ESTIMATION OF REAL-TIME ORIGIN-DESTINATION FLOW USING MOBILE SENSOR NETWORK

Zijia Zhong
Graduate Research Assistant
Department of Civil and Environmental Engineering
New Jersey Institute of Technology
Newark, NJ. 07102
zz46@njit.edu

Joyoung Lee, Ph.D.
Assistant Professor
Department of Civil and Environmental Engineering
New Jersey Institute of Technology
Newark, NJ 07102
+973-596-2475; jo.y.lee@njit.edu

ABSTRACT

This paper proposes an analytical framework to deal with dynamic O-D estimation under the environment of mobile sensor network. With route travel information for each O-D pair and link traffic counts data, a Kalman Filter-based O-D estimation approach is proposed to bypass traffic assignment matrix. To this end, this paper exploits real-time route travel time information captured by both Bluetooth-based sensing technology and roadway traffic counts information by high resolution microwave sensors being deployed for real-time work zone monitoring system in New Jersey, USA. The proposed dynamic O-D estimation framework will be applied for the implementation of work zone management system to estimate and predict alternative routes for work zone area.
Key Words: Mobile Sensor Network; Bluetooth; Kalman Filter; TrEPS; Work Zone Management

INTRODUCTION

Time-dependent O-D information plays a vital role in dynamic traffic assignment which is one of the most crucial elements for Traffic Estimation and Prediction System (TrEPS). Numerous research efforts have been conducted for the past two decades. The majority of those research efforts is primarily based on traffic assignment matrix estimated by simulation model to map assigned traffic demand and their routes available for each O-D pair.

Ashok (1996) proposed an extended Kalman Filter-based dynamic O-D estimation approach by developing state-space and measurement equations to deal with both traffic assignment matrix and link traffic counts information. While there are couple successful case studies in simple network configuration (1), it is highly computationally expensive and nearly impractical to implement such model in real-world scenario, especially when it comes to a complex real-world open network. More recently, a few researchers have attempted to improve the quality of the estimated O-D by using field-observed route traffic information by exploiting Bluetooth-based mobile sensor network. Barceló has applied a Kalman Filter-based approach for travel time prediction based on Bluetooth data captured from a 40-km-

long motorway in Netherlands (2). Unlike Ashok (1995), however, Barceló's research has not contained route choice strategies due to the simplicity of the structure of the test network.

Bluetooth has been recognized as a global standard protocol suitable for mid- to short-range wireless communications between two mobile devices (e.g., laptop, smartphone, or tablet PC). One of unique features of Bluetooth is to sense the identification of those devices by capturing their Medium Access Control (MAC) address without data authentication procedure. By deploying multiple Bluetooth sensors along the roadway to trace the positions of Bluetooth devices, several commercial solutions have been applied for traffic monitoring. In public research sector, Omarni (3) have applied Bluetooth in monitoring network travel time in greater Toronto area; Bullock (4) have used Bluetooth to assess the route choice impact of an unexpected bridge closure in Indiana.

This technical paper proposes a methodology for the estimation of dynamic OD flows by using actual route information collected from Bluetooth-based mobile sensor network system being deployed in and around I-295 reconfiguration construction sites in New Jersey. With the soon-become available real-time traffic flow data, we will be able to further explore the effectiveness and possible improvement of using Bluetooth sensors in determining the dynamic O-D flow.

METHODOLOGY

This section deals with an analytical framework for a Kalman Filter approach that we proposes to deal with dynamic O-D estimation using Bluetooth-based real-time route traffic information. For every aggregated detection cycle of the Bluetooth sensors, there are equal intervals with the length T. The maximum travel time among all the O-D pair is assumed to be the number of q time intervals in a network with n_{LK} links, and among which n_l links are installed with Bluetooth sensors. A recursive linear Kalman filter is adopted to process the travel times and traffic counts collected in every cycle by the Bluetooth sensors deployed around the studied area. It is assumed that the structural information of O-D matrices pattern subsume in the collected data. The state-space (1) and measurement (2) equations are as follows:

$$x_{ij}(h+1) - x_{ij}^H(h+1) = \sum_{p=h-q}^{h} A_h^p [x_{ij}(p) - x_{ij}^H(p)] + w(h) \qquad (0)$$

$$y_l(h) - y_l^H(h) = \sum_{p=h-q}^{h} B_h^p [x_{ij}(p) - x_{ij}^H(p)] + v(h) \qquad (0)$$

where,

$x_{ij}(h+1)$: O-D matrix at time interval $h+1$, with i origins and j destinations

