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Exploration and comparison of crash modification factors for multiple treatments on rural multilane roadways

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ABSTRACT

As multiple treatments (or countermeasures) are simultaneously applied to roadways, there is a need to assess their combined safety effects. Due to a lack of empirical crash modification factors (CMFs) for multiple treatments, the Highway Safety Manual (HSM) and other related studies developed various methods of combining multiple CMFs for single treatments. However, the literature did not evaluate the accuracy of these methods using CMFs obtained from the same study area. Thus, the main objectives of this research are: (1) develop CMFs for two single treatments (shoulder rumble strips, widening shoulder width) and one combined treatment (shoulder rumble strips + widening shoulder width) using before–after and cross-sectional methods and (2) evaluate the accuracy of the combined CMFs for multiple treatments estimated by the existing methods based on actual evaluated combined CMFs. Data was collected for rural multi-lane highways in Florida and four safety performance functions (SPFs) were estimated using 360 reference sites for two crash types (All crashes and Single Vehicle Run-off Roadway (SVROR) crashes) and two severity levels (all severity (KABCO) and injury (KABC)).

The results of both before–after and cross-sectional methods show that the two single treatments and the combined treatment produced safety improvement. It was found that safety effects were higher for the roadway segments with shoulder rumble strips and wider shoulder width. 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. However, although CMFs for multiple treatments were generally lower than CMFs for single treatments, they were similar for the roadway segments with shoulder width of 8–12 feet. More specifically, CMFs for single treatments were lower than CMFs for multiple treatments for the roadway segments with shoulder width of 9 feet or higher. Among different methods of combining CMFs, the HSM, Systematic Reduction of Subsequent CMFs, Applying only the most effective CMF, and Weighted average of multiple CMFs (Meta-Analysis) showed good estimates of the combined CMFs for multiple treatments with 2.2% difference between actual and estimated CMFs. The findings suggest that the existing methods of combining multiple CMFs are generally valid but they need to be applied for different crash types and injury levels separately.

Lastly, an average of the combined CMFs from the best two methods was closer to the actual CMF than the combined CMF from only one best method. This indicates that it is better not to rely on only one specific existing method of combining CMFs for predicting CMF for multiple treatments.

1. Introduction

The Highway Safety Manual (AASHTO, 2010) was developed by the Transportation Research Board and published in 2010 to introduce a science-based technical approach for safety analysis. The HSM provides analytical methods to quantify the safety effects of decisions and treatments in planning, design, operation, and maintenance.

One of the main parts in the HSM, Part D, contains crash modification factors (CMFs) for various treatments on roadway segments and at intersections. A CMF is a factor that can estimate potential changes in crash frequency as a result of implementing a specific treatment (or countermeasure). CMFs in Part D have been developed using high-quality observational before–after studies

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that account for the regression to the mean threat. Observational before–after studies are the most common methods for evaluating safety effectiveness and calculating CMFs of specific roadway treatments. There are generally four approaches used to perform observational before–after studies; (1) naïve before–after study, (2) before–after study with yoked comparison, (3) before–after study with comparison group and (4) before–after study with the Empirical Bayes (EB) approach. Among various before–after studies, Empirical Bayes and Comparison Group methods are more common approaches. Moreover, the HSM contains CMFs derived from cross-sectional studies. The cross-sectional method is also known as safety performance functions (SPFs) or crash prediction models. Part C in the HSM contains various SPFs and detailed procedure of its application.

The HSM provides various CMFs for single treatments, but not CMFs for multiple treatments to roadway segments. The HSM suggests that CMFs are multiplied to estimate the combined safety effects of single treatments. 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. The objectives of this study are (1) to evaluate safety effects (i.e. CMF) of two single treatments (installing shoulder rumble strips, widening shoulder width) and one combined treatment (installing shoulder rumble strips + widening shoulder width) using before–after studies and cross-sectional studies and (2) to compare the CMFs estimated using the existing methods of combining the CMFs for single treatments with actual CMFs for multiple treatments calculated using before–after studies. From this comparison, the study will show whether the existing methods of combining the CMFs over- or under-estimate actual CMFs.

The remainder of this study is organized as follows. The second section reviews the past studies on combining the CMFs for single treatments. The third section describes methodologies of estimating the CMFs. The fourth section describes data collection and preparation. The fifth section presents and discusses the results. The final section draws 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), 'SVROR (all severities)' as SVROR (KABCO), and 'SVROR (Fatal + Injury)' as SVROR (KABC) for crash types and severity levels.

2. Literature review

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 CMFs related to roadside treatments, and (2) studies that assessed safety impacts of multiple treatments, represented by the combined CMF, for various roadway conditions and developed the methods of combining multiple CMFs for single treatments.

2.1. Development and estimation of CMFs related to roadside elements

Roadside elements have been known as one of the most important hazards for roadway safety. 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 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. Turner et al. (2009) also found from 5 recent studies that shoulder rumble strips reduced injury crashes by around 23%. Jovanis and Gross (2008) estimated 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 and methods for combining multiple CMFs

Various methods of combining multiple CMFs for single treatments have been developed to estimate the combined safety effects of multiple treatments. The NCHRP project 17-25 (2008) used a survey to identify the methods of combining multiple CMFs, which have been implemented by different agencies. Table 1 summarizes the existing methods for combining multiple CMFs.

Method 1 is a common approach suggested by the HSM for combining multiple CMFs when independence of treatments is assumed. According to Garber and Hoel (2002), this method was first proposed by Roy Jorgensen and Associates for estimation of overall CMF of multiple CMFs. As shown by the equation, CMFs for single treatments are multiplied to estimate combined effects of multiple treatments. However, the assumption of independence cannot account for the potential correlations among multiple treatments.

Method 2 assumes that expected safety effects of the less effective treatment are reduced by a factor in the equation. However, the factor of this equation has no theoretical basis. Therefore, future research is needed to determine this reduction factor. The difference between Method 2 and Method 1 is that Method 2 accounts for difference in effectiveness among multiple treatments.

Method 3 is similar to Method 2 but it has not been used in any studies to estimate the safety effects of combined treatments. According to a survey of the NCHRP 17-25 project, this method was first introduced by Alabama State and the agency practices may have changed since 2003 when the survey was conducted. To the authors' best knowledge, there is no clear explanation of this method in the literatures. In particular, it is uncertain which treatment is considered as the first treatment when multiple treatments are applied at the same time. Thus, the authors assume that the treatment with the lowest CMF among all treatments is the first treatment in this study.

Method 4 proposed by Turner (2011) applies a specific weighted factor to the multiplication of CMFs for single treatments. The study determined this weighted factor based on different methods of combining CMFs for single treatments. Since the author applied this method to New Zealand only, the validity of this method for other regions needs to be checked.

Method 5 applies only the lowest CMF (i.e. the CMF for the most effective treatment) among CMFs for multiple treatments according to the survey of the NCHRP 17-25 project. However, this method ignores potential combined effect of multiple treatments. Thus, this method is likely to under-estimate the safety effect of multiple treatments.

Lastly, Method 6 introduced by Bahar (2010) determines a weighted average of multiple CMFs for the *same* treatment from different studies. Higher weight is applied to the CMF with smaller errors. Gross and Hamidi (2011) compared this method with other methods of combining CMFs.