Accident Analysis and Prevention 95 (2016) 20–26

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Effect of horizontal curves on urban arterial crashes

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ARTICLE INFO

Article history:
Received 8 January 2016
Received in revised form 15 June 2016
Accepted 19 June 2016

Keywords:
Crash modification factors
Horizontal curve
Urban arterial
Crash prediction

ABSTRACT

The crash prediction models of the Highway Safety Manual (HSM), 2010 estimate the expected number of crashes for different facility types. Models in Part C Chapter 12 of the first edition of the HSM include crash prediction models for divided and undivided urban arterials. Each of the HSM crash prediction models for highway segments is comprised of a "Safety Performance Function," a function of AADT and segment length, plus, a series of "Crash Modification Factors" (CMFs). The SPF estimates the expected number of crashes for the site if the site features are of base condition. The effects of the other features of the site, if their values are different from base condition, are carried out through use of CMFs. The existing models for urban arterials do not have any CMF for horizontal curvature. The goal of this research is to investigate if the horizontal alignment has any significant effect on crashes on any of these types of facilities and if so, to develop a CMF for this feature.

Washington State cross sectional data from the Highway Safety Information System (HSIS), 2014 was used in this research. Data from 2007 to 2009 was used to conduct the investigation. The 2010 data was used to validate the results. As the results showed, the horizontal curvature has significant safety effect on two-lane undivided urban arterials with speed limits of 35 mph and higher and using a CMF for horizontal curvature in the crash prediction model of this type of facility improves the prediction of crashes significantly, for both tangent and curve segments.

1. Introduction

Chapter 12 of the Highway Safety Manual (HSM), 2010 contains crash prediction models for urban arterials. These mathematical models that predict the expected number of crashes for these highway facilities (highway segments and intersections) use several highway/intersection characteristics, but not horizontal curvature. Each of these models has a Safety Performance Function (SPF) and several Crash Modification Factors/Functions (CMFs). The SPF is part of the prediction model that estimates the expected number of crashes for the site if the site features are of certain conditions (called the "base conditions"). The SPFs in the HSM models are functions of the AADT (or AADTs of all intersecting approaches, if the site is an intersection) and the length (if the site is a segment). The effects of other features of the site, if different from base conditions, are considered through the CMFs. Chapter 12 of the 1st Edition of the HSM includes five crash prediction models for urban arterials based on the number of lanes in these highways. These models do not have any CMF for horizontal curvature, meaning that the effect of horizontal curvature on these types of highways is not captured in the models. The goal of this research was to show that the effect of horizontal curvature on crashes on some types of these highways is significant, and to derive a CMF for this characteristic.

HSM crash prediction models are developed and cross validated using data from a few States/regions. For these models to be used for other regions or even the same regions but for different periods the models need to be calibrated. This calibration is conducted by calculating the ratio of the observed crashes for the most recent years for a number of sites with similar features to the number of crashes that is predicted for those sites for the same period by the model. This ratio is called calibration factor for that model and is used for adjusting the model prediction for that State/region for near future years.

The Washington State data for urban arterials segments was used in this study. The data was comprised of highway segment features and crash data over four years (2007–2010). This data – obtained from the FHWA HSIS Laboratory – was extensively manipulated and analyzed. The 2007–2009 data was used to study the need for considering horizontal curvature in the model and to develop a new CMF for horizontal curvature if the effect of this highway feature is found significant. The 2010 data was used to validate the proposed CMFs within the framework of the current HSM

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http://dx.doi.org/10.1016/j.aap.2016.06.014
0001-4575/

models. In this validation effort, the observed numbers of crashes of 2010 were compared to the predictions of the HSM models with and without the proposed CMFs.

2. Related research

This section reviews some major literature related to the development of Crash Modification Factors (CMF), previously known as Accident Modification Factors (AMF) and Crash Reduction Factors (CRFs) that carry similar concepts.

Harwood et al., 2000 recommended combining AMFs used to estimate the effect of certain countermeasures on crashes with a base model to estimate the predicted number of crashes. The model and AMFs presented in this research, with some minor changes, were implemented as the Crash Prediction Module of the Interactive Highway Safety Design Model (IHSDM), 2016. The IHSDM model that was developed for rural two-lane highways was later adopted as the prototype model for the development of the HSM crash prediction models. With respect to the sources for AMFs used in the rural two-lane highway crash prediction models, Harwood et al., 2000 state that, "AMFs were based on a variety of sources including results of before-and-after accident evaluations, coefficients or parameter values from regression models, and expert judgment. The expert panel considered well-designed before-and-after evaluations to be the best source for AMFs. However, relatively few well-designed before-and-after studies of geometric design elements were found in the literature···Coefficients or parameter values from regression models are considered less reliable, but were used when no before-and-after study results were available... Expert judgment alone was exercised in limited cases where no better results were available."