$x_{ij}^H(p)$: the best available historical estimation of O-D matrix at tine interval h

A_h^p : Coefficient matrix of state-space equation including vehicle departs at origin i at p time interval and have detected by sensor located downstream of the route at time interval h

$w(h)$: Random errors vector y_h : Matrix of observed link flows at time interval h

y_h^H : Matrix of historical observed link flows at time interval h

B_h^p : Coefficient matrix of measurement equation

$v(h)$: random errors vector

In Equation (2), the left side is the deviation of observed link counts at time interval h and the right side is the deviation of O-D demand at time interval p. It is also noted that B_h^p is related to dynamic travel time, dynamic entry flows to the network, and dynamic exit flow for the network (2).

$$B_h^p = C\, D^T\, G \qquad\qquad (0)$$

where,

   D: Mapping matrix for dynamic travel time

   C: Mapping coefficient of dynamic entry flows from on-ramps

   G: Mapping coefficient of dynamic exit flows from off-ramps

Based on the calculated O-D deviation from time interval p and h, predict the O-D deviation of time interval h+1. Kalman filter will be used to constantly comparing and incorporate the new incoming data for each cycle.

CONCLUDING REMARKS

The dynamic O-D estimation approach proposed in this paper is developed for work zone monitoring system for the I-295 Direct Connect Project in Camden County in New Jersey, which is one of major highway reconstruction projects to be completed in 2021. To measure the impact of the lane closure and other work zone related activities on the highway network performance, the Intelligent Transportation System (ITS) devices such as Bluetooth sensors and microwave sensors are being deployed to capture prevailing traffic conditions in real-time. With the significant coverage of the deployed Bluetooth sensors and large amount of incoming data from the network, it is expected that the implementation of Bluetooth sensors in time-dependent O-D estimation and prediction could provide useful information for work zone monitoring system.

It is worth noting that the application of the proposed dynamic O-D estimation method would be the first large scale deployment. As an essential part of the bigger work zone mobility project, further incorporation of O-D estimation with other ITS systems is envisioned and desired. Challenges will be also raised for accurate O-D estimation, since either long-term or short-term change on O-D pattern is expected. Hence, this paper will put dynamic O-D estimation into test; and at the same time evaluate the feasibility of using such technique to serve the greater traffic monitoring and management for roadway work zone.

REFERENCE

(1)K. Ashok, Estimation and Prediction of Time-Dependent Origin-Destination Flows. Massachusetts Institute of Technology, 1996.

(2) J. Barceló, L. Montero, L. Marqués, C. Carmona, Travel Time Forecasting and Dynamic Origin-Destination Estimation for Freeways Based on Bluetooth Traffic Monitoring. *Transportation Research Record: Journal of the Transportation Research Board* 2010; **2175**: 19-27.

(3) R. Omrani, P. Izadpanah, G. Nikolic, B. Hellinga, A. Hadayeghi, H. Abdelgawad. Evaluation of Wide-Area Traffic Monitoring Technologies for Travel Time Studies. *Transportation Research Record: Journal of the Transportation Research Board* 2013; **2380**: 108-119.

(4) D. M. Bullock, G. D. Farnsworth, S. M. Remias, S. M. Hubbard, J. S. Wasson, A. M. Hainen, Estimating Route Choice and Travel Time Reliability with Field Observations of Bluetooth Probe Vehicles. *Transportation Research Record: Journal of the Transportation Research Board* 2011; **2256**: 43-50.