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Development of adjustment functions to assess combined safety effects of multiple treatments on rural two-lane roadways

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ABSTRACT

Numerous studies have attempted to evaluate the safety effectiveness of specific single treatment on roadways by estimating crash modification factors (CMFs). However, there is a need to also assess safety effects of multiple treatments since multiple treatments are usually simultaneously applied to roadways. Due to the lack of sufficient CMFs of multiple treatments, the Highway Safety Manual (HSM) provides combining method for multiple CMFs. However, it is cautioned in the HSM and related sources that combined safety effect of multiple CMFs may be over or under estimated. Moreover, the literature did not evaluate the accuracy of the combining method using CMFs obtained from the same study area. Thus, the main objectives of this research are: (1) to estimate CMFs and crash modification functions (CM Functions) for two single treatments (shoulder rumble strips, widening (1–9 ft) shoulder width) and combination (installing shoulder rumble strips + widening shoulder width) using the observational before–after with empirical Bayes (EB) method and (2) to develop adjustment factors and functions to assess combined safety effects of multiple treatments based on the accuracy of the combined CMFs for multiple treatments estimated by the existing combining method. Data was collected for rural two-lane roadways in Florida and Florida-specific safety performance functions (SPFs) were estimated for different crash types and severities. The CM Functions and adjustment functions were developed using linear and nonlinear regression models. The results of before–after with EB method show that the two single treatments and combination are effective in reducing total and SVROR (single vehicle run-off roadway) crashes. The results indicate that the treatments were more safety effective for the roadway segments with narrower original shoulder width in the before period. It was found that although the CMFs for multiple treatments (i.e., combination of two single treatments) were generally lower than CMFs for single treatments, they were getting similar to the roadway segments with wider shoulder width. The findings indicate that the combined safety effects of multiple treatments using HSM combining method are mostly over-estimated and the accuracy of HSM combining method vary based on crash types and severity levels. Therefore, it is recommended to develop and apply the adjustment factors and functions to predict the safety effects of multiple treatments when the HSM combining method is used.

1. Introduction

The Highway Safety Manual (HSM) (AASHTO, 2010) was developed to provide analytical methods to quantify the safety effects of decisions and treatments in planning, design, operation, and maintenance. Among four main chapters in the HSM, part D provides a variety of crash modification factors (CMFs). A CMF is a multiplicative factor that can estimate the expected changes in crash frequencies as a result of improvements with specific treatments. CMFs in part D have been developed using high-quality observational before–after studies that account for the regression to the mean threat. Observational before–after studies are common methods for evaluating safety effectiveness and calculating CMFs of specific roadway treatments (or countermeasures) (Gross et al., 2010). There are generally five approaches used to perform observational before–after studies: (1) naïve before–after, (2) before–after with yoked comparison, (3) before–after with comparison group (CG) method, (4) before–after with empirical Bayes (EB) approach and (5) before–after with the full Bayes (FB) approach. It is known that empirical Bayes and comparison group methods are more common approaches among various before–after studies. Moreover, the cross-sectional method has been

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commonly applied to derive CMFs due to the ease with which data can be obtained and compared to the before–after approaches. The cross-sectional method is also known as safety performance functions (SPFs) or crash prediction models (CPMs).

The HSM provides various CMFs for single treatments, but not CMFs for multiple treatments to roadway segments and intersections. Due to the lack of sufficient CMFs of multiple treatments, the HSM suggests that CMFs are multiplied to assess the combined safety effects of single treatments when the CMFs are estimated for same crash types (e.g., total crashes, night time crashes, bike related crashes, etc.) and severity levels (e.g., injury, fatal, PDO, etc.). However, the HSM cautions that the multiplication of the CMFs may over- or under-estimate combined effects of multiple treatments. Also, since the CMFs in the first edition of the HSM were determined based on past studies for specific regions, they may not represent a safety impact for other locations and conditions even if roadway characteristics are similar.

Thus, the objectives of this study are: (1) to evaluate safety effects of two single treatments (installing shoulder rumble strips, widening shoulder width) and combination (installing shoulder rumble strips + widening shoulder width) through estimation of CMFs and CM Functions, and (2) develop the adjustment factor and functions to assess the combined safety effects of multiple treatments by comparison of the combined safety effects of multiple treatments using the HSM combining method with actual calculated CMFs for multiple treatments. From this comparison, the study will show whether the existing HSM combining method for multiple treatments over- or under-estimates actual CMFs based on different crash types and severities.

