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Approach-level real-time crash risk analysis for signalized intersections

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A R T I C L E I N F O

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A B S T R A C T

Intersections are among the most dangerous roadway facilities due to the complex traffic conflicting movements and frequent stop-and-go traffic. However, previous intersection safety analyses were conducted based on static and highly aggregated data (e.g., annual average daily traffic (AADT), annual crash frequency). These aggregated data may result in unreliable findings simply because they are averages and cannot represent the real conditions at the time of crash occurrence. This study attempts to investigate the relationship between crash occurrence at signalized intersections and real-time traffic, signal timing, and weather characteristics based on 23 signalized intersections in Central Florida. The intersection and intersection-related crashes were collected and then divided into two types, i.e., within intersection crashes and intersection entrance crashes. Bayesian conditional logistic models were developed for these two kinds of crashes, respectively. For the within intersection models, the model results showed that the through volume from "A" approach (the traveling approach of at-fault vehicle), the left turn volume from "B" approach (near-side crossing approach), and the overall average flow ratio (OAFR) from "D" approach (far-side crossing approach), were found to have significant positive effects on the odds of crash occurrence. Moreover, the increased adaptability for the left turn signal timing of "B" approach and more priority for "A" approach could significantly decrease the odds of crash occurrence. For the intersection entrance models, average speed was found to have significant negative effect on the odds of crash occurrence. The longer average green time and longer average waiting time for the left turn phase, higher green ratio for the through phase, and higher adaptability for the through phase can significantly improve the safety performance of intersection entrance area. In addition, the average queue length on the through lanes was found to have positive effect on the odds of crash occurrence. These results are important in real-time safety applications at signalized intersections in the context of proactive traffic management.

1. Introduction

Intersections are among the most dangerous roadway facilities due to the complex traffic conflicting movements and frequent stop-and-go traffic. Take Florida as an example, nearly 26% of crashes happen at or influenced by intersections (including signalized and non-signalized) in 2014. Moreover, signalized intersections are generally large intersections with higher traffic volume, therefore, the safety status of signalized intersection would be even more complicated. Safety analysis for signalized intersection has been a critical research topic during past decades. Substantial efforts have been made by previous researchers to reveal the relationship between crash frequency of signalized intersections and all the possible contributing factors such as roadway geometric, signal control, and traffic characteristics, etc. (Chin and Quddus, 2003; Abdel-Aty and Wang, 2006; Wang et al., 2006, 2009; Guo et al., 2010; Lee et al., 2017; Wang and Yuan, 2017; Cai et al., 2018a, b; Wang et al., 2018).

More specifically, nearly all the traffic volume related variables were found to have significant positive effects on the crash frequency at signalized intersections, including total entering ADT (Poch and Mannering, 1996; Chin and Quddus, 2003; Abdel-Aty and Wang, 2006; Guo et al., 2010), right-turn ADT (Poch and Mannering, 1996; Chin and Quddus, 2003), left-turn ADT (Poch and Mannering, 1996), total ADT on major road (Wang et al., 2009; Dong et al., 2014), total ADT on minor road (Wang et al., 2009; Dong et al., 2014), left-turn ADT on major road (Guo et al., 2010), through ADT on minor road (Guo et al., 2010). However, Guo et al. (2010) found that the through ADT on major road and the left-turn ADT on minor road are significantly negatively associated with the crash frequency at signalized intersections. Moreover, Wang et al. (2009) investigated the relationship between LOS and safety at signalized intersections. They found that LOS D is a desirable level which is associated with less total crashes, rear-end and sideswipe crashes, as well as right-angle and left-turn crashes. Xie et al. (2013) investigated the safety effect of corridor-level travel speed, they

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found that the high speed corridor may results in more crashes at the signalized intersections. Similarly, the speed limit of the corridor was found to be significantly positively correlated with the crash frequency of the signalized intersections (Poch and Mannering, 1996; Abdel-Aty and Wang, 2006; Wang et al., 2009; Guo et al., 2010; Dong et al., 2014).

With respect to the geometric design, number of lanes, median width, and intersection sight distance et al. were found to have significant effects on the crash frequency of signalized intersections. More specifically, the number of lanes was found to be positively correlated with the crash frequency of signalized intersections (Poch and Mannering, 1996; Abdel-Aty and Wang, 2006; Guo et al., 2010; Dong et al., 2014). Median width and intersection sight distance was also found to have positive effect on the crash frequency(Chin and Quddus, 2003). Moreover, Abdel-Aty and Wang (2006) found that the existence of exclusive right-turn lanes could significantly decrease the crash frequency.

In terms of signal control characteristics, the adaptive signal control was found to have significant lower crash frequency than the pre-timed signal control (Chin and Quddus, 2003). The number of phase was found to be positively associated with the crash frequency of signalized intersections (Poch and Mannering, 1996; Chin and Quddus, 2003; Xie et al., 2013). The left-turn protection could significantly improve the safety performance of the signalized interaction (Poch and Mannering, 1996; Chin and Quddus, 2003; Abdel-Aty and Wang, 2006). However, Abdel-Aty and Wang (2006) found that the left-turn protection on minor roadway tends to increase the crash frequency of signalized intersection. Surprisingly, Guo et al. (2010) found that the coordinated intersections are more unsafe than the isolated ones. They explained it as the travel speed is higher for coordinated intersections because of the green wave, which may results in more crashes.

