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Big Data applications in real-time traffic operation and safety monitoring and improvement on urban expressways

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ABSTRACT

The advent of Big Data era has transformed the outlook of numerous fields in science and engineering. The transportation arena also has great expectations of taking the advantage of Big Data enabled by the popularization of Intelligent Transportation Systems (ITS). In this study, the viability of a proactive real-time traffic monitoring strategy evaluating operation and safety simultaneously was explored. The objective is to improve the system performance of urban expressways by reducing congestion and crash risk. In particular, Microwave Vehicle Detection System (MVDS) deployed on an expressway network in Orlando was utilized to achieve the objectives. The system consisting of 275 detectors covers 75 miles of the expressway network, with average spacing less than 1 mile. Comprehensive traffic flow parameters per lane are continuously archived on one-minute interval basis. The scale of the network, dense deployment of detection system, richness of information and continuous collection turn MVDS as the ideal source of Big Data. It was found that congestion on urban expressways was highly localized and time-specific. As expected, the morning and evening peak hours were the most congested time periods. The results of congestion evaluation encouraged real-time safety analysis to unveil the effects of traffic dynamics on crash occurrence. Data mining (random forest) and Bayesian inference techniques were implemented in real-time crash prediction models. The identified effects, both indirect (peak hour, higher volume and lower speed upstream of crash locations) and direct (higher congestion index downstream to crash locations) congestion indicators confirmed the significant impact of congestion on rear-end crash likelihood. As a response, reliability analysis was introduced to determine the appropriate time to trigger safety warnings according to the congestion intensity. Findings of this paper demonstrate the importance to jointly monitor and improve traffic operation and safety. The Big Data generated by the ITS systems is worth further exploration to bring all their full potential for more proactive traffic management.

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1. Introduction

In an age of data explosion, almost every aspect of social activities is impacted by the abundance of information. The information, characterized by alarming volume, velocity and variety, is often referred to as "Big Data" (Beyer and Laney, 2012). As one fundamental elements of human life, transportation also confronts the promises and challenges brought about

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by the Big Data era. Big Data in transportation arena, enabled by the rapid popularization of Intelligent Transportation System (ITS) in the past few decades, is often collected continuously from different sources over vast geographic scale. Huge in size and rich in information, the seemingly disorganized data could considerably enhance experts' understanding of their system. In addition, proactive traffic management for better system performance is made possible due to the real-time nature of the Big Data in transportation.

Operation efficiency and traffic safety have long been deemed as priorities among highway system performance measurement. While efficiency could be evaluated in terms of traffic congestion, safety is studied through crash analysis. Extensive works have been conducted to identify contributing factors and remedies of traffic congestion and crashes respectively. These studies lead to gathering consensus that operation and safety have played as two sides of a coin, ameliorating either would have a positive effect on the other. With the advancement of Big Data, monitoring and improvement of both operation and safety proactively in real-time have become an urgent call.

This study focuses on Central Florida Expressway Authority (CFX)'s system in Central Florida area. The system of interest consists of three expressways that are located in the densely populated urban area. The toll expressways communicate downtown area, airport and other attraction areas in Orlando, serving both commuters and tourists. Multiple ITS systems are equipped on the system for electronic toll collection and traveler information. In 2013, the authority introduced Microwave Vehicle Detection System (MVDS) to monitor traffic conditions across different sections of the expressways. A total of 275 MVDS detectors are densely allocated along the 75-mile expressway network, with average spacing less than 1 mile. Comprehensive traffic flow parameters are archived on one-minute interval basis without interruption. As a result, the large geographic scale of deployment and continuous data collection provide a full view of network performance and serve as the source of Big Data. In this paper, real-time operation and safety analyses based on MVDS data are carried out in the hope to shed some light on the Big Data applications in real-time traffic operation and safety monitoring and improvement.

2. Background

Effective strategies to improve traffic operation and safety simultaneously require profound understanding about their features and relationship. In the age of information, these objectives could be efficiently realized through Big Data applications. Traffic congestion can be viewed as a product of the interaction between demand and capacity. Periodic high demand at specific bottlenecks during peak hours can result in recurrent congestion while incidents, especially crashes, reducing roadway capacity temporarily lead to non-recurrent congestion. To catch this dynamic process, Big Data generated from the ITS detection system could be leveraged to develop congestion measurement in real-time. In the meantime, crash occurrence is often regarded as random events affected by human behavior, roadway design, traffic flow and weather conditions. Big Data applications also introduce new perspectives in safety analysis. Thanks to the advantages brought by Big Data, researchers are able to restore the traffic condition for each crash case and draw general conclusions using individual crash data. As a result, Big Data applications in the current work will focus on developing congestion measurement and uncovering the relationship between safety and congestion, both in real-time.

2.1. Big Data in transportation arena

Big Data in the transportation arena comes not only from a single source but many. Currently, the most widely used data sources are traffic surveillance systems. According to Martin et al. (2003), the state-of-art detection technologies fall into three categories: in-roadway detectors, over-roadway detectors and off-roadway technologies. One of the most representative and widely used in-roadway detectors in real-time crash analysis is the inductive loop detector. The loop detectors have been implemented since the early stage of automatic traffic surveillance thus they are applications of a relatively mature technology. However, they have several drawbacks such as disruption of traffic for installation and repair, and high failure rates in certain conditions (Martin et al., 2003) such as poor road surface conditions and adverse weather. An over-roadway sensor is one that is mounted above the roadway itself or alongside the roadway, offset from the nearest traffic lane by some distance. Existing over-roadway sensors range from video image processors to more up-to-date microwave radar sensors. Compared with the in-roadway sensors, the over-roadway sensors have the significant advantage that they minimize the disruption of traffic during installation and maintenance. Probe vehicle is off-roadway detection technology that is developing fast. Compared with the other two types of sensors mentioned above, probe vehicles also require in-vehicle devices in addition to fixed infrastructure. Current probe vehicle technologies include Global Positioning System (GPS), cellular phones, Bluetooth, Ground-Based Radio Navigation, Automatic Vehicle Identification (AVI) and Automatic Vehicle Location (AVL) (Turner et al., 1998; Martin et al., 2003). With sufficient probe vehicles, they could also provide real-time traffic information at individual vehicle level. Nevertheless, since only part of the vehicles are equipped with in-vehicle devices, some traffic indicators might not be complete or accurate.

Other data sources such as demographic data, weather reporting system, geometric characteristics, and crash data are also extensively used in traffic operation, safety management and research. In recent decades with mobile devices, social media data also become a promising data source. To make the most of these data, efficient data integration and fusion have to be carried out. In real-time traffic safety analysis for example, according to crash locations and times, real-time traffic,

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