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Using network screening methods to determine locations with specific safety issues: A design consistency case study

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A B S T R A C T

The Highway Safety Manual provides multiple methods that can be used to identify sites with promise (SWiPs) for safety improvement. However, most of these methods cannot be used to identify sites with specific problems. Furthermore, given that infrastructure funding is often specified for use related to specific problems/programs, a method for identifying SWiPs related to those programs would be very useful. This research establishes a method for Identifying SWiPs with specific issues. This is accomplished using two safety performance functions (SPFs).

This method is applied to identifying SWiPs with geometric design consistency issues. Mixed effects negative binomial regression was used to develop two SPFs using 5 years of crash data and over 8754 km of two-lane rural roadway.

The first SPF contained typical roadway elements while the second contained additional geometric design consistency parameters. After empirical Bayes adjustments, sites with promise (SWiPs) were identified. The disparity between SWiPs identified by the two SPFs was evident; 40 unique sites were identified by each model out of the top 220 segments. By comparing sites across the two models, candidate road segments can be identified where a lack design consistency may be contributing to an increase in expected crashes. Practitioners can use this method to more effectively identify roadway segments suffering from reduced safety performance due to geometric design inconsistency, with detailed engineering studies of identified sites required to confirm the initial assessment.

1. Introduction

One of the foremost aspirations of transportation professionals, regardless of realm of expertise, is to maintain the highest levels of safety throughout the roadway network. Between 2003 and 2013, there has been a marked decrease in the total number of fatal crashes in the United States (with only the years 2005 and 2012 having increased fatal crashes relative to the prior year). The fatal crash rate over this same time period has decreased from 1.48 to 1.09 fatalities per million vehicle miles traveled (MVMT) (NHTSA, 2015). It remains to be seen whether this trend comes by dint of the recent economic downturn or through the efforts of programs like AASHTO's *Towards Zero Deaths* and the methodologies established in the Highway Safety Manual (HSM) (AASHTO, 2010). However, one fact remains evident: current levels of safety, both those perceived by the roadway user and analytically derived through crash statistics, should leave transportation professionals far from complacent. It is imperative that innovative and more proficient methods for evaluating roadway safety are continuously being developed through research efforts at all levels of the profession.

In the safety management process, network screening is often used to determine where safety improvements are likely to have the largest impact. This is referred to as finding Sites with Promise (SWIPs), blackspot identification, hotspot identification, etc. (Cheng and Washington, 2008; AASHTO, 2010; Montella, 2010). Once locations with potential for safety improvements have been identified, they are diagnosed to determine the reasons for safety issues and identification of safety countermeasures. However, funding for transportation improvements is often allocated for specific types of projects and problems. As such, a method for determining where roadway locations are with those specific types of problems, with adverse safety outcomes, is desired.

Other methods for identifying potentially unsafe sections of roadway have been developed. One such method, which has warranted significant study over the past decade, utilizes inconsistencies in roadway design. Although the notion of using design consistency as a means of assessing roadway safety is not a novel one, the manner in

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which professionals define "design consistency" has been subject to substantial discrepancy. Several researchers have defined consistency using evaluations of specific parameters (e.g., the consistency of operating speeds on successive elements (Krammes and Glascock, 1992; Krammes et al., 1995; Lamm et al., 1995)), while others have placed spatial limitations on the notion of design consistency (e.g., speed differentials on consecutive tangents and curves) (Fitzpatrick and Collins, 2000; Fitzpatrick et al., 2000). In general, design consistency (or rather, inconsistency) can be defined as the presence of a geometric feature or combination of adjacent features that violate driver expectancy, which in turn, may surprise drivers and make them drive in an unsafe manner (Messer, 1980) and leads to increased crash frequencies.

2. Literature review

2.1. Methods for identifying sites with promise

The HSM details multiple methods for identifying SWiPs, including discussion of the strengths and limitations of each method (AASHTO, 2010; Hauer, 1996). These methods include:

- Average Crash Frequency (ACF),
- Crash Rate (CR),
- Equivalent Property Damage Only Average Crash Frequency (EPDO-ACF),
- Relative Severity Index (RSI),
- Critical Rate (CritR),
- Excess Predicted Crash Frequency Using Method of Moments (EPCF-MM),
- Level of Service of Safety (LOSS),
- Excess Predicted Crash Frequency Using Safety Performance Functions (EPCF-SPF),
- Probability of Specific Crash Types Exceeding Threshold Proportion (PSCTETP),
- Excess Proportion of Specific Crash Types (EPSCT),
- Expected Average Crash Frequency with EB Adjustment (EACF-EB),
- EPDO Average Crash Frequency with EB Adjustment (EPDO-ACF-EB), and
- Excess Expected Average Crash Frequency with EB Adjustment (EACF-EB)

A number of issues can bias and impact the results when identifying SWiPs. These include regression-to-the-mean (RTM) bias, not accounting for traffic volumes, not establishing a performance threshold, not accounting for crash severity (if it is a desired criterion), not accounting for crash variance, prioritizing high crash locations, prioritizing high or low volume locations, over-emphasizing high severity locations, and the ability of the method to be used for diagnostics. For each of these issues, Table 1 shows which methods from the HSM account for/are impacted.

