Accident Analysis and Prevention 75 (2015) 35–42

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Potential crash reduction benefits of shoulder rumble strips in two-lane rural highways

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ARTICLE INFO

Article history:
Received 10 July 2014
Received in revised form 3 November 2014
Accepted 5 November 2014
Available online 20 November 2014

Keywords:
Run-off-the-road crashes
Shoulder rumble strips
EB before-and after analysis
Two-lane rural highways

ABSTRACT

This paper reports the findings from a study aimed at examining the effectiveness of shoulder rumble strips in reducing run-off-the-road (ROR) crashes on two-lane rural highways using the empirical Bayes (EB) before-and-after analysis method. Specifically, the study analyzed the effects of traffic volume, roadway geometry and paved right shoulder width on the effectiveness of shoulder rumble strips. The results of this study demonstrate the safety benefits of shoulder rumble strips in reducing the ROR crashes on two-lane rural highways using the state of Idaho 2001–2009 crash data. This study revealed a 14% reduction in all ROR crashes after the installation of shoulder rumble strips on 178.63 miles of two-lane rural highways in Idaho. The results indicate that shoulder rumble strips were most effective on roads with relatively moderate curvature and right paved shoulder width of 3 feet and more.

1. Introduction

Run-off-the-road (ROR) crashes account for a large number of severe crashes in the United States. In 2011, ROR crashes resulted in 16,948 fatalities – 51% of the total fatal crashes in the Unites States (FHWA, 2013). The Federal Highway Administration (FHWA, 2004) reports that up to 70% of ROR fatalities occur on rural highways and, of these, about 90% occur on two-lane roads where the geometry of the road often includes sharper curve and narrower shoulder width, increasing the frequency and severity of these crashes.

The majority of ROR crashes involve only a single vehicle and are caused by driver performance errors, specifically distraction, drowsiness, fatigue or inattention (Liu and Ye, 2011; Liu and Subramanian, 2009). Rumble strips are a counter measure aimed at reducing the frequency and severity of ROR crashes specific to driver performance errors. Installed along the edge of a travel lane, shoulder rumble strips produce noise and vibration that alert drivers when their vehicles are drifting off the roadway.

The safety benefit of shoulder rumble strips in reducing the frequency and severity of ROR crashes have been emphasized in many earlier studies (see, Torbic et al., 2009; Persaud et al., 2004; Gårder and Davies, 2006; El-Basyouny and Sayed, 2012); however, the research methodologies, target roadways, and the range of results obtained in earlier studies are vary considerably. Most of the studies in transportation safety research have used the before-and-after analysis to evaluate the safety benefits of roadway treatments such as shoulder rumble strips. The objective of the before-and-after analysis is to compare the actual number of crashes that occur after the installation of a safety measure with the expected number of crashes that would have occurred during the after period had the treatment not been installed. In this study, before period crash counts refer crash counts before the installation of the treatment and after period crash counts refer crash counts after the treatment has installed. Four types of before-and-after methods exist in the literature: (1) simple (Naïve) before-and-after analysis, (2) comparison group (CG) analysis, (3) empirical Bayes (EB) analysis and (4) full Bayes (FB) analysis.

The Naïve before-and-after analysis assumes the crash data follows a Poisson distribution and then compares the crash counts for a location before and after a treatment to assess the safety benefit attributed to a treatment. However, this method leads to inaccurate and misleading (usually overestimated safety benefits) conclusions because of its inherent limitations to address regression to mean bias and external causal factors that change with time (Shen and Gan, 2003).

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http://dx.doi.org/10.1016/j.aap.2014.11.007
0001-4575/

The CG analysis method was developed to take into account different causal factors that change with time by using an untreated comparison site or a group of sites that have similar road geographic and traffic volume characteristics as the treatment site. To estimate the crashes that would have occurred without the treatment during the after period, the crash data of comparison site(s) are used. The CG method can produce better estimates of the after period crashes compared to Naïve before-and-after analysis; however, the accuracy of the CG analysis results greatly depends on the selection of comparison sites and cannot address the regression to mean bias limitation.

The EB Method for estimating safety, developed by Hauer (1997) and Hauer et al. (2002), increases the precision of estimation to address the limitation of the Naïve and CG Methods by accounting for the regression-to-the-mean effect (Shen and Gan, 2003). The EB method also accounts for external causal factors that change with time. Such factors can be weather, crash reporting practices, and driving habits. This method is based on the recognition that crash counts are not the only measure of safety for an entity. To estimate the expected number of crashes in the treatment site without treatment, the EB Method considers two trends: (1) the crash trend at the treatment site prior to the treatment installation, and (2) the safety performance or crash trends at similar sites, referred as comparison sites that did not have any treatment during the analysis period.

