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Relating crash frequency and severity: Evaluating the effectiveness of shoulder rumble strips on reducing fatal and major injury crashes

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ABSTRACT

To approach the goal of "Toward Zero Deaths," there is a need to develop an analysis paradigm to better understand the effects of a countermeasure on reducing the number of severe crashes. One of the goals in traffic safety research is to search for an effective treatment to reduce fatal and major injury crashes, referred to as severe crashes. To achieve this goal, the selection of promising countermeasures is of utmost importance, and relies on the effectiveness of candidate countermeasures in reducing severe crashes. Although it is important to precisely evaluate the effectiveness of candidate countermeasures in reducing the number of severe crashes at a site, the current state-of-the-practice often leads to biased estimates. While there have been a few advanced statistical models developed to mitigate the problem in practice, these models are computationally difficult to estimate because severe crashes are dispersed spatially and temporally, and cannot be integrated into the *Highway Safety Manual* framework, which develops a series of safety performance functions and crash modification factors to predict the number of crashes. Crash severity outcomes are generally integrated into the *Highway Safety Manual* using deterministic distributions rather than statistical models. Accounting for the variability in crash severity as a function geometric design, traffic flow, and other roadway and roadside features is afforded by estimating statistical models. Therefore, there is a need to develop a new analysis paradigm to resolve the limitations in the current *Highway Safety Manual* methods. We propose an approach which decomposes the severe crash frequency into a function of the change in the total number of crashes and the probability of a crash becoming a severe crash before and after a countermeasure is implemented. We tested this approach by evaluating the effectiveness of shoulder rumble strips on reducing the number of severe crashes. A total of 310 segments that have had shoulder rumble strips installed during 2002–2009 are included in the analysis. 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.

1. Introduction

"Toward Zero Deaths" is a national strategy, developed by the Federal Highway Administration (FHWA), to develop a systematic approach to eliminate highway traffic fatalities. The primary effort focuses on developing countermeasures that directly impact highway safety through engineering, enforcement, education, and emergency medical services (4 E's) (FHWA, 2012a). This goal can be translated into searching for effective treatments to reduce fatal and major injury crashes, referred to as severe crashes, through the 4E's. To achieve this goal, the selection of promising countermeasures is of utmost importance, and relies on the effectiveness of candidate countermeasures in reducing severe crashes. Although it is important to precisely evaluate the effectiveness of candidate countermeasures in reducing the number of severe crashes at a site, the evaluation is challenging because severe crashes are dispersed spatially and temporally. The current state-of-the-practice, found in the American Association of State Highway and Transportation Officials' (AASHTO) *Highway Safety Manual* (HSM) [AASHTO, 2010], does not offer a consistent approach to jointly consider crash frequency and severity in the safety prediction algorithms for two-lane, two-way roads, rural multi-lane highways, and urban and suburban arterials. For example, the two-lane, two-way roads safety prediction algorithm evaluates the reduction in the total number of crashes resulting from implementation of a

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Table 1
The crash data for the hypothetical example in the before period.

	Before	After
Total number of crashes	100	50 (predicted)
Number of severe crashes	20	
Probability of a crash becoming a severe crash	20%	

Table 2
The crash data for the hypothetical example in the after period.

	Before	After
Total number of crashes	100	50 (observed)
Number of severe crashes	20	15 (observed)
Probability of a crash becoming a severe crash	20%	30% (observed)

countermeasure, and then multiplies the proportion of severe crashes among all crashes to approximate the reduction in severe crashes. This approach essentially assumes that the crash severity distribution remains constant before and after the implementation of a countermeasure, which may lead to biased estimates. A similar approach is used when considering various crash types in the rural multi-lane and urban and suburban arterials crash prediction algorithms. Advanced statistical methods, which combine crash frequency and severity (e.g., Ma and Kockelman, 2006; Aguero-Valverde and Jovanis, 2009; Chiou and Fu, 2013), have recently been developed to improve the precision of traffic safety countermeasure effectiveness by considering the association among different crash severity levels. However, obtaining robust safety estimates using these methods is challenging due to the low relative proportion of severe crashes among all crashes. This study proposes a simple approach to estimate the effectiveness of a countermeasure based on the number of severe crashes. This approach cannot only identify the sources associated with the change in severe crash outcomes resulting from countermeasure implementation, but also builds on the HSM framework (AASHTO, 2010). The proposed approach is demonstrated by evaluating the effectiveness of shoulder rumble strips on reducing the number of severe crashes using data from Pennsylvania.

