Transportation Research Part C 71 (2016) 406–418

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Real-time estimation of secondary crash likelihood on freeways using high-resolution loop detector data

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A R T I C L E I N F O

Article history:
Received 28 February 2016
Received in revised form 8 August 2016
Accepted 23 August 2016

Keywords:
Secondary crashes
Real-time
Traffic flow
Random effect logit model
Freeways

A B S T R A C T

This study aimed to develop a secondary crash risk prediction model on freeways using real-time traffic flow data. The crash and traffic data were collected on the I-880 freeway for five years in California, United States. The secondary crashes were identified by a method based on speed contour plot. The random effect logit model was used to link the probability of secondary crashes with the real-time traffic flow conditions, primary crash characteristics, environmental conditions, and geometric characteristics. The results showed that real-time traffic variables significantly affect the likelihood of secondary crashes. These traffic variables include the traffic volume, average speed, standard deviation of detector occupancy, and volume difference between adjacent lanes. In addition, the primary crash characteristics, environmental conditions and geometric characteristics also significantly affect the risks of secondary crashes. The model evaluation results showed that the predictive performance of the developed model was deemed satisfactory. The inclusion of traffic flow variables and random effect increases prediction accuracy by 16.6% and 7.7%, respectively. These results have the potential to be used in advanced traffic management systems to develop proactive traffic control strategies to prevent the occurrences of secondary crashes on freeways.

1. Introduction

Secondary crashes are the crashes that result from a prior crash. They usually occur within the spatial and temporal impact ranges of an existing primary crash. The occurrence of secondary crashes on freeways leads to increased risks of additional crashes, reduced freeway capacity, and increased travel time uncertainty. Previous studies suggested that the risks of secondary crashes can be reduced by improved incident management (Sun and Chilukuri, 2010; Zhan et al., 2009). To develop incident management strategies of preventing secondary crashes on freeways, increased attentions have been given to studying the contributing factors to secondary crashes.

A review of literature revealed that significant efforts have been conducted to identify secondary crashes in previous studies (Raub, 1997; Karlaftis et al., 1998; Moore et al., 2004; Hirunyanitiwattana and Mattingly, 2006; Zhan et al., 2008; Chilukuri and Sun, 2006; Sun and Chilukuri, 2010; Zhang and Khattak, 2010; Chou and Miller, 2010). The proposed approaches to identify secondary crashes in previous studies are briefly summarized in Table 1. In early studies, the static

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http://dx.doi.org/10.1016/j.trc.2016.08.015
0968-090X/

Table 1
Summary of secondary crash identification methods in previous studies.

Author	Year	Method
Raub	1997	Static thresholds of 1 mile and 15 min
Karlaftis et al.	1998	Static thresholds of 1 mile and 15 min
Moore et al.	2004	Static thresholds of 2 miles and 2 h
Hirunyanitiwattana and Mattingly	2006	Static thresholds of 2 miles and 1 h
Zhan et al.	2008	Static thresholds of 2 miles and 15 min
Chilukuri and Sun	2006	Incident progression curve
Sun and Chilukuri	2010	Incident progression curve
Zhan et al.	2009	Method based on cumulative arrival and departure plots
Zhang and Khattak	2010	Method based on queue length estimations
Khattak et al.	2011	Method based on queue length estimations
Chou and Miller-Hooks	2010	Simulation-based method
Imprialou et al.	2013	Method based on spatiotemporal impact area of primary crash
Yang et al.	2014a	Method based on spatiotemporal impact area of primary crash
Park and Haghani	2015	Method based on spatiotemporal impact area of primary crash
Sarker et al.	2015	Method based on spatiotemporal impact area of primary crash
Mishra et al.	2016	Method based on spatiotemporal impact area of primary crash
Wang et al.	2016	Method based on spatiotemporal impact area of primary crash

