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A full Bayesian approach to appraise the safety effects of pedestrian countdown signals to drivers

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ABSTRACT

Although they are meant for pedestrians, pedestrian countdown signals (PCSs) give cues to drivers about the length of the remaining green phase, hence affecting drivers' behavior at intersections. This study focuses on the evaluation of the safety effectiveness of PCSs to drivers, in the cities of Jacksonville and Gainesville, Florida, using crash modification factors (CMFs) and crash modification functions (CMFunctions). A full Bayes (FB) before-and-after with comparison group method was used to quantify the safety impacts of PCSs to drivers. The CMFs were established for distinctive categories of crashes based on crash type (rear-end and angle collisions) and severity level (total, fatal and injury (FI), and property damage only (PDO) collisions). The CMFs findings indicated that installing PCSs result in a significant improvement of drivers' safety, at a 95% Bayesian credible interval (BCI), for total, PDO, and rear-end collisions. The results of FI and angle crashes were not significant. The CMFunctions indicate that the treatment effectiveness varies considerably with post-treatment time and traffic volume. Nevertheless, the CMFs on rear-end crashes are observed to decline with post-treatment time. In summary, the results suggest the usefulness of PCSs for drivers. The findings of this study may prompt a need for a broader research to investigate the need to design PCSs that will serve the purpose not only of pedestrians, but drivers as well.

1. Introduction

Each year, more than 32,000 fatalities and 2 million injuries occur on the United States (U.S) roadways. These tragedies amount to an estimated societal burden of more than $230 billion of medical and other costs (NHTSA, 2010). The U.S has experienced a 31% decrease in its motor vehicle fatality rate per capita over the past 13 years. Even so, compared with 19 other developed countries, which experienced on average a 56% reduction in the frequency of fatal crashes during the same period, the U.S has the slowest reduction (31%) (Sauber-Schatz et al., 2016). Shockingly, the latest data from the National Highway Traffic Safety Administration (NHTSA) indicate a 7.2% increase in roadway fatalities in 2015, shooting from 32,744 in 2014–35,092 in 2015 (NHTSA, 2016). This amounts to nearly 700 deaths every week due to traffic collisions. To put these statistics in perspective, the number of lives lost due to roadway crashes in the U.S. is equivalent to two commercial large aircrafts, i.e. the Airbus A340 500 (capacity of 372 seats), crashing every week.

Although intersections include a small proportion of the overall roadway network, compared to other roadway segments, they are characterized by increased conflicts due to various conflicting traffic movements converging at the same location. The U.S. Department of Transportation estimates that 43% of motor-vehicle crashes occur at or related to intersections. In some cases, the conflicts at intersections involve more than one transportation mode as drivers, pedestrians and cyclists come across at the same point.

The Pedestrian countdown signals (PCSs) are conventionally installed to improve pedestrian safety at signalized intersections. Generally PCSs, through the timer, are used to show the remaining seconds for pedestrians to cross the intersection during the pedestrian clearance interval. There is ample research evidence that shows safety benefits of PCSs for pedestrians (Chen et al., 2015; Schmitz, 2011; Vasudevan et al., 2011). Despite being intended for pedestrians, the same information offered by PCSs to pedestrians has been observed to give cues to drivers as well. A few studies have documented on the effect of PCSs to drivers. These studies have mostly concentrated on the operational and capacity effects of these signals, such as the studies by Nambisan and Karkee (2010), Schmitz (2011), and Elekwachi (2010). The literature on the safety effectiveness of PCSs on drivers is scarce.

A literature search uncovered only two studies, both recent, that evaluated the safety effectiveness of PCSs on drivers. The first study (Kwigizile et al., 2015) was conducted in Michigan using the before-

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and-after with the comparison group method. According to the study, the presence of PCSs at signalized intersections reduce 5% of total crashes for all drivers. This finding was in line with a Florida study (Kitali et al., 2017) that employed the same method and observed an 8.2% reduction in total crashes. This indicates that drivers utilize information provided by PCS' timers to make informed decisions when approaching and crossing signalized intersections. Both studies employed the empirical Bayes (EB) before-and-after technique, which suffers from methodological and statistical limitations, including small sample size and inability to account for the uncertainty of the computed regression coefficients from the safety performance function (SPF) into the odds ratio computations (two-step procedure). These limitations can be potentially addressed by employing a full Bayes (FB) method in lieu of a conventional EB approach. While the EB method has been the most acceptable technique for evaluating safety effectiveness of various roadway countermeasures, since the inception of the first Highway Safety Manual (HSM) (AASHTO, 2009), there has been an increased use of the FB technique for safety studies over the last few years.

