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Developing crash modification functions for pedestrian signal improvement

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ABSTRACT

Pedestrian signals are viable traffic control devices that help pedestrians to cross safely at intersections. Although the literature is extensive when dealing with pedestrian signals design and operations, few studies have focused on the potential safety benefits of installing pedestrian signals at intersections. Most of these studies employed simple before–after (BA) safety evaluation techniques which suffer from methodological and statistical issues.

Recent advances in safety evaluation research advocate the use of crash modification functions (CMFunctions) to represent the safety effectiveness of treatments. Unlike crash modification factors (CMFs) that are represented as single values, CMFunctions account for variable treatment location characteristics (heterogeneity). Therefore, the main objective of this study was to quantify the safety impact of installing pedestrian signals at signalized intersections by developing CMFunctions within an observational BA study. The use of observational BA framework to develop the CMFunctions avoids the cross-sectional approach where the functions are derived based on a single time period and no actual treatment intervention.

Treatment sites heterogeneity was incorporated into CMFunctions using fixed-effects and random-effects regression models. In addition to heterogeneity, the paper also advocates the use of CMFunctions with a time variable to acknowledge that the safety treatment (intervention) effects do not occur instantaneously but are spread over future time. This is achieved using non-linear intervention (Koyck) models, developed within a hierarchical full Bayes context. The results demonstrated the importance of considering treatment sites heterogeneity (i.e., different circulating volumes and area type among treated locations) and time trends when developing CMFunctions for pedestrian signal improvement.

1. Introduction

Pedestrian signals are viable traffic control devices that help pedestrians cross safely at intersections. Although there is extensive literature dealing with pedestrian signals design and operations, few studies have focused on the potential safety benefits of installing pedestrian signals at intersections. Most of these studies employed simple before–after (BA) safety evaluation techniques which suffer from methodological and statistical issues. For instance in Canada, a review for 25 intersection pedestrian signals in Hamilton (Ontario) concluded that the total average collision rates declined after the installation of pedestrian signals (Tam, 2004). However, some locations showed an increased number of collisions that did not involve pedestrians. Such collisions may be related to increased exposure to rear-end crashes as an increasing number of vehicles are required to stop. Also, a safety review in the City of Edmonton identified that the rate of pedestrian–motor vehicle collisions declined by 40% between 1989 and 2000 after the installation of pedestrian signal devices (ITE, 2006). A study of the effectiveness of High-Intensity Activated Crosswalk (HAWK) pedestrian signals at 21 locations in Tucson (Arizona) found that pedestrian collisions were reduced by about 58%. The study also warned that the system might be less effective if overused (Fitzpatrick and Park, 2009). The countdown pedestrian signal technology was also studied in Maryland where the pedestrian vehicle conflicts were found to decrease significantly at four observed intersections after installing countdown pedestrian signal (Rousseau and Davis, 2003). A case study in San Francisco reported a 25% pedestrian crash reduction factor associated with countdown timers (Markowitz et al., 2006).

Overall, the literature showed an improvement of safety levels after implementing pedestrian signals. However, many of these studies have some methodological and statistical issues. The main

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challenge in conducting observational BA studies is to make use of a methodology that accounts for many potential confounding factors, such as the regression to the mean effect, traffic volume changes, maturation and other effects unrelated to the treatment (HSM, 2010). As well, recent advances in safety evaluation research advocate the use of crash modification functions (CMFunctions) to represent the safety effectiveness of treatments (Gross et al., 2010). CMFunctions account for variable treatment location characteristics (heterogeneity). In fact, the heterogeneity among the treatment locations in terms of their characteristics and the effect of this heterogeneity on safety treatment effectiveness are usually ignored with single crash modification factors (CMFs).

CMFunctions have frequently been developed from cross-sectional (CS) studies, i.e., studies where collision frequency of a group of locations having a specific component of interest is compared to the collision frequency of a group of locations that lack the presence of this specific component. The component of interest (e.g., a specific geometric feature) can be controlled for in the regression model and a CMF or a CMFunction for the component can be inferred from the model form and the coefficients (Gross et al., 2010). Recent examples of these CMFunctions can be found in the literature for different highway design and traffic control features: presence of turn lanes at signalized intersections (Chen and Persaud, 2014), urban roadway widening (Park et al., 2015), and lane widening (Lee et al., 2015).

2. Objective and methodology

The main objective of this paper is to quantify the safety impact of installing pedestrian signals at urban/suburban signalized intersections. The objective was pursued through methodologically and statistically-valid techniques in a way to strength and supplement the results of the literature.

