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Use of empirical and full Bayes before–after approaches to estimate the safety effects of roadside barriers with different crash conditions

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ABSTRACT

Introduction: Although many researchers have estimated the crash modification factors (CMFs) for specific treatments (or countermeasures), there is a lack of prior studies that have explored the variation of CMFs. Thus, the main objectives of this study are: (a) to estimate CMFs for the installation of different types of roadside barriers, and (b) to determine the changes of safety effects for different crash types, severities, and conditions. *Method:* Two observational before–after analyses (i.e. empirical Bayes (EB) and full Bayes (FB) approaches) were utilized in this study to estimate CMFs. To consider the variation of safety effects based on different vehicle, driver, weather, and time of day information, the crashes were categorized based on vehicle size (passenger and heavy), driver age (young, middle, and old), weather condition (normal and rain), and time difference (day time and night time). *Results:* The results show that the addition of roadside barriers is safety effective in reducing severe crashes for all types and run-off roadway (ROR) crashes. On the other hand, it was found that roadside barriers tend to increase all types of crashes for all severities. The results indicate that the treatment might increase the total number of crashes but it might be helpful in reducing injury and severe crashes. In this study, the variation of CMFs was determined for ROR crashes based on the different vehicle, driver, weather, and time information. *Practical applications:* Based on the findings from this study, the variation of CMFs can enhance the reliability of CMFs for different roadway conditions in decision making process. Also, it can be recommended to identify the safety effects of specific treatments for different crash types and severity levels with consideration of the different vehicle, driver, weather, and time of day information.

1. Introduction

Evaluation of the safety effects of specific treatments (or countermeasures) is essential in the traffic safety field. In order to introduce a science-based technical approach for safety analysis, the Highway Safety Manual (HSM) (AASHTO, 2010) was published by the Transportation Research Board. The HSM provides analytical methods to quantify the safety effects of decisions and treatments in planning, design, operation, and maintenance through development of crash modification factors (CMFs). A CMF is a factor that can estimate potential changes in crash frequency as result of implementing a specific treatment on roadways. CMFs in the HSM have been developed using high-quality observational before–after studies that account for the regression-to-the-mean threat and the cross-sectional method (Gross, Persaud, & Lyon, 2010; Lord & Bonneson, 2007; Gross & Donnell, 2011; Carter, Srinivasan, Gross, & Council, 2012; Fink, Kwigizile, & Oh, 2016). It is known that the empirical Bayes (EB) approach has been the most common and rigorous approach to perform observational before–after evaluations in the last two decades (Abdel-Aty et al., 2014; Gross et al., 2010; Park & Abdel-Aty, 2015a). On the other hand, with the advancement in statistical modeling techniques and computing capabilities, utilizing the full Bayes (FB) approach has been utilized recently (Aul & Davis, 2006; Pawlovich, Li, Carriquiry, & Welch, 2006; Li, Carriquiry, Pawlovich, & Welch, 2008; Lan, Persaud, Lyon, & Bhim, 2009; Persaud, Lan, Lyon, & Bhim, 2009; El-Basyouny & Sayed, 2010; El-Basyouny & Sayed, 2011, 2012; Ahmed, Abdel-Aty, & Park, 2015). In this paper, two observational before–after studies (i.e. EB and FB methods) have been conducted to evaluate the safety effectiveness of the installation of roadside barriers on freeways in Florida.

The HSM provides various CMFs for single treatments for general types of crashes (all crashes, head-on crashes, turning crashes, etc.) and severities (all severity levels, fatal and injury, etc.), but not CMFs for different types of crashes based on vehicle type, driver characteristics, weather conditions, and time changes. Although there are few studies that have investigated the variation of CMFs based on different roadway conditions and socio-economic characteristics (Elvik, 2005, 2009, 2011; Lee, Abdel-Aty, Park, & Wang, 2015; Park & Abdel-Aty, 2015b; Park, Abdel-Aty, & Lee, 2014; Park, Abdel-Aty, Lee and Lee, 2015), and time changes (Park, Abdel-Aty, Wang and Lee, 2015; Sacchi & Sayed, 2014; Sacchi, Sayed, & El-Basyouny, 2014; Wang, Abdel-Aty,

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Park, Lee, & Kuo, 2015), there are no studies that identified the changes of safety effects based on different vehicle size (passenger and heavy), driver age (young, middle, and old), weather condition (normal and rain), and time difference (day time and night time).

A number of studies addressed the safety effects of guardrails and different types of barriers on roadside and median of roadways. Specifically, guardrails and barriers have been widely implemented on roadways during the last several years to improve traffic safety. It is worth noting that the addition of barriers might increase the crash frequency, but it might be helpful in reducing severe crashes (Donnell & Mason, 2006; Elvik, Hoye, Vaa, & Sorensen, 2009; Miaou, Bligh, & Lord, 2005; Tarko, Villwock, & Blond, 2008; Zou, Tarko, Chen, & Romero, 2014). Moreover, installation of roadside guardrails is found to be effective in reducing crash severity (Holdridge, Shankar, & Ulfarsson, 2005; Lee & Mannering, 2002; Michie & Bronstad, 1994). On the other hand, Jang, Lee, and Kim (2010) found that installations of median barrier and roadside guardrail can reduce all types of crashes by 77% and 58%, respectively. Also, it should be noted that a new chapter for freeway and interchanges was recently added in the HSM, and the new chapter contains the CMFs for addition of roadside barriers. However, it is worth mentioning that the CMF is representing the safety effects of all types of roadside barriers including concrete and cable barriers, w-beam guardrail, and bridge rail, but not CMF for specific types of roadside barriers.

