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Real-time Monitoring of Dynamic Traffic States by State-Space Model

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Abstract

We propose real-time traffic state estimation using a state-space model that takes account of variability in the fundamental diagram (FD) and sensing data. In free flow situations, for instance, the FD regulating driving behavior may vary among drivers who possess differing characters. In addition, FD is affected by external factors such as interactions with pedestrians and vehicles. Variational theory (VT) was used as the system model, and measurement data were taken from probe vehicles and traffic detectors. VT is a static model, making real time estimation of traffic state changes difficult. We applied VT to a state-space model. Our proposal showed better agreement between simulated and benchmark traffic states than deterministic VT. For model validation, we applied the model to Komazawa Street in Tokyo, Japan.

Keywords: traffic state estimation, data assimilation, kinematic wave theory, probe vehicle trajectory

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1. Introduction

In free flow situations, the fundamental diagram (FD) regulating driving behavior may vary among drivers with differing characters. The FD is also affected by external factors such as on-street parking and interactions with pedestrians and vehicles.

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Against this background, we propose a system that monitors traffic states in real time based on a traffic flow model using all the available sensing data. Because sensing data may not cover an entire study area, a traffic flow model was used to interpret traffic states in areas that lack sensing data. Our proposal used both sensing data and a traffic flow model to assimilate the data.

The variational theory (VT) proposed by Daganzo (2006) is considered to belong to the data assimilation family because it cumulatively counts traffic based on a kinematic wave model and by using measurement data. The kinematic wave model has been established as a standard flow model that accurately reproduces real phenomena. The key postulate of the Lighthill-Whitham-Richards (LWR) model is that a functional relationship exists between flow q and density k. This relationship, called the FD, may vary with location x but not with time t, as shown in Fig. 1. Given the FD and a boundary condition, traffic states are usually estimated by using the kinematic wave model to solve the differential flow conservation equation along a characteristic curve on which flow is constant. VT converts the problem to the shortest path calculation on a network design based on the FD. Using probe vehicle and traffic detector data, Mehran et al. (2012, 2013) proposed a modified VT to deal with vehicles coming in and out of a study road section and to estimate the trajectories of all vehicles running along a signalized arterial road.

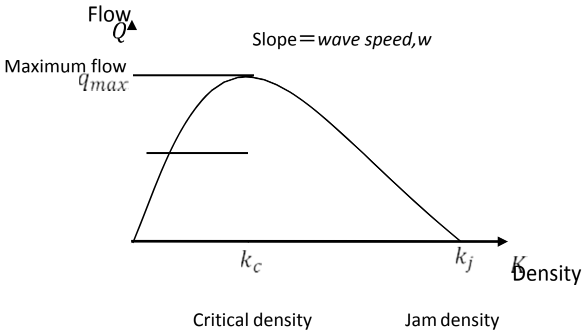

Fig. 1. Fundamental diagram.

VT deterministically estimates traffic states, but in practice, several stochastic factors influence traffic state estimation. In free flow, for example, the FD regulating driving behavior may be different for drivers with differing characters. In a disaster, the FD varies significantly due to exogenous factors such as the number of pedestrians and abandoned cars. Another stochastic factor arises from boundary traffic conditions, which are conventionally defined from sensing data. Mehran et al., for example, defined the boundary condition based on traffic counts from detectors installed at entrances and exits of the study section and on probe vehicle trajectories. Traffic volume itself varies stochastically and contains random sensing errors. A probe trajectory may also have random measurement errors.

A promising data assimilation method for incorporating these stochastic properties is the state-space model, which comprises a system and measurement models. Recent studies that have reported the use of such a model include Chen et al.'s (2014) state-space model for estimating travel time on motorways. Specifically, their model predicts the travel time in a short time period by matching the degree of similarity between patterns in currently observed and previous travel time data. Dong et al. (2014) proposed a state-space model for estimating flow and speed on a motorway network. Claudel et al. (2011) applied data assimilation techniques for estimating motorway traffic states. A state-space model based on the Hamilton–Jacobi equation uses GPS measurements, but Deng et al. (2013) proposed a similar data assimilation model using a range of data including probe, Bluetooth, and traffic detector data. Yuan et al. (2015) proposed the application of a Kalman filter to the LWR model for a system model using a traffic detector and probe data. Nates et al. (2015) constructed a cell-based model similar to CTM for a local street and estimated the traffic status using an extended Kalman filter based on speed measurements from probe and Bluetooth data. Patire et al. (2015) analyzed similar methods using probe and detector data.

The present study followed the previous literature in that an essentially kinematic wave model was used as the system model and probe and detector data were used for measurement. What makes this study unique, however, is that the kinematic wave model used for the system model applied a stochastic FD and that stochastic variability and random errors were included in the measurements.