An Application of Probe Vehicle Data on Traffic State Estimation

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1. Introduction

As availability and reliability of observed traffic data significantly affect the accuracy of traffic state estimation, traffic data from probe vehicle technique, which has a potential of network coverage, might be helpful to improve the traffic state estimation. The applications of probe vehicle data are still limited as they mostly concentrated on travel time detection, such as in Chen [1]. While some authors has used probe data to estimate O-D data, and detect incidents [3]. As knowledge of the authors, so far, no work has applied the probe data with the macroscopic model to estimate traffic states. However, fundamental traffic state variables (traffic volume, space mean speed, and traffic density) have some advantages over travel time, such as, they are better to reflect traff conditions; they have a capability to convert to other variables easily; and they are more suitable for real-time applications than travel time data because travel time can be obtained only after vehicles completely traverse a link.

The objective of this paper is to propose an idea of using probe vehicle data together with fixed detector data to estimate traffic states in real-time.

2. Probe Vehicle Technique

Nowadays, the most common mechanism for traffic data collection is the usage of traffic detectors. As the network to monitor is larger the number of detectors required for efficient network surveillance is increasing. That requires a large amount of investment of infrastructures to install the detectors under the road surface. Consequently, Various alternatives for detecting traffic information have been developed in order to improve network coverage and to be appropriate to real-time applications. Probe vehicle technique is one of those surveillance techniques, which receives considerable interest recently.

The probe vehicle concept is the monitoring technique that uses the vehicles as the moving sensors traveling in traffic, in contrast to the fixed detectors such as inductive loops, which exist only limited locations. The probe vehicle is a vehicle that measures and reports traffic flow conditions to roadside devices as real-time manner. A sufficient large number of probe vehicles should reasonably represent the traffic conditions that they experienced. With such mechanism, data from the links that no detector installed can be obtained. Several types of information can be collected by this technique, such as position, speed, time, lane used, link travel time, congested time, etc.

3. Traffic State Estimation

Traffic state information is essential for the development of efficient control strategies and management schemes for traffic systems. Unfortunately, by mean of field observation, it is impossible to obtain such traffic data for a large network. As a result, traffic state estimation is required. The common way to estimate traffic states is to use mathematical models. However, the results from static mathematical models seem to be not sufficient for real time applications. As a result, several strategies were introduced to apply with the models for real-time traffic prediction, such as artificial neural network, and Kalman filtering.

3.1 Macroscopic Traffic Flow Model

Among the mathematical traffic models, the macroscopic models describing the traffic states in an aggregate manner seems to be the most appropriate for real-time applications because of their lowest degree of computation and fastest simulation time. Furthermore, they can be applied with other supplementary techniques for real-time application. The most well-known macroscopic model was proposed by Payne [2]. It is composed of three relationships as the followings.

$$\frac{\partial \rho}{\partial t} + \frac{\partial q}{\partial x} = g(x,t) \quad \text{(Continuity Eq.)} \tag{1}$$

$$q = \rho v \tag{2}$$

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x} = \frac{1}{\tau}\left[v - v_e(\rho)\right] - \frac{\nu}{\tau\rho}\frac{\partial \rho}{\partial x} \quad \text{(Momentum Eq.)} \tag{3}$$

where t indicates time increment, whereas x indicates space increment. ρ, v, and q are the fundamental traffic state variables, which are density, space mean speed, and traffic volume, respectively. v_e

is the speed at equilibrium state, which can be obtained from density-speed curve. τ, and ν are model parameters.

3.2 Kalman Filtering Technique (KFT)

KFT is the method for combining measurement data which are contaminated with noise. It can be applied to the problem of traffic state estimation using macroscopic traffic model. Traffic states are estimated by the macroscopic model and then adjusted according to KFT algorithm. The adjustment of state variables is proportional to the difference between observed values and model predicted values of observation variables.

To formulate KFT the white noise errors were induced in both macroscopic model formula and measurement process as follows:

$$x(t+1) = f[x(t)] + \xi(t) \quad \text{(state equation)} \quad (4)$$

$$y(t) = g[x(t)] + \zeta(t) \quad \text{(observation equation)} \quad (5)$$

where $\xi(t)$ and $\zeta(t)$ are noises vectors representing the modeling errors and measurement errors, respectively. Then, the state and observation equations are linearized around the nominal solution. The model becomes:

$$\tilde{x}(t+1) \cong f[\hat{x}(t)] + \frac{\partial f}{\partial x}(x(t) - \hat{x}(t)) + \xi(t) \quad (6)$$

$$\tilde{y}(t) \cong g[x(t)] + \frac{\partial g}{\partial x}(x(t) - \tilde{x}(t)) + \zeta(t) \quad (7)$$

$\tilde{x}(t)$ and $\hat{x}(t)$are the estimated state vector before and after obtaining actaul measurement data, $y(t)$, respectively.

For a case which measurement data are otained from fixed detectors only, traffic density and space mean speed are considered to be the state variables, $x(t)=(\rho, v)(t)$, whereas traffic volumes and spot speeds are treated as obsevation variables, $y(t)=(q, w)(t)$, where w is the time mean speed. Continuity equation and a momentum equation were treated as state equations, while observation equations consist of Eq. 2 and the relationship between spot speed and state variables.

4. State Estimation using Probe Data

To include probe data into the updating algorithm, several considerations have to be taken into account as the followings:

1) How to deal with the inconsistency of traffic data for different time steps.
2) How to combine the probe data with the fixed detector data in case of traffic data are available from both sources.
3) How should probe vehicles report the traffic data; at the end of every time step, or when they pass the pre-specified observation points.
4) Statistic of errors of probe vehicle data.

To perform further analysis the authors proposed four study scenarios as follows:

1) Probe data are reported at specific observation points with no fixed detector data
2) Probe data are reported at specific observation points and fixed detector data are available at certain points
3) Probe data are reported at every time step with no fixed detector data
4) Probe data are reported at every time step with some available fixed detector data

Moreover, preliminary concepts to perform KFT for each scenario were proposed as shown in Table 1.

Table 1 Basic consideration for KFT formulation

		Variables	Equation	Note
Case 1	State	ρ v	Continuity Momentum	
	Observed	w	$w = g_w(x)$	
Case 2	State	ρ v	Continuity Momentum	
	Observed	w	$w = g_w(x)$	combine two sources of data
Case 3	State	ρ v	Continuity Momentum	
	Observed	v	$v = g_v(x)$	
Case 4	State	ρ v	Continuity Momentum	
	Observed	v w	$v = g_v(x)$ $w = g_w(x)$	

5. Conclusion

An application of probe vehicle technique, which has a potential to cover a large network, on the estimation of traffic state variables using a macroscopic model should be investigated. In order to improve estimation accuracy, KFT will be applied to update the estimates as real-time feedback manner. In addition, the effect of number of probes to the reliable of estimation should be investigated.

6. References

1) Chen, M., et al., "Dynamic Freeway Travel Time Prediction Using Probe Vehicle Data: Link-based vs. Path-based". *TRB 80th Annual Meeting*, 2001.
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3) Sanwal, K., et al., "Vehicles as Probes", Cal. PATH Working Paper, Inst. of Transpn. Studies, Univ. of California, Berkley, 1995.