Thus, the main objective of this study is to evaluate safety effects of adding a specific type and combination of roadside barriers on freeways for different crash types and severity levels based on different vehicle types, driver characteristics, weather conditions, and time changes. The safety effects of installation of different types of roadside barriers for different crash types were estimated using the before–after with EB and FB methods, and quantified in the CMFs. Moreover, the safety effects of roadside barriers were evaluated for different characteristics (i.e. vehicle, driver, weather, and different time). The identified variation of CMFs with different crash information provide general insights into roadway design and selection of sites for installation of roadside barriers for reducing severe crashes. It is expected that the finding from this study will be helpful for safety engineers and policy makers in their decision making process. The following sections illustrate the procedures of preparing the data, statistical methodologies, results and discussion, and the conclusions. In this paper, we refer to 'All crash types' as All crashes' and 'run-off roadways crashes' as ROR crashes for crash types. Crash severities were categorized according to the KABCO scale as follows: fatal (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and property damage only (O).

2. Data description and preparation

Multiple data sources maintained by the Florida Department of Transportation (FDOT) were used in this study. The road geometry data for roadway segments were obtained for 9 years (2003–2011) from the database of the roadway characteristics inventory (RCI). The RCI database provides current and historical roadway characteristics data, and reflects features of specific segment for selected dates. In order to identify the treated sites on freeways, the financial management system was used. The financial management system offers a searching system named financial project search. This system provides detailed information on a specific financial project such as district number, status, work type, and year.

A total of 147 freeway segments totaling 68.168 miles were identified as treated sites with installation of roadside barriers during 2007. A segment is represented by roadway identification numbers, and beginning and end mile points. It was found that among the 147 treated sites, w-beam guardrails were implemented on 127 sites and concrete barriers were installed on 20 sites. In order to validate the treated locations from the financial management system, historical images from Google Street View were used. The barriers were installed on roadside when there were hazardous features such as trees, new poles, ditches, etc. Fig. 1 presents an example of before and after location views for a specific treated location.

The crash records were obtained from the crash analysis reporting system (CARS) for the 4-year before (2003–2006) and 4-year after (2008–2011) periods. Also, the reference sites were identified using the RCI database. A total of 328 roadway segments with 119.899 miles in length were identified as reference sites. It is to be noted that reference sites are different from the comparison group; the reference sites are broader than the comparison group with more variation in Annual Average Daily Traffic (AADT), roadway characteristics, and crash history to correct for the regression-to-the-mean threat. In order to account for these traffic parameters and multiple roadway characteristics, EB and FB techniques were applied in this study. The FB approach integrates the EB two-step into one and hence, FB utilizes information from a reference group of sites and the before information from the treated sites to estimate the long-term expected crash frequency (Ahmed et al., 2015). The before–after techniques can also account for unreported crashes since the percentage of these crashes would even out from the before and after crash data, and would not be considered in the evaluation process. These unreported crashes might be a problem when the CMF is estimated by cross-sectional analysis. Table 1 presents a summary of distributions of each variable for the treated segments along with crash frequency.

3. Methodology

3.1. Safety performance functions

A safety performance function (SPF) is generally known as a crash prediction model that relates the crash frequency to traffic and geometric parameters. Data from the untreated reference sites was used to estimate the SPFs. The negative binomial (NB) model (known as Poisson-Gamma) is most commonly used to develop a SPF since the function can account for over-dispersion. Crash data have a gamma-distributed mean for a population of systems, allowing the variance of the crash data to be more than its mean (Park, 2015; Shen, 2007). Suppose that the number of crashes on a roadway section is Poisson distributed with a mean λ, which itself is a random variable and is gamma distributed, then the distribution of frequency of crashes in a population of roadway sections follows a negative binomial probability distribution (Hauer, 1997) as below.

$$y_i \mid \lambda_i \approx \mathrm{Poisson}(\lambda_i)$$

$$\lambda \approx \mathrm{Gamma}(\mathrm{a}, \mathrm{b})$$

Then,

$$\mathrm{P}(y_i) \approx \mathrm{Negbin}\ (\lambda_i, k) \qquad = \frac{\Gamma(1/k + y_i)}{y_i!\Gamma(1/k)}\left(\frac{k\lambda_i}{1+k\lambda_i}\right)^{y_i}\left(\frac{1}{1+k\lambda_i}\right)^{1/k} \quad (1)$$

where,

y number of crashes on;
λ expected number of crashes per period on the roadway section;
k over-dispersion parameter.

A SPF that relates crash frequency of the sites to their characteristics can be estimated for the untreated reference sites. Two types of SPFs, which are the full SPF and the simple SPF, have been mainly used in the literature. The full SPF relates the frequency of crashes to both traffic and roadway characteristics, whereas the simple SPF considers a traffic parameter only such as AADT as an explanatory variable. It is worth noting that the HSM provides the CMFs calculated based on the simple SPF only. In this study, the full SPF was used for before–after analysis with the EB method since the simple SPF is an over-simplified function