Accident Analysis and Prevention 76 (2015) 83–91

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Development of crash modification factors for changing lane width on roadway segments using generalized nonlinear models

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ARTICLE INFO

Article history:
Received 23 July 2014
Received in revised form 18 December 2014
Accepted 8 January 2015
Available online xxx

Keywords:
Crash modification factor
Generalized nonlinear model
Lane width
Speed limit
Roadway segment

ABSTRACT

This study evaluates the effectiveness of changing lane width in reducing crashes on roadway segments. To consider nonlinear relationships between crash rate and lane width, the study develops generalized nonlinear models (GNMs) using 3-years crash records and road geometry data collected for all roadway segments in Florida. The study also estimates various crash modification factors (CMFs) for different ranges of lane width based on the results of the GNMs. It was found that the crash rate was highest for 12-ft lane and lower for the lane width less than or greater than 12 ft. GNMs can extrapolate this nonlinear continuous effect of lane width and estimate the CMFs for any lane width, not only selected lane widths, unlike generalized linear models (GLMs) with categorical variables. The CMFs estimated using GNMs reflect that crashes are less likely to occur for narrower lanes if the lane width is less than 12 ft whereas crashes are less likely to occur for wider lanes if the lane width is greater than 12 ft. However, these effects varied with the posted speed limits as the effect of interaction between lane width and speed limit was significant. The estimated CMFs show that crashes are less likely to occur for lane widths less than 12 ft than the lane widths greater than 12 ft if the speed limit is higher than or equal to 40 mph. It was also found from the CMFs that crashes at higher severity levels (KABC and KAB) are less likely to occur for lane widths greater or less than 12 ft compared to 12-ft lane. The study demonstrates that the CMFs estimated using GNMs clearly reflect variations in crashes with lane width, which cannot be captured by the CMFs estimated using GLMs. Thus, it is recommended that if the relationship between crash rate and lane width is nonlinear, the CMFs are estimated using GNMs.

1. Introduction

Crash modification factors (CMFs) express the expected changes in crash frequency after a treatment (countermeasure) is implemented on a roadway facility. CMFs have been estimated using observational Before–After study or the Cross-sectional method. The Before–After study evaluates the safety effects (i.e., effectiveness in reducing crash frequencies) of treatments by comparing crash frequencies during the time periods before and after the treatments are applied. On the other hand, the Cross-sectional method is used when the Before–After study cannot be used due to the following conditions (AASHTO, 2010): (1) the date of the treatment installation is unknown,(2) the data for the period before treatment installation are not available, and (3) the effects of other factors on crash frequency must be controlled for creating a crash modification function (CMFunction).

The last condition above typically occurs when multiple treatments are applied simultaneously. For example, it is possible that changing lane width is accompanied with the other changes (e.g., median width, speed limit). However, it is difficult to isolate the effect of a single treatment from the effects of the other treatments applied at the same time using the Before–After method (Harkey et al., 2008). For this reason, CMFs have been estimated using the Cross-sectional analysis (Lord and Bonneson, 2007; Stamatiadis et al., 2009; Li et al., 2011; Carter et al., 2012).

The Cross-sectional method requires the development of safety performance functions (SPFs) or crash prediction models for calculation of CMFs. In general, the SPFs describe crash frequency as a function of geometric factors, average annual daily traffic (AADT) and length of roadway segment (SPFs for segments only). The most common type of SPFs has been a generalized linear model (GLM) with negative binomial (NB) distribution as the model accounts for over-dispersion. The coefficient associated

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http://dx.doi.org/10.1016/j.aap.2015.01.007
0001-4575/

with a specific variable (i.e., treatment) obtained from the model estimation is used to calculate the CMF (Stamatiadis et al., 2009).

Since the coefficient is assumed to be fixed in the GLM, the CMF for a specific treatment is also fixed. However, the fixed CMF cannot account for nonlinear effects of the treatment on crash frequency. For instance, increasing lane width may not always reduce crash frequency. Thus, in order to reflect nonlinear effects of variables, researchers have applied different methods. For instance, Haleem et al. (2013) used the truncated basis functions to represent nonlinear effects of shoulder width, median width, and AADT on crash frequency. These functions capture different rates of change in crash frequency for different ranges of variables in multivariate adaptive regression splines (MARS). However, the rate of change is assumed to be fixed within a given range of a variable although the rate can vary within the range.

Ma and Yan (2014) examined the nonlinear relationship between driver's age and the odds of being at fault in rear-end crashes using an additive logistic regression model. In this method, the effect of each explanatory variable is described in the "smooth" function of the variable instead of the step function. The result of the smooth function shows that the rates of change in the odds vary across different age groups, whereas the rates are assumed to be fixed in the step function. Similarly, Zhang et al. (2012) estimated nonlinear relationships between crash frequency and exposure for different segment types using the generalized additive models (GAM). Li et al. (2011) also developed the method of estimating CMFs using the GAM. However, the estimation of the additive models is complex since they include more parameters and the coefficients of the variables may not be clearly estimated (Li et al., 2011).