The remainder of this study is organized as follows. The second section provides a background and the third section describes data collection and preparation. The fourth section documents methodologies. The fifth section presents and discusses the results and the final section provides the main conclusions. In this paper, we refer to 'all crash types (all severities)' as all crashes (KABCO), 'all crash types (fatal + injury)' as all crashes (KABC), 'single vehicle run-off roadways crashes (all severities)' as SVROR (KABCO), and 'single vehicle run-off roadways crashes (fatal + injury)' as SVROR (KABC) for crash types and severity levels. 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). Moreover, we refer to 'installing shoulder rumble strips' as SRS, 'widening (1–9 ft) shoulder width' as WSW, and 'installing shoulder rumble strips + widening (1–9 ft) shoulder width' as SRS + WSW.

2. Background

Since the first edition of HSM provides general procedures and statistical tools for estimating expected number of crashes, researchers have conducted research on the validation and application of the procedures to a specific area and different roadway facilities. In particular, safety effects of multiple treatments have recently emerged as an important issue of validation of the HSM procedures. In this section, two groups of recent studies were reviewed and discussed as follows: (1) studies that focused on the evaluation of safety effects of shoulder rumble strips and width, and (2) studies that assessed safety impacts of multiple treatments.

2.1. Safety effects of shoulder rumble strips and width

Roadside elements have been known as one of the most important hazards for roadway safety. In particular, shoulder rumble strips have been known to be effective in improving traffic safety (Griffith, 1999; Carrasco et al., 2004; Patel et al., 2007). Wu et al. (2014) proposed an approach to account for the variability in crash severity as a function of geometric design, traffic flow and other roadway features, and tested it by evaluating the safety effects of shoulder rumble strips on reducing crashes. It was found that shoulder rumble strips reduce the total number of crashes, but have no statistically significant effect on reducing the probability of a severe crash outcome. Park et al. (2014) assessed the safety effects of installing shoulder rumble strips and widening shoulder width on rural multilane roadways in Florida using the before–after with CG and EB studies, and cross-sectional method. The study showed that both installing shoulder rumble strips and widening shoulder width treatments are generally safety effective for all crashes and SVROR crashes. It was also found that the treatments were more safety effective (i.e., lower CMF) for the roadway segments with narrower original shoulder width in the before period. Zeng and Schrock (2013) evaluated the safety effects of 10 shoulder design types in winter and non-winter periods. They developed CMFs using cross-sectional methods. The results showed that wider and upgraded shoulders had significantly lower impact on safety in winter periods than non-winter periods. Turner et al. (2012) found that the installation of shoulder rumble strips resulted in an average of 21% reduction of all crashes and 40% reduction of run-off roadway crashes based on their review of 13 studies. Similar results to this study, Sayed et al. (2010) found that rumble strips can reduce run-off roadway crashes by 22.5%. Turner et al. (2009) also found from 5 recent studies that shoulder rumble strips reduced injury crashes by around 23%. Torbic et al. (2009) in the NCHRP 17-32 study investigated the safety effectiveness and optimal placement and dimensions of shoulder and centerline rumble strips. The study found that the installation of shoulder rumble strips on rural freeways resulted in an average of 11% reduction of SVROR (KABCO) crashes and 16% reduction of SVROR (KABC) crashes. It was also found that the installation of shoulder rumble strips on rural two-lane roadways resulted in an average of 15% reduction of SVROR (KABCO) crashes and 29% reduction of SVROR (KABC) crashes. Jovanis and Gross (2008) estimated the safety effects of shoulder width using case control and cohort methods. The results of the two methods showed that crashes decrease as shoulder width increases.

2.2. Safety effect of multiple treatments

Although the HSM cautions that the assumption of independence of different treatments can lead to over- or under-estimation of actual safety impact of multiple CMFs, there was a lack of studies that assess the combined safety effects of multiple treatments. Bauer and Harwood (2013) evaluated the safety effect of the combination of horizontal curvature and percent grade on rural two-lane highways. Safety prediction models of five types of horizontal and vertical alignment combinations for fatal-and-injury and PDO crashes were developed and CMFs representing safety performance relative to level tangents were calculated from these models. According to Pitale et al. (2009), the safety effects of paving shoulders, widening paved shoulders (from 2 ft to 4 ft), and installing shoulder rumble strips on rural two-lane roadways are 16%, 7%, and 15% reductions in crash rates, respectively. Moreover, the result indicated a 37% reduction in crash rates associated with installing shoulder rumble strips + paving shoulders to segments with aggregate shoulders. However, these results were estimated by simply comparing crash rates between the before and after conditions. Park et al. (2014) utilized six existing combining methods of multiple CMFs to compare predicted and actual calculated CMFs for installing shoulder rumble strips and widening shoulder width. Among the six existing methods of combining CMFs for single treatments, the HSM, systematic reduction of subsequent CMFs, applying only the most effective CMF, and