1.1. The limitations of current practice and statistical approaches

In general, there are two approaches in the current state-of-the-practice (e.g., HSM method) to assess crash severity. The first approach applies a safety performance function (SPF) to predict severe crash frequency, and then multiplies the result by a crash modification factor (CMF) that represents the effect of a specific countermeasure in reducing the number of severe crashes. Since severe crashes are dispersed temporally and spatially, the CMFs and SPFs are usually accompanied by high standard errors (e.g. Torbic et al., 2009). As high standard errors reduce the reliability of the estimated reduction in severe crash frequency, an alternative approach is often applied instead.

The alternative approach is a simplification of the first approach. Although the results may seem to be more efficient (lower standard errors), they may be biased. Consider a hypothetical example for a site where a countermeasure is planned for implementation. The purpose of the countermeasure is to reduce the number of severe crashes, and the “before” period crash data are shown in Table 1. The approach would initially predict the reduction in the total number of crashes using a SPF, before and after countermeasure implementation. For the purposes of this example, assume that the predicted total number of “after” period crashes is 50. Further, assume that based on historical, reported crash data that the number of severe crashes before the countermeasure was implemented is 20. Therefore, there is a 20 percent chance that a reported crash will result in a severe outcome during the before period. Because the proportion of severe crashes at this site is 20 percent based on historical reported crash data, the HSM would predict that the number of severe crashes after implementing a countermeasure to be $(100 - 50) \times 0.2 = 10$, because the change in the proportion of crash severity outcomes is not explicitly considered in the crash prediction algorithms. The HSM method would thus suggest that both total and severe crashes are reduced by 50 percent (100 – 50 total crashes and 20 – 10 severe crashes).

This approach may over- or underestimate severe crash reductions resulting from countermeasure implementation. The current state-of-the-practice does not consider how severe crash probabilities may change due to the implementation of the countermeasure.

Continuing with this hypothetical example, suppose there are 15 severe crashes reported after the countermeasure has been implemented, and the severe crash proportion increases to 30 percent of total crashes. The severe crash reduction can be decomposed into $(100 - 50) \times 0.2 + 50 \times (0.2 - 0.3) = 10 - 5 = 5$, which shows that ten severe crashes decrease to five severe crashes as a result of countermeasure implementation (Table 2).

The HSM crash prediction algorithm employs SPFs and crash modification factors to estimate the expected number of severe crashes on rural two-lane, rural multi-lane, and urban/suburban arterials. Default proportions are then applied to estimate crash severity outcomes (see HSM, volume 2, Table 10-5). The HSM encourages users to adjust these default proportions based on crash data available at the study sites, but the HSM does not consider that the severity proportions may change before or after implementation of a countermeasure.

Although more advanced methods, which combine crash frequency and severity models, have recently been developed to utilize the associations among crash severity levels to more precisely estimate countermeasure effectiveness, it is difficult to obtain robust estimates from these advanced models due to the low proportion of severe crashes in crash data. Recent studies have found that there is a lack of independence in crash types or crash severities that constitute the total number of crashes (Ma and Kockelman, 2006; Park and Lord, 2007; Ma et al., 2008; Yannis et al., 2008; Aguero-Valverde and Jovanis, 2009; El-Basyouny and Sayed, 2009; Ye et al., 2009), which would lead to excess variation around fitted values that cannot be captured (Berk and MacDonald, 2007). Therefore, a multivariate Poisson log-normal model (MVPLN) has been proposed as a promising alternative for simultaneously modeling crash frequency in terms of different crash severity outcomes. Chiou and Fu (2013) advanced the MVPLN model, which considers the crash severity distribution, and takes both crash frequencies and severities into account. This is referred to as multinomial generalized Poisson (MGP) model. Although these two model types can be used to evaluate the effects that a countermeasure has on the number of severe crashes, these models are computationally difficult to estimate due to the low proportion of severe crashes in the total crash distribution. Neither the MVPLN nor MGP models can take event attributes into account (e.g., daytime/nighttime conditions), and they cannot be integrated into the HSM framework because these models are more generalized than the current HSM framework and require the correlation structure of different severe crash outcomes. Therefore, there is a need to develop a new analysis paradigm to resolve these challenges.

1.2. Evaluate the effectiveness of a countermeasure in reducing severe crashes

Consider Fig. 1 as an illustration. A crash can be classified as a severe crash, or a less severe crash. In this illustration, a severe crash is defined as a fatal or major injury crash, while a less severe crash is