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Surrogate safety measure for evaluating rear-end collision risk related to kinematic waves near freeway recurrent bottlenecks

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ABSTRACT

This study presents a surrogate safety measure for evaluating the rear-end collision risk related to kinematic waves near freeway recurrent bottlenecks using aggregated traffic data from ordinary loop detectors. The attributes of kinematic waves that accompany rear-end collisions and the traffic conditions at detector stations spanning the collision locations were examined to develop the rear-end collision risk index (RCRI). Together with RCRI, standard deviations in occupancy were used to develop a logistic regression model for estimating rear-end collision likelihood near freeway recurrent bottlenecks in real-time. The parameters in the logistic regression models were calibrated using collision data gathered from the 6-mile study site between 2006 and 2007. Findings indicated that an additional unit increase in RCRI results in increasing the odds of rear-end collision by 21.1%, a unit increase in standard deviation of upstream occupancy increases the odds by 19.5%, and a unit increase in standard deviation of downstream occupancy increases the odds by 18.7%. The likelihood of rear-end collisions is highest when the traffic approaching from upstream is near capacity state while downstream traffic is highly congested. The paper also reports on the findings from comparing the predicted number of rear-end collisions at the study site using the proposed model with the observed traffic collision data from 2008. The proposed model's true positive rates were higher than those of existing real-time crash prediction models.

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1. Introduction

Backward moving kinematic waves emanating from freeway bottlenecks force approaching vehicles to abruptly change their traveling speeds. When approaching vehicles do not adjust their speeds in a timely manner, the spacing between vehicles can decrease rapidly and potentially cause rear-end traffic collisions. The objective of this paper is to develop a surrogate safety measure to quantify the likelihood of rear-end collisions in the vicinity of recurrent bottleneck areas by monitoring the changes in traffic conditions induced by backward moving kinematic waves using aggregated traffic data from ordinary loop detectors.

Previous studies have proposed statistical models as the surrogate safety measure to evaluate traffic collision risk using aggregated traffic data obtained from loop detectors on freeways (Lee et al., 2002, 2003; Golob and Recker, 2003; Golob et al., 2004; Abdel-Aty et al., 2004, 2005; Abdel-Aty and Pande, 2005; Pande and Abdel-Aty, 2006; Kockelman and Ma, 2007; Zheng et al., 2010; Hassan and Abdel-Aty, 2011; Hossain and Muromachi, 2011; Abdel-Aty et al., 2012; Xu et al., 2012). For example, Abdel-Aty et al. (2004) developed a logistic regression model to predict the occurrence of traffic collisions using real-time traffic data from a section of freeway. The study reported that the 5-min average occupancy observed at an upstream detector station and the coefficient of variation of speed at a downstream location 5–10 min prior to collisions significantly affect the collision occurrence. Findings from a more recent study by Zheng et al. (2010) indicated that the standard deviation of speed in a 10-min interval could be considered a surrogate safety measure for collisions under congested traffic conditions. These studies estimated collision risk based on statistical data mining approach and did not evaluate how the propagation of kinematic waves affects rear-end type collision risk.

To develop the surrogate safety measure for rear-end collisions, several researchers used different types of hazardous traffic conditions (i.e., situations in which a driver must take evasive action to avoid traffic collision), including time-to-collision (Saccomanno

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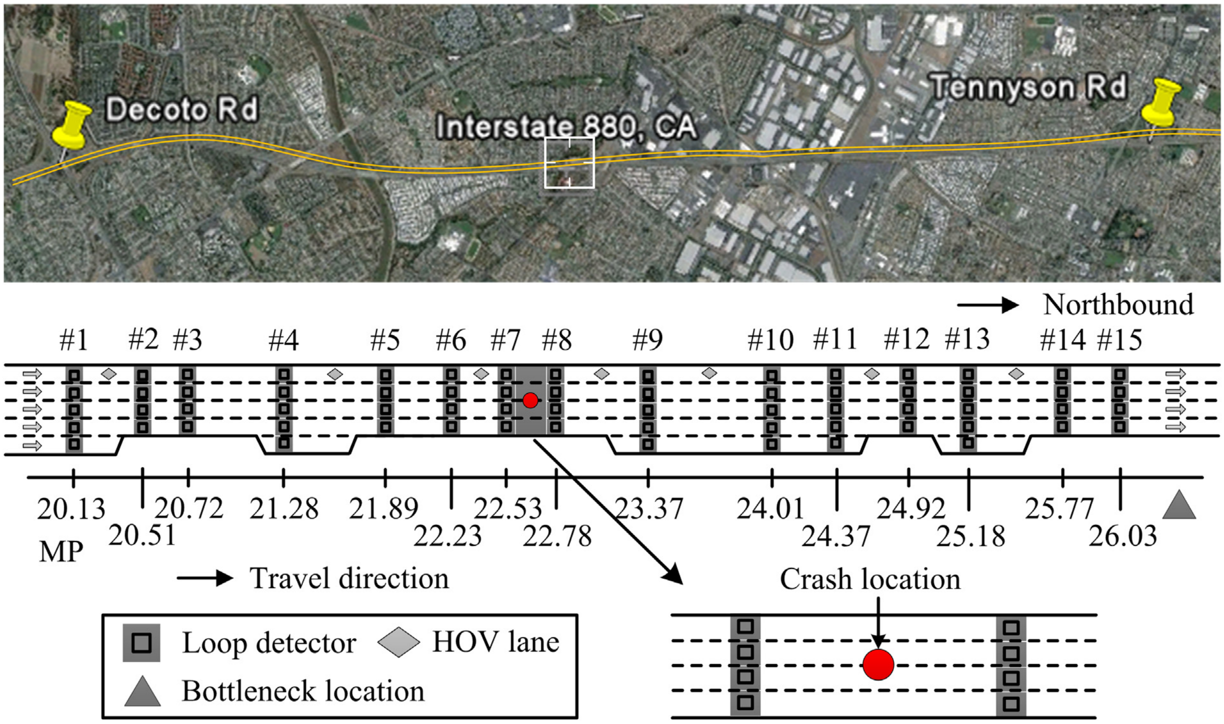