However, these studies were conducted based on static and highly aggregated data (e.g., Annual Average Daily Traffic (AADT), annual crash frequency). These aggregated data limit the reliability of the findings simply because they are averages and cannot reflect the real conditions at the time of crash occurrence. With the rapid development of traffic surveillance system and detection technologies, real-time traffic data are not only available on freeways and expressways but also on urban arterials (including road segments and intersections). During the past decade, an increasing number of studies have investigated the crash likelihood on freeways by using real-time traffic and weather data (Oh et al., 2001; Lee et al., 2003; Abdel-Aty et al., 2004; Zheng et al., 2010; Abdel-Aty et al., 2012; Ahmed et al., 2012a; Xu et al., 2013a, b; Yu and Abdel-Aty, 2014; Yu et al., 2014; Basso et al., 2018; Theofilatos et al., 2018). It is worth noting that Theofilatos et al. (2018) investigated crash occurrence by utilizing real-time traffic data while considering that the number of crashes is very few, and they could be considered as rare events. In this context, they compared the model results of different crash to non-crash ratio (1:10 and full sample of non-crash events) by using two different statistical models (bias correction and firth model), respectively. It was found that the two methods have different advantages and disadvantages, and the choice of the most appropriate method depends on several criteria. Also, Basso et al. (2018) developed real-time crash prediction model for urban expressway based on the original unbalanced data, rather than artificially balanced data by using Synthetic Minority Over-sampling Technique (SMOTE). They claimed that their model performance are among the best in the literature.

However, little research has been conducted on the real-time safety of urban arterials (Theofilatos, 2017; Theofilatos et al., 2017; Yuan et al., 2018), especially signalized intersections (Mussone et al., 2017). Mussone et al. (2017) examined the factors which may affect the crash severity level at intersection based on real-time traffic flow and environmental characteristics, and they found that the real-time traffic flow characteristics have a relevant role in predicting crash severity. However, they didn't consider the crash likelihood at intersections, which means that the effects of real-time traffic flow and environmental characteristics on the crash likelihood at intersections are still unclear.

Moreover, the conflicting traffic movements at signalized intersection are temporally separated by traffic signals. Therefore, signal timing plays a very important role in the intersection safety, especially when the adaptive signal control technology was widely adopted on major urban arterials. Adaptive signal control technology optimize signal timing plans in real-time, it was found to have significant effects in reducing stops and delays (Khattak et al. 2018a) and improving traffic safety (Chin and Quddus, 2003; Khattak et al., 2018b). However, the safety effect of real-time signal status has never been considered, while improper signal timing may result in dangerous situation. Therefore, the relationship between real-time signal timing and intersection safety need to be further investigated.

On the other hand, with the rapid development of connected vehicle technologies in recent years, it is feasible for us to implement efficient proactive traffic management strategies at intersections, e.g., dynamic message sign (DMS) to show the real-time crash risk for the downstream intersections, and vehicle-level optimal speed advisory through vehicle-to-infrastructure (V2I) communication (Yue et al., 2018). In this context, an efficient and reliable real-time crash risk predictive algorithm for intersections is required. However, traditional intersection safety analysis were usually conducted by modeling historical crash frequency with geometric, AADT, and static signal control characteristics, which ignore the impacts of real-time traffic environment (e.g., traffic and weather) when crashes occur.

To the best of the authors' knowledge, there have been no studies done on the real-time crash risk at signalized intersections. To bridge this gap, this study aims to investigate the relationship between crash likelihood at signalized intersections and real-time traffic, signal timing, and weather characteristics by utilizing data from multiple sources, i.e., Bluetooth, weather, and adaptive signal control datasets.

2. Data preparation

There are 23 intersections chosen from four urban arterials in Orlando, Florida, as shown in Fig. 1. A total of four datasets were used: (1) crash data from March 2017 to March 2018 provided by Signal Four Analytics (S4A); (2) travel speed data collected by 23 IterisVelocity Bluetooth detectors installed at 23 intersections; (3) signal phasing and 15 min interval traffic volume provided by 23 adaptive signal controllers; (4) weather characteristics collected by the nearest airport weather station.

S4A provides detailed crash information, including crash time, coordinates, severity, type, weather condition, etc. In terms of the crash time information, there are three kinds of time information for each crash, i.e. time of crash occurrence, time reported, and time dispatched. Only the time of crash occurrence was utilized in this study, and the difference between this recorded crash time and the actual crash time is supposed to be within 5 min since there exist several efficient and accurate technologies for the police officer to identify the accurate time of crash occurrence, e.g. closed-circuit television cameras and mobile phones.

First, all crashes occurred at intersection or influenced by intersection (within 250 feet of intersection) from March 2017 to March 2018 were collected. Second, all the single-vehicle crashes and the crashes under the influence of alcohol and drugs were excluded, since these kinds of crashes are usually not attributed to the real-time traffic and signal characteristics which are the focus of this study. After that, a total of 803 crashes remained and these crashes were divided into three types based on their location, which are within intersection area, intersection entrance area, and intersection exit area, as shown in Fig. 2. There are 446 (55.54%) crashes that had occurred within intersection, 264 (32.88%) crashes that had occurred in the intersection entrance area, and 93 (11.58%) crashes that had occurred in the intersection exit area. In terms of the sample size, only within intersection crashes and intersection entrance crashes were utilized in this study.