Shen et al., 2004 provided a comprehensive survey of the use of Crash Reduction Factors (CRFs) in State DOTs. Of 42 states that responded to the survey, 34 confirmed that they use these factors in their safety improvement programs. As they pointed out, there are two major approaches for developing such factors: (I) before-and-after studies, and (II) regression analysis using cross-sectional data. They concluded that, "the before-and-after method is the more widely used approach for developing CRFs." This survey confirmed that, of the three types of before-and-after studies (i.e., "simple method," "with comparison group method," and "with EB method"), the "simple method" was still the most widely used among state DOTs.

Lord and Bonneson, 2006 also provided a useful summary of the history of CRFs and Accident Modification Factors (AMFs). They suggested three major applications for AMFs, namely, "within the preliminary design stage", "for assessing design consistency", and "for evaluating design exceptions."

Bonneson et al., 2005 noted that, "In some instances, an AMF is derived from a safety prediction model as the ratio of 'crash frequency with a changed condition' to "crash frequency without the change." In other instances, the AMF is obtained directly from a before-after study. Occasionally, crash data reported in the literature were used to derive an AMF."

Washington et al., 2005, in evaluating the IHSDM intersection crash prediction models, used a regression analysis procedure to recalibrate the models. They proposed a method using cross sectional data, with the main principles being to use a sub-set of data to develop a base model and then to use other sub-sets of data to develop AMFs. The same evaluation and approach was presented in C. Lyon et al., 2003. However, in a study by Lord and Bonneson, 2007, in which they developed a model for rural frontage road segments in Texas, they rejected the applicability of the above method to their problem mostly because of the "small number of crashes in the database." They instead developed a negative binomial model, and from that model extracted AMFs for the explanatory variables.

Gross et al., 2010 provided a thorough overview of the CMF development process, including methods for developing reliable CMFs and issues to consider when applying the various methods. This overview shows a number of methods and provides instructions for deriving the most appropriate ones depending on a number of factors including the type of data available. With respect to cross-sectional studies it defines the CMF as "the ratio of the average crash frequency for sites with and without the feature." In terms of method used for this type of study it identified the "multiple variable regression" as the most common modeling method for deriving CMFs in this type of study. With respect to before-after studies it focused on the studies with comparison groups and also the empirical Bayes studies.

Carter et al., 2012 provided recommendations similar to Gross et al., 2010 for cross sectional studies. Their conclusion was: "The CMF can be derived by taking the ratio of the average crash frequency of sites with the feature to the average crash frequency of sites without the feature." They then added "For this method to work, the two groups of sites should be similar in their features except for the feature. In practice, this is difficult to accomplish and multiple variable regression models are used. These cross-sectional models are also called safety performance functions (SPFs) or crash prediction models (CPMs)." With respect to before-after studies, Carter et al., 2012 provided guidance on how to consider major biases associated with these studies including "regression-to-the-mean," "change in traffic volume," and "history trend" bias. However, since cross sectional data was used, most of these issues related to before-after studies did not apply.

Banihashemi, 2015 studied the effect of horizontal curvature on crashes on Rural Multilane highways and proposed CMFs for this feature that improved the prediction of crashes for both tangent and curve sections of highways. A two-step process was used by M. Banihashemi. At the first step the ratios of the observed number of crashes to the predicted number of crashes were calculated for the entire data as well as for the subsets of the data that were produced by splitting the data into bins/groups based on horizontal curvature. The deviations of these ratios for the subsets confirmed the significance of the effect of the curvature on crashes. At the second step the horizontal curvature CMFs were estimated by studying the way these ratios change. This methodology is similar to the approach Carter et al., 2012 recommended for cross sectional studied.

3. Methodology

The methodology used in this study was exactly similar to the one used by Banihashemi (*13*) except there was an additional split of the data based on the posted speed of the highways. Arterials with posted speed of 30 mph and lower were grouped together and the ones with posted speed of 35 mph and higher were grouped together. The two speed categories already exist in the HSM Chapter 12 as "Low" and "Intermediate or High." Urban arterials were classified into five highway types as they are in HSM models. These were two-lane undivided (2U), two-lane undivided with a two-way left turn lane (3T), four-lane divided (4D), four-lane undivided (4U), and four-lane undivided with a two-way left turn lane (5T). At first for each of these arterial types it was determined whether the effect of horizontal curvature on crashes was significant, and then a CMF was developed if this effect was significant. A validation process was also developed to validate the findings of the research. Washington State data from 2007 to 2009 (experiment data) were used in the development process. 2010 data (validation data) were used to validate the quality of the developed CMF.