The FB analysis method is a generalized version of the EB method, where instead of using crash trend information from similar sites, a distribution of likely values is generated that is combined with the treatment site specific crash trend to estimate the expected crashes at the treatment sites without the treatment. The FB analysis is a useful before-and-after method because it better accounts for uncertainty in data used, however, is a complex alternative to the EB approach (Persaud et al., 2010). The complexity of the FB method makes it less attractive to use than the EB method.

As a result, the EB method has been the standard for more than a decade in road safety analysis aimed at evaluating the effectiveness of different crash countermeasures. Examples of some transportation safety research using the EB method for evaluating the effectiveness of different crash countermeasures include, but are not limited to, shoulder rumble strips (Torbic et al., 2009; Sayed et al., 2010; Patel et al., 2007; Griffith, 1999); centerline rumble strips (Torbic et al., 2009; Persaud et al., 2004), curve delineation with signing enhancement (Srinivasan et al., 2010); HAWK pedestrian cross-walk treatment (Fitzpatrick and Park, 2010), actuated advance warning dilemma zone protection system (Appiah et al., 2011); and high-visibility school crosswalks (Feldman et al., 2010).

The evaluation of a crash countermeasure is very important to allocate safety improvement program funds to maximize the benefits of safety improvement projects. The result of the before-and-after analysis is also used to develop crash modification factors (CMF) aimed at estimating the potential changes in number of crashes after the implementation of crash countermeasures. For example, the Highway Safety Manual (AASHTO, 2010) provides CMFs for various crash countermeasures.

Several states conducted studies to evaluate the safety benefit of shoulder rumble strips and found that it is an effective crash countermeasure to reduce single-vehicle ROR crashes (please see, AASHTO, 2010; Park et al., 2014 for a detail review). For freeway facilities and multi-lane rural facilities many different studies are available that analyze the effectiveness of rumble strips, but for two-lane rural highways, the availability of published research is very limited (AASHTO, 2010). The CMFs supplied by the Highway Safety Manual (HSM) only considered the daily traffic volume of highways to evaluate the safety benefit of shoulder rumble strips. Because road geometries of two-lane rural highways vary considerably, a need exists to study how road geometry affects driver inattention, and how effective rumble strips are at reducing ROR crashes caused by driver error. For example, a straight segment of road increases the probability of falling asleep while driving. Earlier research studies indicated that the effectiveness of shoulder rumble strips can depend on the road geometry (Patel et al., 2007); however, no earlier study was found to examine the effect on different roadway geometry. Again, the shoulder width can also affect the effectiveness of shoulder rumble strips. This study contributes to the literature of transportation safety research by evaluating the effectiveness of shoulder rumble strips in reducing the number of ROR crashes in two-lane rural highways in Idaho. Specifically, this study uses the EB analysis method to investigate the effect of a roadway's degree of curvature and shoulder width on the crash reduction benefits of shoulder rumble strips in two-lane rural highways.

The paper is structured as follows. The next section presents the EB before-and-after analysis for count data. Section 3 presents details of data used in the study followed by analysis results in Section 4. The final section offers concluding thoughts and directions for further research.

2. Methodology

The EB analysis method employs two sources of data to estimate the expected number of crashes (A') during the after period in the treatment site without the treatment. The first source is the accident trend of the treatment site before the treatment was installed (A'_1); and the second source is the safety performance or accident trends of control site that do not have any treatment in the analyzed period (A'_2). Let A be the observed number of reported crashes in the after period. Then the change in safety for ROR crashes on a road section with shoulder rumble strips installed is given by:

$$\text{Changeinsafety} = A' - A \quad (1)$$

In the EB method, a safety performance function (SPF) for control sites is used to estimate the annual number of crashes at control sites that do not have any treatment in the analyzed period. The SPF is a mathematical model that relates the dependent variable crash frequency of a road entity to the independent variables such as traffic volume and geometric characteristics of the entity. Literature shows that the Poisson and negative binomial (NB) regression models have been extensively studied and developed for crash data analysis. However, the over dispersion characteristics of crash data suggests that the Poisson distribution is inadequate for crash data. The NB distribution assumes that the mean of the Poisson distribution is gamma distributed. The NB regression model takes into account the over dispersion parameter and thus it is now common to assume that accident data comes from a negative binomial distribution. The sum of the annual crashes estimated using SPF during the before periods gives the estimate of A'_2. Then the expected number of crashes (A') before shoulder rumble strips installation can be estimated as:

$$A'' = w_1 \times A'_1 + w_2 \times A'_2; \text{where} w_1 + w_2 = 1 \quad (2)$$

where w_1 and w_2 are relative weights that determine the relative significance of A'_1andA'_2.

These relative weights are estimated from the mean and variance of the NB regression estimate as:

$$w_1 = \frac{A'_2}{A'_2 + 1/k} \text{and} w_2 = 1 - w_1 \quad (3)$$

where k is the dispersion parameter estimated along with the NB regression model parameters of SPF.