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Traffic conflict models to evaluate the safety of signalized intersections at the cycle level

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ABSTRACT

The safety of signalized intersections has often been evaluated at an aggregate level relating collisions to annual traffic volume and the geometric characteristics of the intersection. However, for many safety issues, it is essential to understand how changes in traffic parameters and signal control affect safety at the signal cycle level. This paper develops conflict-based safety performance functions (SPFs) for signalized intersections at the signal cycle level. Traffic video-data was recorded for six signalized intersections located in two cities in Canada. A video analysis procedure is proposed to collect rear-end conflicts and various traffic variables at each signal cycle from the recorded videos. The traffic variables include: traffic volume, maximum queue length, shock wave characteristics (e.g. shock wave speed and shock wave area), and the platoon ratio. The SPFs are developed using the generalized linear models (GLM) approach. The results show that all models have good fit and almost all the explanatory variables are statistically significant leading to better prediction of conflict occurrence beyond what can be expected from the traffic volume only. Furthermore, space-time conflict heat maps are developed to investigate the distribution of the traffic conflicts. The heat maps illustrate graphically the association between rear-end conflicts and various traffic parameters. The developed models can give insight about how changes in the signal cycle design affect the safety of signalized intersections. The overall goal is to use the developed models for the real-time optimization of signalized intersection safety by changing the signal design.

1. Introduction

The safety of signalized intersections has often been evaluated at an aggregate level relating historical collision records to annual traffic volume and the geometric characteristics of the intersection. The collision-based safety evaluation is very useful in several applications such as identifying and ranking hazardous locations, and conducting before-and-after safety studies. However, collisions at signalized intersections can occur for several reasons including drivers' behavior in dilemma zones, approach queues and shock waves (Papaioannou, 2007; Machiani and Abbas, 2016). For intersection safety solutions that target these collisions, it is essential to understand how changes in traffic parameters and signal control affect safety at the signal cycle level. Unfortunately, modeling the safety of signalized intersections using collisions at the cycle level can be difficult for several reasons:

(1) The use of the historical collision data in safety analysis requires collisions to occur and be recorded over an adequately long period (e.g. years) in order to conduct a statistically sound safety diagnosis (Sayed and Zein, 1999; Chin and Quek, 1997).

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(2) The use of several years of collisions requires reliance on aggregate exposure measures such as the annual daily traffic (AADT) which does not explicitly account for the fact that not all vehicles are interacting unsafely (El-Basyouny and Sayed, 2013) and does not represent the variation of traffic flow between cycles.
(3) Collecting data on important traffic parameters such as delay, queue length, and traffic volume at each cycle is difficult and requires special sensing needs.
(4) Important cycle-related variables that can affect intersection safety such as the arrival type and the shock wave characteristics are difficult to collect and need special advanced algorithms.

This paper develops safety performance functions (SPFs) for signalized intersections at the signal cycle level. The models relate the rear-end conflicts occurring in each cycle to variables such as traffic volume, maximum queue length, shock wave characteristics (e.g. shock wave speed and shock wave area), and the platoon ratio. The developed models can give insight about how changes in the signal cycle design affect the safety of signalized intersections. The overall goal is to use the developed models for the real-time optimization of signalized intersection safety by changing the signal design. The approach presented in this paper provides several advantages as follows:

- The use of real traffic data, obtained by video recordings at six different intersections, which reflects actual driving behavior (i.e. the results are not based on microsimulation models).
- Proposing a video analysis procedure to collect data at the cycle level.
- The use of traffic conflicts as a measure of safety. Conflicts are extracted automatically and quantified using a conflict indicator (e.g. Time to collision). Also, the actual conflict location is determined.
- The proposed approach allows for the extraction of various traffic parameters including: the traffic volume, the maximum queue length, the shock wave characteristics, and the platoon ratio.
- The traffic conflict data and the various traffic parameters are measured directly from the video data and evaluated at a cycle level. As such, no hourly aggregation is needed.

2. Previous work

Safety performance functions (SPFs) of signalized intersections have been widely developed, investigated and calibrated in the literature. The highway safety manual (HSM) (AASHTO, 2010) provides SPFs that estimate the average crash frequency for signalized intersections on different road classes including rural two-lane roads, rural multi-lane roads, urban and suburban arterials. Also, several studies locally developed, adopted and calibrated SPFs for signalized intersections to local conditions of specific zones (Poch and Mannering, 1996; Miaou and Lord, 2003; Lyon et al., 2005; Wang et al., 2006; Wong et al., 2007; Wang and Abdel-Aty, 2008; Guo et al., 2010; Persaud et al., 2012; Abdel-Aty et al., 2014; Lee et al., 2017). The traffic exposure measure used in most of these studies is an aggregation of the traffic volume (e.g. AADT) and the predicted number of collisions is aggregated to several years.

There are several shortcomings with the reliance on crash data in safety analysis. A large number of crashes is needed to obtain statistical reliability which often requires a period of several years (Sayed and Zein, 1999; Ismail et al., 2010; Chin and Quek, 1997). As well, there are well-recognized availability and quality problems associated with crash data. The use of traffic conflicts for safety analysis is gaining acceptance as a proactive approach to study road safety from a broader perspective than relying only on collision data analysis (Sayed and Zein, 1999; Songchitruksa and Tarko, 2006). Traffic conflicts occur more frequently, can be clearly observed, and can provide insight into the failure mechanism that leads to collisions. Many researchers have shown that reducing traffic conflicts can lead to reducing the frequency of road collisions (Sacchi et al., 2013) as they further argued that the same failure mechanism in the driving process leads to the occurrence of both traffic conflicts and road collisions (Ismail et al., 2011). Therefore, the use of traffic conflicts for safety diagnosis has been recently gaining acceptance among road safety researchers as a surrogate or a complementary approach to the collision data analysis approach. A traffic conflict is defined as "*an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remained unchanged*" (Amundsen and Hydén, 1977). Recently, with the advances in computer vision techniques, the automated extraction of traffic conflicts from video recordings was demonstrated in several studies (Autey et al., 2012; Saunier and Sayed, 2008; Laureshyn et al., 2009; among others). The automated conflicts analysis approach overcomes many shortcomings in manual data collection and provides a more practical and efficient way to capture traffic conflicts. Previous studies have shown that SPFs for signalized intersections can be developed on the basis of field-observed traffic conflicts (Sayed and Zein, 1999; El-Basyouny and Sayed, 2013; Zhang et al., 2014; Sacchi and Sayed, 2016a, 2016b). In these studies, the exposure measure in the SPFs is represented by the average hourly traffic volume, and the traffic conflicts are aggregated to hours (i.e. number of conflicts/hour).

Conducting conflict-based safety evaluations using microsimulation models has also been proposed recently (Gettman et al., 2003). Microsimulation models have been widely calibrated and validated to evaluate the safety of signalized intersections using simulated traffic conflicts estimated by the SSAM tool (e.g. Gettman et al., 2008; Cunto and Saccomanno, 2008; Dijkstra et al., 2010; Huang et al., 2013; Shahdah et al., 2014; Essa and Sayed, in press, 2015, 2016). In most of these studies, the simulated results are usually aggregated into larger time periods such as hours. Other studies considered signalized intersection safety issues that related to dilemma zone (Papaioannou, 2007; Machiani and Abbas, 2016), or related to red-light running violations (Elmitiny et al., 2010; Jahangiri et al., 2016).

Although there are several studies developing SPFs for signalized intersections, to the best of the authors' knowledge, no studies have attempted to develop SPFs at the cycle level. This study aims to fill this research gap by relating the number of traffic conflicts