The safety benefits of this specific treatment were quantified through developing CMFunctions within an observational BA study. Single CMFs obtained from observational BA studies are usually estimated from applying a safety treatment to a group of sites, calculating the safety impact (i.e., index of effectiveness) for each site and averaging these impacts to reach an overall CMF value along with a measure of its uncertainty. In this study, the methodology adopted to develop CMFunctions for the inclusion of treatment site heterogeneity is the use of meta-regression (Sacchi and Sayed, 2014). After obtaining the treatment effectiveness for each site, meta-regression is used to relate the index of treatment effectiveness to the location characteristics. Meta-regression is similar in principle to simple/multiple regression, in which a dependent variable is predicted by means of one or more explanatory variables. The main difference is that in meta-regression the outcome variable (i.e., the treatment effectiveness for each single location in this context) is weighted by its own precision such that the resulting CMFunction represents an objective and statistically rigorous model that combines different CMFs.

In addition to heterogeneity, the paper also advocates the use of CMFunctions with a time variable to acknowledge that the safety treatment (intervention) effects do not occur instantaneously but are spread over future time periods (El-Basyouny and Sayed, 2011, 2012a,b; Sacchi et al., 2014). This can be pursued with non-linear intervention models (i.e., dynamic regressions which can identify the lagged effects of the treatment in order to measure its effectiveness over time), developed within a hierarchical full Bayes (FB) context.

3. Crash modification function development

As mentioned before, CMFunctions can be developed with the CS approach. However, this method suffers from many shortcomings. These include the use of inappropriate functional forms, potential correlation that might exist among variables in the model such that it is difficult to separate their individual effects on safety, and the presence of other unforeseen factors whose inclusion in the model was not possible.

Alternatively, observational BA studies can be used to develop CMFunctions as proposed by Sacchi and Sayed (2014). BA studies are perceived by many researchers to be the best way to estimate the safety effect of changes in location or traffic characteristics (Sawalha and Sayed, 2001; Gross et al., 2010; Hauer, 2010). The reason for the superiority of a BA study is that it is a longitudinal analysis, i.e., it bases its results on actual changes that have occurred in one data set over a period of time extending from the before condition to the after condition. The use of observational BA framework to develop the CMFunctions avoids the CS approach where the functions are derived based on a single time period and no actual treatment intervention. In this section, the methodology introduced by Sacchi and Sayed (2014) that allows estimating CMFunctions from BA safety studies is replicated and summarized.

3.1. Modeling crash frequency

A crash count Y_{it} recorded at site i ($i = 1, 2, \ldots, n$) during year t ($t = 1, 2, \ldots, m$) can be modeled with a Poisson distribution with mean and variance equal to λ_{it}, assuming that Y_{it} are independently distributed. If site-level random effects are introduced and modeled as log-normally distributed, using a hierarchical structure it is possible to write:

$$Y_{it}|\lambda_{it} \sim \text{Poisson}(\lambda_{it}), \tag{1}$$

$$\ln(\lambda_{it}) = \ln(\mu_{it}) + \varepsilon_i, \tag{2}$$

$$\varepsilon_i \sim N(0, \sigma_\varepsilon^2), \tag{3}$$

where σ_ε^2 represents the extra-Poisson variation.

To investigate the association between crash frequency and covariates, it is necessary to define the term μ_{it}. A way to define μ_{it} is the use of so-called "intervention" model which has been available in literature for some time (Li et al., 2008; El-Basyouny and Sayed, 2011). Within the framework of an observational BA study where crash data are available for a reasonable period of time before and after the intervention and a set of crash data for the same period of time is available for a comparison group similar to the treatment sites, it is possible to define a piecewise linear or non-linear function of the covariates to accommodate a possible change in the slope of crash frequency on time at treatment sites that might be attributable to the intervention.

However, it should be noted that in all of these studies, linear slopes were assumed to represent the time and treatment effects across the treated and comparison sites in the regression term μ_{it}. To overcome potential shortcomings the linear slopes assumption, El-Basyouny and Sayed (2012a,b) advocated the use of the non-linear 'Koyck' intervention model (Koyck, 1954) to represent the lagged treatment effects that are distributed over time. The Koyck model is an alternative dynamic regression form involving a first-order autoregressive (AR1) SPF that is based on distributed lags. The model affords a rich family of forms (over the parameter space) that can accommodate various profiles for the treatment effects. Therefore, the Koyck model is used as an alternative non-linear intervention model to estimate the effectiveness of safety treatments in BA designs. Recently, a comparison of several Bayesian evaluation techniques has shown the advantages of using the non-linear intervention model for BA studies (Sacchi and Sayed, 2015).