Fig. 1. Schematic of the study site, northbound Interstate 880, Oakland, CA.

et al., 2008; Oh and Kim, 2010), stopping distance index (Oh et al., 2006, 2009), modified time to collision (Ozbay et al., 2008), and individual vehicle speeds and headways (Hourdos et al., 2006). These earlier studies demonstrated that hazardous traffic conditions could be used as a surrogate safety measure. However, these measures are not suitable for monitoring collision risk when only the information from conventional loop detectors is available – monitoring the hazardous conditions specified in the studies mentioned above requires extracting information from individual vehicle trajectories. Additionally, these studies did not consider the collision risk associated with kinematic waves and proximity to recurrent bottleneck areas on freeways.

Several recent studies analyzed the collision risks among different traffic states and evaluated the safety impacts of kinematic waves at freeway bottleneck areas. Yeo et al. (2010) evaluated the relative risk of traffic collisions after dividing freeway traffic into four traffic states. Their findings indicated that collisions are about 3.6 times more likely to occur at the back of the queue compared with the free-flowing traffic state; findings from a later study by Xu et al. (2012) further confirmed Yeo's study. Chung et al. (2011) examined the attributes of moving kinematic waves that preceded traffic collisions in the vicinity of a recurrent bottleneck. The findings suggested that sudden and pronounced changes in speed induced by fast backward moving kinematic waves increase the likelihood of traffic collisions, and that the propagation of kinematic waves has a large impact on the probability of such collisions. Li et al. (2013) examined the impacts of downstream queues on the occurrence of traffic collisions. Their study suggested that the likelihood of a collision increases as both the spatial and the temporal proximities to the tail of an expanding or receding queue become smaller.

These previous studies mentioned in the preceding paragraph examined the attributes of kinematic waves that accompanied traffic collisions near freeway recurrent bottlenecks. However, these studies did not attempt to develop a model to quantify risk of rear-end collision during the propagation of kinematic waves in real-time which could be important in developing dynamic traffic control measures for reducing collision risks near freeway bottlenecks. The findings from these studies shed light on developing a surrogate safety measure for rear-end collisions upstream of recurrent bottleneck as proposed in the present study.

The description of the site used in the present study is provided in Section 2, while Section 3 discusses the logic behind developing the proposed surrogate safety measure. Section 4 explains the design of case-control used to estimate the parameters of the proposed surrogate safety measure. Section 5 reports on evaluation of the performance of the proposed measure using empirical data. This paper ends with brief concluding remarks and topics for future research in Section 6.

2. Study site

Fig. 1 shows a 6-mile (10-km) northbound section of the Interstate 880 freeway in Oakland, California, selected as the study site. The 6-mile section is comprised of segments that are 4- to 5-lanes wide, with the median lane of the section reserved for high-occupancy vehicles (carpools and buses) during peak hours. The freeway section is plagued by a recurrent bottleneck at its downstream end (represented in the figure as a gray triangle located downstream of detector station 15). Backward moving kinematic waves frequently emanate from near the bottleneck while it remains active.

The freeway section is equipped with inductive loop detectors installed in all travel lanes. The approximate locations of the 15 detector stations in the study section are shown in Fig. 1. When a collision (represented by the red dot in Fig. 1) occurs between two neighboring detectors (represented by the gray shaded region between stations 7 and 8), data observed from the immediate upstream and downstream detectors are used to develop the surrogate safety measure. The spacing between detector stations ranges from 0.25 to 0.64 mile (0.42–1.02 km) with an average of 0.43 mile (0.69 km). Each detector station reports average flow, occupancy (i.e., dimensionless measure of density), and speed observed during 30-s period ($\Delta t = 30$ s).