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A full Bayes before-after study accounting for temporal and spatial effects: Evaluating the safety impact of new signal installations

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ABSTRACT

Recently, important advances in road safety statistics have been brought about by methods able to address issues other than the choice of the best error structure for modeling crash data. In particular, accounting for spatial and temporal interdependence, i.e., the notion that the collision occurrence of a site or unit times depend on those of others, has become an important issue that needs further research.

Overall, autoregressive models can be used for this purpose as they can specify that the output variable depends on its own previous values and on a stochastic term. Spatial effects have been investigated and applied mostly in the context of developing safety performance functions (SPFs) to relate crash occurrence to highway characteristics. Hence, there is a need for studies that attempt to estimate the effectiveness of safety countermeasures by including the spatial interdependence of road sites within the context of an observational before-after (BA) study. Moreover, the combination of temporal dynamics and spatial effects on crash frequency has not been explored in depth for SPF development.

Therefore, the main goal of this research was to carry out a BA study accounting for spatial effects and temporal dynamics in evaluating the effectiveness of a road safety treatment. The countermeasure analyzed was the installation of traffic signals at unsignalized urban/suburban intersections in British Columbia (Canada). The full Bayes approach was selected as the statistical framework to develop the models.

The results demonstrated that zone variation was a major component of total crash variability and that spatial effects were alleviated by clustering intersections together. Finally, the methodology used also allowed estimation of the treatment's effectiveness in the form of crash modification factors and functions with time trends.

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1. Introduction

A variety of statistical methods have been employed to analyze crash data. Recently, crash data modeling has resorted to increasingly sophisticated statistical techniques to uncover new inferences relating crash occurrence to highway characteristics and to randomness and the unobserved heterogeneity of the data. The main outcome from the modeling process is typically a regression model that produces an estimate of the collision frequency for a location based on the traffic exposure (volume) and site-specific traffic and geometric characteristics (i.e., a safety performance function (SPF)) Traditionally, the techniques used to develop SPFs have accounted for Poisson variation (crashes are random, discrete, non-negative and sporadic events) and extra-Poisson variation due to potential population heterogeneity that leads to over-dispersion (Miaou, 1994).

In addition to the Poisson error structure, other count data distributions have been proposed over the years to deal with specific crash data issues (Lord and Mannering, 2010). Recently, important advances in the field have been brought about by methods able to address issues other than the choice of the best error structure for modeling crashes. In particular, accounting for spatial and temporal effects (dependencies), has become an important issue that needs further research. Overall, autoregressive (AR) models can be used for this purpose as they can specify that the output variable depends on its own previous values and on a stochastic term. In doing so, it is possible to study unobserved factors due to the spatial proximity of road sites or temporal dynamics of crash frequency (Miaou et al., 2003).

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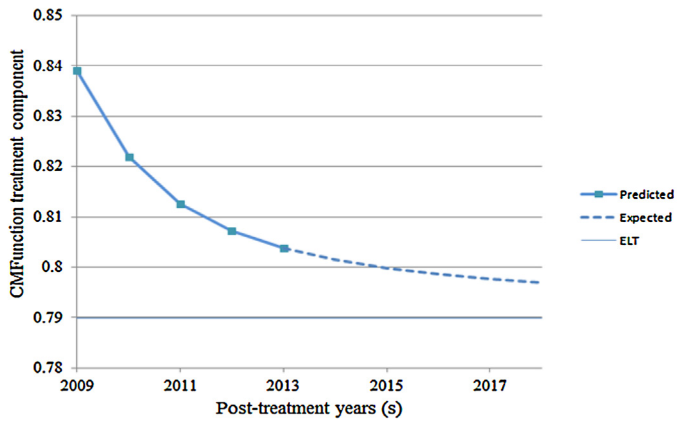

Fig. 1. Estimated and expected profile of the CMFunction treatment component for total collisions.