In this regard, Lao et al. (2013) proposes a generalized nonlinear model (GNM) for application to crash analysis. Unlike GLMs, GNMs account for nonlinear effects of independent variables on a dependent variable using a "nonlinearizing" link function. The study demonstrated that right shoulder width, AADT, grade percentage, and truck percentage have nonlinear effects on rear-end crashes. They also found that GNMs can better reflect the nonlinear relationships than GLMs based on residual deviance. However, the study investigated only the main effects of each variable, but not the effects of interaction between variables, and focused on rear-end crashes only. Moreover, although the estimation of GNMs is relatively simpler than the estimation of the other methods, GNMs have not been applied to the estimation of the CMFs.

The objectives of this study are to develop the method of estimating the CMFs for changing lane width using GNMs and assess the safety effects of changing lane width for different ranges of lane width and severity levels based on the estimated CMFs.

2. Lane width and safety

Many researchers have examined the relationship between lane width and crash frequency in past studies. In general, they found that an increase in lane width reduces crash frequency (Lord and Bonneson, 2007; Yanmaz-Tuzel and Ozbay, 2010; Labi, 2011; Park et al., 2012; Haleem et al., 2013). This is mainly because a wider lane increases the separation between vehicles in adjacent lanes and allows larger deviation of vehicles from the center of the lane (Akgügör and Yıldız, 2007). Larger lane width helps prevent crashes by reducing chances of vehicle encroachment to adjacent lanes. Drivers also feel less pressure as the distance with the other objects in both sides of their vehicles increases (Yang et al., 2013).

It is also suggested in the Highway Safety Manual (HSM) (AASHTO, 2010) that crash frequency decreases as lane width increases – i.e., the CMF increases as lane width decreases from 12-ft lane. However, according to the HSM, CMF for a given lane width varies with AADT based on the studies by Zegeer et al. (1988) and Griffin and Mak (1987). More specifically, the CMF is lowest for AADT < 400 veh/day and highest for AADT > 2000 veh/day. Based on the expert panel's judgment, the CMF is assumed to increase linearly with AADT for AADT between 400 and 2000 veh/day (Harwood et al., 2000). For this range of AADT, the CMF is estimated using the CMFunctions which describe the CMF as a function of AADT.

However, Hauer (2000) suggested that an increase in separation of vehicles on wider lanes tends to increase vehicle speeds and reduce spacing between vehicles. Consequently, an increase in lane width may rather increase crash frequency. In fact, Qin et al. (2004) found that wider lane increased single-vehicle crashes on highway segments in Michigan. Mehta and Lou (2013) also found that crash frequency increased with lane width on rural two-lane roads and rural four-lane divided roads in Alabama. The study accounted for the effects of speed limits and shoulder width in the crash prediction models.

Some studies explained that these opposite effects of increasing lane width are due to the association between lane width and shoulder width, and differences in local conditions. Gross et al. (2009) reported that effects of lane width on crash frequency were neither consistently positive nor negative due to variation in shoulder width. Thus, they suggested that CMFs be determined considering interaction between lane width and shoulder width. Potts et al. (2007) also recommended that narrowing lane width be used as a treatment based on local conditions since the effect of lane width varies with location.

These inconsistent results are also because the relationship between lane width and crash frequency is not linear. Gross and Jovanis (2007) and Gross (2013) found that the odds ratio of crash occurrence increases or decreases depending on ranges of lane width where the base case is 12 ft (=3.66 m). The odds ratio increases for the ranges of lane width less than 10.5 ft and greater than 12.5 ft but it decreases for lane width of 10.5–12.5 ft. Similarly, Xie et al. (2007) showed that the relationship between lane width and crash frequency is described in a "concave-downward" polynomial function – crash frequency increases as lane width increases from 9 ft to 10 ft and decreases as lane width increases from 10 ft to 13 ft. This indicates that there is a need to reflect this nonlinear relationship for developing the CMFs to assess safety effects of changing lane width.

Some studies showed that changing lane width is also associated with crash injury severity. Labi (2011) found that increasing lane width reduced higher percentage of fatal/injury crashes but lower percentage of PDO crashes. In particular, wider lanes are more effective in reducing fatal/injury crashes for rural major collectors. Similarly, Wong et al. (2007) reported that a decrease in lane width increases fatal/injury crashes at signalized intersections. However, Park et al. (2012) found that an increase in lane width rather increases fatal/injury crashes at nighttime. Hauer et al. (2004) showed that lane width is associated with PDO crashes, but not injury crashes on four-lane undivided roadway segments. However, differential effects of changing lane width on crash injury severity have not been associated with nonlinear relationship between lane width and crash frequency.

3. Data

In the Cross-sectional method, it is recommended in the HSM that crash prediction models are developed using the crash data for both treated and untreated sites for the same time period – typically 3–5 years (AASHTO, 2010). Typically, the Cross-sectional method requires much more samples than the Before–After study, say 100–1000 sites (Carter et al., 2012). Sufficient sample size is particularly important when many variables are included in the crash prediction models. This ensures large variations in crash frequency and variables, and helps to better understand their inter-