threshold methods were used to identify secondary crashes based on some fixed spatial and temporal criteria. These studies assumed that secondary crashes should occur within a maximum spatial and temporal impact range of a primary incident. For example, Karlaftis et al. (1998) used static spatial and temporal thresholds of 1 mile and 15 min to identify secondary crashes. Any crash occurring within 1 mile upstream of and less than 15 min after a prior crash is defined as a secondary crash. Hirunyanitiwattana and Mattingly (2006) proposed the static thresholds of 1 h and 2 miles upstream of a primary incident for identifying secondary crashes. Other studies conducted by Raub (1997), Moore et al. (2004), and Zhan et al. (2008) used the similar static thresholds. One limitation associated with the static method is that they need a subjective determination of fixed spatial and temporal thresholds. As a result, the static method may not have adequate accuracy in identifying second crashes (Chilukuri and Sun, 2006; Sun and Chilukuri, 2010; Zhang and Khattak, 2010; Chou and Miller, 2010).

To overcome the limitation associated with the static threshold methods, a number of studies proposed various dynamic methods to identify secondary crashes. These dynamic methods include the incident progression curve (Chilukuri and Sun, 2006; Sun and Chilukuri, 2010), queue length estimations (Zhang and Khattak, 2010), cumulative arrival and departure plots (Zhan et al., 2009), and simulation-based method considering shockwave (Chou and Miller, 2010). Sun and Chilukuri (2010) developed incident progression curves to estimate the end of the varying queue throughout the entire incident. The results showed that the method based on incident progression curves can improve the secondary crash identification accuracy by 30%, compared with the static method. In a study conducted by Zhang and Khattak (2010), a dynamic spatial threshold method based on queue length estimations was developed to identify secondary incident. Zhan et al. (2009) proposed a method for detecting secondary crashes based on cumulative arrival and departure plots. In this method, the cumulative arrival and departure plots were used to estimate the maximum queue length and the recovery time of associated queue for incidents with lane blockages.

Recently, a number of studies detected secondary crashes by identifying the spatiotemporal impact area of primary crashes (Imprialou et al., 2013; Yang et al., 2014a; Park and Haghani, 2015;; Sarker et al., 2015; Mishra et al., 2016; Wang et al., 2016a, 2016b). Yang et al. (2014a) used the speed contour plot to identify secondary crashes on freeways. The results showed that 50% of secondary crashes occurred within 70 min after and 2 miles upstream of the primary crashes. Imprialou et al. (2013) used the Automatic Tracking of Moving Jams method to detect secondary crashes by defining the actual boundaries of the spatiotemporal influence area of primary crashes. The results showed that the proposed method provides better accuracy in detecting secondary crashes than conventional static threshold methods. Park and Haghani (2015) developed a Bayesian structure equation model to identify spatiotemporal impact area by using the vehicle probe data. Sarker et al. (2015) proposed a method to detect secondary crashes based on spatiotemporal impact area analysis and shockwave principles. The validations results showed that the proposed method can achieve a good detection accuracy ranging from 72% to 91%.

In addition to secondary crash identifications, some studies have also been conducted to explore the characteristics of secondary crashes (Hirunyanitiwattana and Mattingly, 2006; Yang et al., 2014a; Khattak et al., 2009; Karlaftis et al., 1998, 1999; Carrick et al., 2015; Xie et al., 2016; Mishra et al., 2016; Jalayer et al., 2015; Zhang et al., 2015; Wang et al., 2016a, 2016b). Hirunyanitiwattana and Mattingly (2006) used the proportional tests to compare the characteristics of secondary crashes and primary crashes on freeways with respect to time of day, roadway classification, severity level and type of accident. The results showed that secondary crashes are more likely to be property-damage-only (PDO) rear-end crashes occurring during peak hours. Yang et al. (2014a) conducted a thorough examination of the spatio-temporal distributions, clearance time, crash type and severity of secondary crashes. The results showed that most secondary crashes occurred within two hours and two miles upstream of primary crashes. They also found that secondary crashes are likely to involve two or more vehicles and to be rear-end crashes. Carrick et al. (2015) compared the roadway, environmental, and vehicle