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Before-after safety analysis using extreme value theory: A case of left-turn bay extension

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ABSTRACT

There is growing interest in the use of traffic conflicts in before and after safety evaluations because of well-recognized quality and quantity problems associated with historical crash records. Most of these studies apply statistical techniques to compare the number of conflicts before and after the implementation of safety countermeasures. However, to identify the number of conflicts, a specific threshold for various conflict indicators needs to be used and the results of the evaluation can vary significantly depending on the selection of this threshold. As well, there is an issue with how to account for conflict severity in the evaluation. This study proposes adopting the extreme value theory approach to overcome these two issues. The approach was applied to a case of left-turn bay extension at three signalized intersections, and the automated traffic conflict technique was used to identify conflicts with TTC values from the video data collected from treatment sites and matching control sites. Generalized extreme value (GEV) models with different covariates were developed and compared. The results show that there are apparent shape change in the GEV distribution (i.e., from narrow peak up to high severities to wide spread with fewer conflicts at high severity levels) after the treatment, indicating reduction in conflict severity. The safety improvement is further confirmed by the total reduction of 63.9% in estimated crashes. Moreover, with the aid of GEV model, the most severe conflicts that are also rare and random are included into the OR calculation, and a significant reduction of 73.2% is found in the estimated most severe conflicts.

1. Introduction

Before-after studies are a key component of road safety programs with the goal to quantitatively measure the safety benefits (or absence thereof) derived from a safety treatment. The traditional crash-based approach to before-after studies is based on the estimation of the reduction in the frequency and severity of crashes that can be attributed to the treatment evaluated (Hauer, 1997; Elvik, 2002; Sayed and Sacchi, 2016). However, there are well-recognized quality and quantity problems associated with the crash data. In addition, to draw statistically stable conclusions, researchers typically observe collisions for prolonged periods (1–3 years) before as well as after the introduction of the treatment. The use of traffic conflicts as a surrogate or complementary measure of road safety have experienced rapid development in the past 50 years (Zheng et al., 2014a). Traffic conflicts occur more frequently, can be clearly observed and can provide insights into the failure mechanism that leads to crashes (Sayed and Zein, 1999).

There has been a recent increase in the use of traffic conflicts in before-after safety studies. Brown (1994) evaluated the safety effect of signal installations using traffic conflicts defined by time-to-collision (TTC) $\leq$ 1.5 s. Tarrall and Dixon (1998) conducted a before-after analysis to evaluate the safety effect of changes in left-turn signal phasing using traffic conflicts determined by field observation and expert judgement. Ismail et al. (2010) and Sayed et al. (2012) introduced the automated computer vision technique into before-after safety analysis. The same technique was also used in conflict-based before-after studies in Autey et al. (2012) and Reyad et al. (2017) for evaluating the safety effectiveness of right-turn smart channels and improved traffic signal visibility, respectively. Both studies used TTC as a conflict indicator with 3 and 4 s thresholds, respectively. In general studies of traffic conflict techniques, the most frequently used TTC threshold values are 1.5 s, 2 s and 3 s (Laureshyn et al., 2016), and a threshold is usually determined based on the researcher's subjective judgement according to the study objectives and previous experience.

Despite the recent growing interest in using traffic conflicts in before-after safety studies, there are some shortcomings. To identify the

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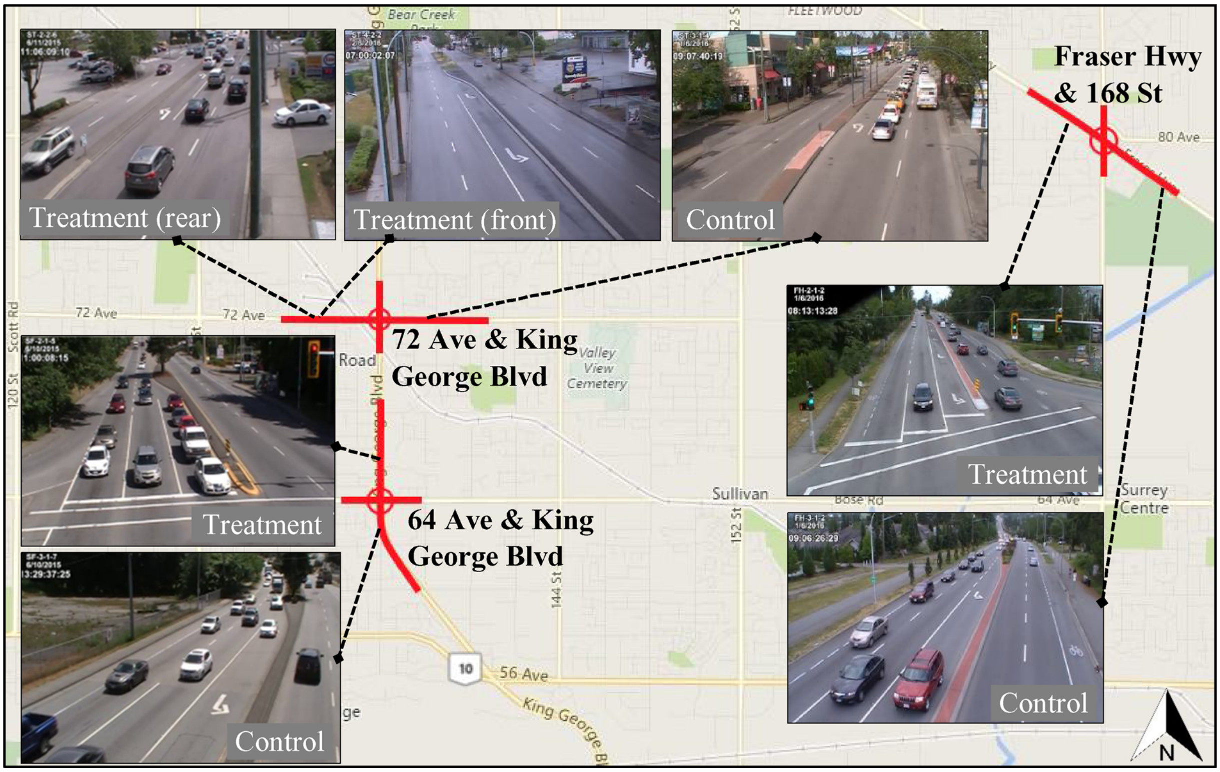