As indicated in Table 1, none of the methods account for all of the issues that are possible. It is interesting to note that the empirical Bayes (EB) based methods, typically considered the preferred method in the HSM, either prioritize high crash locations or over-emphasize high severity locations. The reason for the prioritization of high crash locations is that they do not account for crash variance. Instead, they use the difference between the observed and EB adjusted observed crashes to rank locations and identify SWiPs.

The PSCTETP and EPSCT methods can be used for diagnostics due to accounting for specific crash types. While this is useful in situations where there are specific crash types (i.e., target crashes), this is not useful for situations where a target crash type is not readily identifiable. When this is the case, other diagnosis tools are employed after identifying SWiPs. However, this makes finding SWiPs with specific problems (e.g., associated with a specific funding programs outcomes) difficult, and there is no guarantee that the best SWiPs for the program have been identified using the HSM process.

2.2. Design consistency

The design consistency literature provides several measures of consistency. As a rule, they focus on variations that impact drivers in negative ways. These measures include:

- speed profiles (Fitzpatrick et al., 2000; Fitzpatrick and Collins, 2000; Lamm et al., 1999; Anderson et al., 1999; Ng and Sayed, 2003; Awatta and Hassan, 2002; Anderson and Krammes, 1999; Wu et al., 2013; Montella and Imbriani, 2015),
- driver workload (Fitzpatrick et al., 2000; Wooldridge et al., 2003; Messer, 1980; Messer et al., 1981; Krammes and Glascock, 1992; Ng and Sayed, 2003), vehicle stability (Ng and Sayed, 2003; Torbic et al., 2014; Lam et al., 1999; McLean, 1974; Dunlap et al., 1978; Lamm et al., 1991; Morrall and Talarico, 1994) (based on AASHTO design guidance (AASHTO, 2011)), and
- alignment indices (Fitzpatrick et al., 2000; Polus and Dagan, 1987; Krammes et al., 1995; Castro et al., 2005; Anderson et al., 1999; Awatta and Hassan, 2002).

Many of these measures have also been included in safety evaluations. For instance, significant relationships have been found linking inconsistent speed profiles to a higher crash frequency (Anderson et al., 1999; Ng and Sayed, 2003; Awatta and Hassan, 2002; Anderson and Krammes, 1999; Wu et al., 2013; Montella and Imbriani, 2015). Krammes and Glascock (1992) and Ng and Sayed (2003) both evaluated the impacts of driver workload on crash frequency. The impacts of vehicle stability on crash experience has also been evaluated (Lam et al., 1999; McLean, 1974; Dunlap et al., 1978; Lamm et al., 1991; Morrall and Talarico, 1994; Ng and Sayed, 2003; Awatta and Hassan, 2002; Himes and Donnell, 2014). Studies including multiple design consistency measures have also found statistically significant relationships between design consistency measures and crash frequency (e.g., driving dynamics, operating speed consistency, inertial speed consistency, and the length of tangent preceding the curve) (Montella and Imbriani, 2015). In many cases, design consistency has been found to have a significant impact on crash outcomes.

While the majority of design consistency measures have been linked to safety in multiple studies, the impacts of alignment indices (i.e., factors capturing changes to the alignment of the road) on safety has received little attention. Anderson et al. (1999) has been one of the only studies to apply indices in safety regression models. The researcher investigated the impacts of average radius, the ratio of maximum to minimum radius, and the average rate of vertical curvature on crash frequency. The results indicated that all four indices were significant predictors of crash frequency. Awatta and Hassan (2002) also tested the ratio of maximum to minimum radius and found it to be a good indicator of crash rates.

There are several benefits to using alignment indices in consistency analysis over traditional design consistency measures. First, they are relatively easy to understand and calculate for use by practitioners (Fitzpatrick et al., 2000). This is essential when attempting to establish methods that can be implemented in real world scenarios. Additionally, the indices are direct functions of the horizontal and vertical alignments, which would allow for "quantitative analysis of successive segments from a system-wide perspective" (Fitzpatrick et al., 2000) without relying on speed prediction models that may not predict the actual operating speeds well. Ultimately, this is the main motive for conducting design consistency analysis.

Given the considerable lack of applied safety analysis, an abundance of literature to help conjecture at the plausibility of alignment indices as a measure of design consistency (Fitzpatrick et al., 2000; Polus and Dagan, 1987; Krammes et al., 1995; Castro et al., 2005), and the benefits of using alignment indices, there is great potential to expand on the

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