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Application of traffic microsimulation for evaluating safety performance of urban signalized intersections

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ABSTRACT

The primary objective of this paper is to provide a statistical relationship between traffic conflicts estimated from microsimulation and observed crashes in order to evaluate safety performance, in particular the effect of countermeasures. A secondary objective is to assess the effect of conflict risk tolerance and number of simulation runs on the estimates of countermeasure effects so obtained. Conflicts were simulated for a sample of signalized intersections from Toronto, Canada, using VISSIM microscopic traffic simulation and several crash–conflict relationships were obtained. A separate sample of treated intersections from Toronto was used to compare countermeasure effects from the integrated crash–conflict expression to a conventional, but rigorous crash-based Empirical Bayes before-and-after analysis that was already done, with the results published, for the same sites and treatment. The countermeasure considered for this investigation involved changing the left turn signal operation for the treated intersection sample from permissive to protected-permissive. The results support the view that countermeasure effects can be estimated reliably from conflicts derived from microsimulation, and more so when a suitable number of simulation runs and conflict tolerance thresholds are used in the crash–conflict relationship.

1. Introduction

The application of observational models based on reported crash history is the most common approach used to assess safety performance and to determine the effectiveness of road safety interventions or countermeasures. Recently, microscopic traffic simulation has been used to estimate surrogate measures of safety performance based on high-risk vehicle interactions (or conflicts) for different road and traffic conditions. Proponents of traffic conflict simulation argue that by taking into account these conflicts a better understanding is gained of potential safety problems than is possible from conventional crash prediction models. They provide inferences not only on where crashes are likely to occur, but also why they are occurring at these sites and how specific countermeasures act to reduce these crashes.

In crash prediction models, crashes are viewed as objective and verifiable failures in the transportation system, thereby providing an objective basis for assessing lack of safety. However, not all transportation system failures result in crashes. Reliance on reported crashes poses a number of problems for these types of observational prediction models, such as low

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reporting rates for less severe crashes, and unreported near-misses (Nicholson, 1985; Farmer, 2003; Davis, 2004; Saunier and Sayed, 2007). For example, Hauer and Hakkert (1989) reported that 50% of cashes with injuries and 60% of property-damage-only crashes were not reported in police data. These low severity crashes and near-misses may contain essential information concerning lack of safety that is important for effective safety intervention.

It seems reasonable that the use of conflicts can help to resolve sample size issues that can plague before-and-after treatment evaluation based on observed crashes. This approach has been used traditionally to estimate countermeasure effects or, more specifically, crash modification factors (CMFs). Empirical Bayes (EB) before-and-after methodology is now widely used for the estimation of CMFs because it can address regression-to-the-mean (RTM) problems, as well as account for other changes in safety not related to the treatment (Hauer, 1997). However, the EB method requires a large sample of untreated reference sites from which to develop Safety Performance Functions (SPFs), and this can be both costly and impractical (Lan, 2010). Furthermore, in conducting EB before-and-after evaluations, countermeasure effects can only be estimated after implementing treatment, and then only if sufficient site-years of treatment data are available to ensure statistically meaningful results. Crash-based prediction models are subject to lack of specification in the crash data, and this can severely restrict their ability to explain how treatments act to reduce crashes at a given site. They function essentially as a kind of "treatment effect black box", and it seems reasonable to suggest that more behavioral approaches are needed for estimating meaningful CMFs for safety intervention.

Recently, researchers have used surrogate measures of safety performance based on predicted high-risk vehicle interactions. When these interactions exceed established risk tolerance thresholds, they are referred to as traffic conflicts. Safety studies using traffic conflicts were initially proposed by Perkins and Harris (1967) and researchers from the General Motors Laboratory. Traffic conflict analysis provides an alternative approach to observational crash-based studies, where crash data are limited or where there is a need to assess the potential safety effects of a treatment prior to their implementation.

Amundsen and Hyden (1977) defined traffic conflicts as "observable situations in which two or more road users or vehicles approach each other in space and time to such an extent that there is a risk of collision if their movement remains unchanged". The use of traffic conflicts in safety studies is based on the premise that conflicts occur more frequently than crashes, although the mechanism leading to both types of events can be quite comparable. As a consequence, conflicts can address some of the statistical issues linked to the rare random nature of crashes, especially those crashes with low severity that tend to be under-reported. Additionally, they consider the transportation failure mechanism from a somewhat broader "more mechanistic" perspective than can be inferred from observational crash data alone (Brown, 1994; Sayed et al., 1994; Van der Horst, 1990).

Traffic conflicts or higher vehicle interactions can be estimated either by monitoring the traffic stream with a view to extracting vehicle paths over time or, more practically, by simulation of specific traffic input scenarios. Gettman and Head (2003a) discuss how microscopic traffic microsimulation platforms, such as VISSIM (PTV, 2012) and AIMSUN (TSS, 2013), can be used to estimate safety performance based for individual vehicle tracks. Microsimulation also provides a way to investigate different traffic scenarios, when vehicle tracking data are not available for a given site.

However, the traffic conflict approach has been criticized for lacking a formal link to observational crashes, which are normally viewed as being the only "verifiable" measure of transportation system failure from a safety perspective. Establishing a link to observed crashes can address this criticism and provide an observational basis for using simulated traffic conflicts to identify sites with safety problems and evaluate countermeasures, especially if it can be determined that these result in differences in conflicts but not in the relationship between crashes and conflicts. The need to provide a link between simulated conflicts and crashes provides the motivation for the research discussed in this paper.

This research has three basic objectives: (1) provide a statistical link between simulated traffic conflicts and observed crashes so as to evaluate the safety implications of specific treatments, (2) compare the resultant countermeasure effects to those obtained from a conventional Empirical Bayesian (EB) before and after analysis for the same sites and treatment, and (3) assess the effect on model results of key microsimulation inputs and assumptions, such as conflict tolerance thresholds and number of simulation runs. The paper builds on recent research by Sachi et al. (2013) who used conflict-based analysis to evaluate a right turn treatment at signalized intersections and El-Basyouny and Sayed (2013) who investigated the relationship between crashes and conflicts and came to a conclusion that traffic conflicts could provide useful insights into the failure mechanism that leads to crashes.

A crash–conflict relationship is calibrated for a sample of untreated signalized intersections from Toronto. A separate sample of treated intersections from Toronto was used to compare countermeasure CMF estimates from the integrated crash–conflict approach to CMFs from a published crash-based EB before-and-after study that used the same sample. The countermeasure considered for this comparison involved changing the left turn signal operation for the treated intersection sample from permissive to protected-permissive. Traffic conflicts for left turn opposing (LTOPP) movements were simulated using VISSIM 5.40 (PTV, 2012). The inputs into the simulation were the observed intersection peak hour approach volumes and turning movements (through, left-turn and right-turn), as reported in the database.

2. Microsimulation of traffic conflicts

A sample of 53 signalized untreated intersections from the Toronto database was used to investigate the statistical relationship between crashes and simulated traffic conflicts, and between crashes and intersection approach volumes.