Fig. 1. Locations of the studied intersections and fields of view from cameras.

number of conflicts, a specific threshold for various conflict indicators needs to be used. The selection is somewhat arbitrary and the results of the evaluation may vary significantly depending on the selected threshold. As well, there is an issue with how to account for conflict severity in the evaluation, which is difficult if only one threshold is used. Finally, since crashes should be the ultimate criteria used in the evaluation, some may argue that only most severe conflicts that logically closest to crashes should be included in the analysis. However, using only the most severe conflicts may cause a problem of scarcity and inherited randomness. This study attempts to overcome these issues by adopting the extreme value theory (EVT) approach. The advantage is using all observed traffic conflicts with different severity levels (different conflict indicator values) to obtain a distribution, which is used to estimate crashes and other less observed extreme events.

2. Literature review on EVT

The EVT approach is unique as a statistical tool that enables extrapolation from observed levels to unobserved levels with a class of models. The approach has been widely used in many fields starting from the early part of the 20th century (Coles, 2001), and its application in road safety analysis is rather recent and limited.

Applying the EVT approach to safety analysis was firstly proposed by Campbell et al. (1996). In their study, the Weibull type of generalized extreme value (GEV) distribution was adopted to traffic conflicts to evaluate the benefits of active safety technologies. The EVT approach was further applied and validated in studies of Songchitruksa and Tarko (Songchitruksa, 2004; Songchitruksa and Tarko, 2006). They used the GEV distribution to estimate the frequency of right-angle collisions at signalized intersections and the results showed a promising relationship between the estimated crashes and observed crashes. Tarko (2012) also proposed to use the generalized Pareto distribution (GPD), an alternative of GEV distribution in the EVT approach, to estimate the risk of crash occurrence based on traffic conflicts. The advantages of EVT approach were summarized in the white paper prepared by Tarko et al. (2009) which include abandoning the assumption of fixed crash-to-surrogate ratio and no need of crash data in the model estimation process.

There are also several other recent studies that show EVT approach is a powerful tool to connect traffic conflicts to crashes. Gordon et al. (2013) used the EVT approach to estimate the road departure crash frequency based on the indicator of time to road edge crossing. They found reasonable crash estimates compared to the observed crash data. Zheng et al. (2014b) used the EVT approach to estimate safety related to lane changing maneuver on freeway, and also compared the EVT approach to crash-based negative binomial regression approach. Their results showed that safety estimates from the EVT models carry useful safety information (Zheng et al., 2015). The authors also suggested that the EVT fitted well within the safety continuum framework and thus developed a parametric safety continuum model using this approach (Zheng et al., 2014c; Zheng and Ismail, 2017). In addition, Farah and Azevdo (2017) applied the EVT approach to analyze the head-on conflicts related to passing maneuvers on two-lane rural highways; Åsljung et al. (2017) showed that the EVT approach could be used to validate the safety of autonomous vehicles. Wang et al. (2018) found that a larger sample size of conflict data obtained through simulation could improve EVT performance in the safety estimation. Tarko (2018) estimated the expected number of crashes from Lomax type of GPD and confirmed that traffic conflicts defined by sufficiently small threshold separation of indictors can generate unbiased crash estimates.

Previous studies focus more on testing the reliability of using EVT approach to establish relationship between traffic conflicts and crashes. Given it has been demonstrated to be a promising tool, this study applies the EVT approach to an important area of road safety analysis: before-after evaluations.