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Sensitivity analysis of an accident prediction model by the fractional factorial method

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Abstract

Sensitivity analysis of a model can help us determine relative effects of model parameters on model results. In this study, the sensitivity of the accident prediction model proposed by Zegeer et al. [Zegeer, C.V., Reinfurt, D., Hummer, J., Herf, L., Hunter, W., 1987. Safety Effect of Cross-section Design for Two-lane Roads, vols. 1–2. Report FHWA-RD-87/008 and 009 Federal Highway Administration, Department of Transportation, USA] to its parameters was investigated by the fractional factorial analysis method. The reason for selecting this particular model is that it incorporates both traffic and road geometry parameters besides terrain characteristics. The evaluation of sensitivity analysis indicated that average daily traffic (ADT), lane width (*W*), width of paved shoulder (PA), median (*H*) and their interactions (i.e., ADT–*W*, ADT–PA and ADT–*H*) have significant effects on number of accidents. Based on the absolute value of parameter effects at the three- and two-standard deviation thresholds ADT was found to be of primary importance, while the remaining identified parameters seemed to be of secondary importance. This agrees with the fact that ADT is among the most effective parameters to determine road geometry and therefore, it is directly related to number of accidents. Overall, the fractional factorial method was found to be an efficient tool to examine the relative importance of the selected accident prediction model parameters.
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Keywords: Accident prediction model; Number of accidents; Road safety; Sensitivity analysis; Factorial design method

1. Introduction

Rapidly growing population and urbanization result in a significant increase in number of vehicles and traffic accidents as well. Unfortunately, nearly one million people lose their lives and about ten millions face different injuries worldwide in various traffic accidents every year. Additionally, millions of dollars are lost due to accidents and a significant amount of money is spent for health treatment and rehabilitation. All these have made transportation planners and transportation engineers consider road safety more seriously. Designing safer roads and/or rehabilitation of current road geometries are among important factors in reducing traffic accidents.

Traffic accidents take place due to a number of factors such as road, environment, driver and vehicle, and their interrelationship. Therefore, traffic accident prediction models are developed including certain parameters to represent the effect of these factors. Since average daily traffic is considered the most effective parameter many researchers have taken it as the only parameter in their models (McDonald, 1953; Webb, 1955; Pickering et al., 1986; Hauer et al., 1988; Bonneson and McCoy, 1993 among others). In order to obtain more reasonable accident predictions, road geometry elements were also included in some accident prediction models (e.g., Belmont, 1954; Zegeer et al., 1987; Zegeer and Deacon, 1987; Li et al., 1994).

Sensitivity analysis of a model is very useful to determine relative effects of model parameters on model results. The most commonly used sensitivity method is the traditional "change one-factor-at-a-time" approach. The major weakness of this method is its inability of identifying multiple factor interactions among the model parameters. As discussed in the following section, several studies have been presented in the literature to investigate the sensitivity of accident prediction models to traffic and road geometry parameters by the standard "change one-factor-at-a-time" approach. However, in addition to main parameter effects, multiple factor interactions should also be

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identified to better understand internal model dynamics of accident prediction models.

As an alternative approach, the factorial design method developed by Box et al. (1978) has been employed in various sensitivity analyses of environmental models (e.g., Henderson-Sellers, 1992, 1993; Liang, 1994; Liong et al., 1995; Barros, 1996; Henderson-Sellers and Henderson-Sellers, 1996; Yildiz, 2001; Gebremichael and Barros, 2005). Unlike the traditional approach, this method has the advantage of testing the sensitivity of model results: (a) to changes in main parameters and (b) to interactions between groups of parameters.

The objective of this study is to utilize the factorial design method in the sensitivity analysis of a widely used accident prediction model proposed by Zegeer et al. (1987) which includes both traffic and road geometry parameters besides terrain characteristics.

2. Background

The influence of traffic volume and road geometry elements on accident rate has been a subject of various scientific studies. There is an interesting relationship between number of accidents and traffic volume such that accident rate increases for both low and high traffic volumes. In the former case, mostly individual vehicles are involved in accidents, while in the latter case, group of vehicles are involved in accidents in general. Road design parameters including lane and shoulder widths and numbers, sight distance, and curve characteristics, etc. can play a significant role on the type of accidents mentioned previously.