Regarding unobserved factors, the recent inclusion of spatial effects in the development of SPFs has been gaining considerable attention (Aguero-Valverde and Jovanis, 2008; El-Basyouny and Sayed, 2009). For example, researchers have used the Gaussian conditional autoregressive (CAR) distribution for hierarchical models to account for local spatial dependencies. CAR specifications are introduced through random effects in the mean structure of the data. In the literature, it has been demonstrated that the inclusion of spatial effects can be a surrogate for unknown and relevant covariates, thereby improving model estimation (Dubin, 1988; Cressie, 1992; El-Basyouny and Sayed, 2009).

To accommodate temporal dynamics in crash occurrence, nonlinear intervention models have been recently proposed to account for potential changes in the slope of crash frequency over time at road sites, which might be attributable to a safety treatment (intervention) (El-Basyouny and Sayed, 2012a). They have been successfully applied to longitudinal (before-after) road safety studies. The nonlinear intervention models aim to represent the lagged treatment effects that are distributed over time. They are alternative dynamic regression forms that involve a first-order autoregressive (AR1) SPF based on distributed lags and can accommodate various profiles for the treatment effects. Examples of these advanced SPFs applied to observational before-after (BA) studies can be found in El-Basyouny and Sayed, (2012a) for the evaluation of general intersection improvements, El-Basyouny and Sayed (2012b) for rumble strips, and Sacchi and Sayed (2014) for evaluating signal visibility improvements.

Spatial effects have been investigated and applied mostly in the context of SPF development to relate collision occurrence and highway characteristics. Hence, there is a need for studies that attempt to estimate the effectiveness of safety countermeasures by including the spatial and temporal dependencies of road sites within the context of a BA study. In fact, including spatial effects within a nonlinear intervention model can represent an important contribution to road safety analysis.

Therefore, the main goal of this paper is to conduct an observational before-after study accounting for spatial effects and temporal dynamics in evaluating the safety impact of a road safety countermeasure. The treatments analyzed were traffic signal improvements at urban/suburban intersections in British Columbia (Canada).

The full Bayes (FB) approach was selected as the statistical framework to develop the models. The FB method has several advantages over the well-known empirical Bayes technique, including the ability to allow inference at more than one level for hierarchical (multi-level) models, conduct a multivariate analysis (Park et al., 2010; El-Basyouny and Sayed, 2011), treat each time period as an individual data point, and integrate the estimation of the safety performance function (SPF) and treatment effects in a single step—whereas those are two separate steps in the EB method (Persaud et al., 2010).

Finally, the methodology used can estimate the treatment's effectiveness in the form of a crash modification factor (CMF) and crash modification functions (CMFunction) with temporal trends to analyze how the treatment impact was spread over time (Sacchi et al., 2014).

2. Installation of new traffic signals

A number of treatments can be implemented at intersections to ensure safer and more efficient traffic operations. One of these treatments is the installation of traffic signals. In the literature, several studies have shown that, under appropriate circumstances, traffic signals can lead to safer conditions by separating conflicting movements in time and providing efficiency in traffic operations (HSM, 2010; Chandler et al., 2013). The effects are generally a decrease in severe head-on and angle crashes and an increase in less severe rear-end crashes.

The effectiveness of installing new signals has been the focus of several studies. The earlier studies were carried out using road safety evaluations that did not control for confounding factors. For instance, Short et al. (1982) analyzed the safety impact of signal installations in Wisconsin with a simple before-after approach. They found a significant decrease (34%) in right-angle crashes, a significant increase in rear-end and other crashes, and no or little change in non-severe crashes. More recently, a National Cooperative Highway Research Program (NCHRP) study that aimed to develop the crash experience warrant for traffic signals at four-legged intersections showed that new signal installations cause an overall reduction of 23% for injury crashes, 67% for right-angle crashes, and an increase in rear-end crashes by 38% (McGee et al., 2003). Other studies performed across the United States showed that signal installation could result in a 15% to 20% reduction in overall crashes and an approximate 60% reduction in right-angle crashes (Ermer and Sinha, 1991; Thomas and Smith, 2001; Agent et al., 1996; Gan et al., 2005). Finally, Aul and Davis (2006) analyzed 18 intersections where new signals were installed in Minneapolis–Saint Paul, Minnesota. Even though the reduction/increase in right-angle and rear-end crashes (respectively) were found similar in direction to the NCHRP study, the authors found no change in crash frequency for the total number of intersection-related crashes.

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