A FB approach has the ability to account for most of the uncertainties in the dataset and model parameters (Park et al., 2016). The FB methodology is also a single-step integrated procedure, i.e. it integrates the process of estimating the SPF and treatment effect in a single step, hence incorporates the uncertainties of the SPFs in the final estimates. This method is also independent of sample size, yielding robust results even when used with small sample size (Li et al., 2013). Unlike the negative binomial (NB) model, a widely used regression model in the EB methodology, the FB approach makes use of hierarchical models i.e. Poisson-Gamma and Poisson-lognormal distributions (Lan et al., 2009; Pawlovich et al., 2006). Additionally, the FB approach divides the periods into time intervals (yearly in this case) and models, each time interval as a separate data point to account for time variations, unlike the EB methodology which average the data into a single data point. Fawcett and Thorpe (2013) concluded that relative to a fully Bayesian treatment, which provides a more flexible and complete inferential procedure, the EB method is over-optimistic when quantifying the variability of estimates of collision frequency. Also, the FB hierarchical model developed by Fawcett et al. (2017) has the ability to allow crash counts from multiple time-points to inform predictions, with counts in more recent years lending more weight to predictions than counts from time-points further in the past. This study explores the use of the FB technique for evaluating the safety effects of PCSs to drivers, considering its novelty and the fact that none of the previous studies has quantified the effects of PCSs to drivers using this approach.

The main purpose of this study is to evaluate the safety effectiveness of PCSs to drivers. The study employs the FB methodology to evaluate the overall safety effectiveness in terms of effectiveness for specific types of crashes – rear-end and angle crashes, in particular, and injury severity. Further, taking an advantage of the FB capability in analyzing changes of treatment effectiveness with time, the study also examines the time-based effectiveness for the post-intervention years.

2. Background

2.1. Full Bayes methodology

Historically, crash prediction models have employed mainly maximum likelihood models (Park et al., 2015a; Persaud and Lyon, 2007). Even after the introduction of the first version of the HSM (AASHTO, 2009), which advocated the use of the EB method, model coefficients were still determined based on maximum likelihood models, the NB being a preferred one. Recently, there has been a substantial increase in the use of hierarchical Bayesian approach in crash modeling. This increase can be attributed to a number of factors including the availability of open source scripting software packages and the invention of strong computers that can perform complex statistical iterations such as Markov Chain Monte Carlo (MCMC) simulations.

The use of FB in crash predictions dates more than two decades ago (Schlüter et al., 1997). However, it was in this decade when highway safety modeling scholars have increasingly used the FB approach applying the MCMC simulations (Lan et al., 2009; Li et al., 2008; Park et al., 2010; Pawlovich et al., 2006; Persaud et al., 2010; Sacchi et al., 2015). It is worth mentioning that it was only about a decade ago when the hierarchical Poisson regression models with a change point to before-and-after evaluation were introduced (Lan et al., 2009; Li et al., 2008; Park et al., 2010; Pawlovich et al., 2006; Persaud et al., 2010; Sacchi et al., 2015).

Unlike the classical statistical theory, Bayesian statistics use the density function to estimate the effect of a given parameter on the model rather than a discrete coefficient (Saito et al., 2011). Use of the density function permits for a better understanding of the amount of uncertainty in the data, where the density function for each parameter provides the likelihood pertaining to a certain prediction effect (Saito et al., 2011). In Bayesian statistics, all unknown parameters are considered as random, thus requiring the definition of initial prior distribution.

The Bayesian technique incorporates prior information and observed information to develop an estimate for the expected crashes of the sites of interest, intersections with PCSs for this case. In the context of the crash prediction modeling, the prior information is the anticipated crash frequency from comparison locations and the observed information are the historical crashes on the treatment sites before the installation of the treatment (Persaud et al., 2010). Due to the increasing complexity of Bayesian computations, a statistical technique such as the MCMC is a necessary tool for estimating such a complex integration. With an appropriate sample size that allows the model to converge, the true posterior distribution can be accurately estimated.

2.2. FB approach improvements on the SPF development

The abovementioned benefits of the FB approach over other safety effectiveness methodologies including EB allow for additional flexibility in the development of the crash prediction model (SPF). In the FB methodology, prior information and observed data are combined to develop a single robust statistical model which is used to generate a posterior distribution from which inference on selected parameters can be based. The hyper-prior distributions defined while estimating the posterior distribution for the anticipated number of crashes is carried over throughout the modeling process and finally the safety effectiveness computations. Conversely, the EB approach employs the use of an external function, SPFs, to derive the parameters of prior distributions for the predicted crashes, and consider them as true parameters once they are estimated. Ostensibly, for the EB method, the associated uncertainties in the regression model parameters of SPFs are not included in the final safety effectiveness estimate (Park et al., 2010).

The FB approach has the capability to account for different variations and characteristics existing in the crash data such as the use of intervention models during evaluation of the safety effects of the installed countermeasure on a road (El-Basyouny and Sayed, 2011; Li et al., 2008; Park et al., 2010; Pawlovich et al., 2006). An intervention model allows for the exploration of trends that may occur in between the before, or after, periods. This model also allows for the investigation of the temporal effects of traffic safety under the hypothesis that its effect changes over time as opposed to occurring instantaneously.

2.3. Jump parameter

Crash frequency for treatment sites is subject to change due to the effect of the installed treatment. Given that changes may not be gradual, an immediate drop or increase in crash frequency is expected at the respective sites after the intervention. The model parameter that accounts for the immediate drop or increase in the crash frequency at the treatment sites is conventionally referred to as a jump parameter. It