Using "change one-factor-at-a-time" approach various studies regarding sensitivity of accident rate on road geometry elements (lane width, shoulder width and type, and median) have been presented in the literature. Increasing lane width from 9 to 12 ft Cope (1955) showed that fatal accident rate decreases by 40.5%, while nonfatal accident rate decreases by 19.8%. On the other hand, decreasing total lane width from 48 to 40 ft Heimbach et al. (1983) found out that accident rate increases about 25%. Using the study results of Heimbach et al. (1983), McLean (1997) estimated that increasing each lane width by 0.25 m accident rate decreases between 2 and 2.5%. Similar studies investigating the effect of lane with on accident rate were performed by Zegeer et al. (1987), Hadi et al. (1995), Zegeer and Council (1995), Miaou (1996) and Wang et al. (1998). Overall, these studies demonstrate that lane width has a significant influence on accident rate.

In an early study on the effect of shoulder width on accident rate, Silyanov (1973) reported that accident rate is almost 2.2 times higher on roads with 0.5 m shoulder as compared to roads with 3 m shoulder. In addition to shoulder width, the same author indicated that shoulder type is also an effective parameter on accident rate. More specifically, when increasing unpaved and paved shoulder widths by 3 ft accident rate decreases by 19 and 22%, respectively (TRB, 1987). According to Zegeer and Council (1995), one foot increase in paved and unpaved shoulder width yields about 8 and 7% decrease in accident rate, respectively.

It was shown that existence of median itself and its physical characteristics has significant influence on decline of accident rate on multilane roads. For example, in a research performed on a 2 × 2 lane road with median in Australia (Tunç, 2004), considerable amount of decrease in accident rate was observed for different type of medians: 30% for a narrow painted median, 48% for a narrow raised median and 54% for a wide median. According to the same research equipping medians with barriers significantly lessened severity of accidents and widening them up to 3 m resulted in a considerable decrease in accident rate.

3. Factorial design method

Unlike the standard "change-one-factor-at-a-time" method, the factorial design method has the advantage of testing both the sensitivity to changes in individual parameters, and to interactions between groups of parameters. Given specific perturbations of the magnitudes of the parameters (usually two levels: upper and lower) the method tests a fixed number of possible values for each of the model parameters, and then identifies and ranks each parameter according to some pre-established measure of model sensitivity by running the model through all possible combinations of the parameters. For example, a factorial design at two perturbation levels for n parameters will result in 2^n combinations of the model parameters. This is illustrated in the following three-parameter (2^3 factorial) design with parameters α, β and θ, and prediction variable X. The corresponding design and computation matrices for single parameters and parameter interactions are given in Table 1 where "+" and "−" signs represent the two possible values of each parameter and parameter interactions (upper and lower levels, respectively). The sign of parameter interactions is determined using the following rule: plus times minus gives a minus and minus times minus or plus times plus gives a plus. The effects due to each parameter and parameter interactions are estimated using the following equation:

$$E_j = \frac{\sum_{i=1}^{n}(S_{ij}X_i)}{N_j} \tag{1}$$

in which E_j represents the effect of the jth factor (i.e., in jth column), n the total number of experimental runs (i.e., $n = 8$), S_{ij} represents the sign in row i and column j, X_i represents the value of the prediction variable obtained from the ith experimental run and N_j is the number of "+" signs in column j.

Table 1
Design and computation matrices for the three-parameter example

Run	Design matrix			Computation matrix				Prediction variable
	α	β	θ	$\alpha\cdot\beta$	$\alpha\cdot\theta$	$\beta\cdot\theta$	$\alpha\cdot\beta\cdot\theta$	X
1	−	−	−	+	+	+	−	X_1
2	+	−	−	−	−	+	+	X_2
3	−	+	−	−	+	−	+	X_3
4	+	+	−	+	−	−	−	X_4
5	−	−	+	+	−	−	+	X_5
6	+	−	+	−	+	−	−	X_6
7	−	+	+	−	−	+	−	X_7
8	+	+	+	+	+	+	+	X_8

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