the problem of freeway travel time prediction aiming to address the needs of both the freeway operators and travelers, it has to be capable to tell the travel times starting at any future time points from any locations on the freeway to their downstream destination ramps. Instead of simply summing up instantaneous travel times of all segments