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Crash frequency analysis of left-side merging and diverging areas on urban freeway segments – A case study of I-75 through downtown Dayton, Ohio

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ABSTRACT

This paper analyzes the effect of left- and right-side merging and diverging areas and other variables such as light condition, roadway pavement condition, drivers' age and presence of construction work zones on the occurrence frequency of crashes. A 6.5-mile (10.5-km) section of I-75 that passes through downtown Dayton, Ohio was considered. The area of interest has a high traffic volume and consists of different geometric design challenges including closely spaced merging and diverging ramps. A four-year record of crash data (2005–2008) and a statistical modeling technique that assumes a negative binomial distribution on generalized linear models (GLMs) were used to develop separate models for merging and diverging areas. The model results show that left-side merging and diverging areas are critical elements in crash frequency in the vicinity of ramps on freeways. In addition, pavement condition, light condition, and work zones were found to be significant predictors of crash frequency. Specifically, the results indicate that crashes are about 7.88 times more likely to occur on merging areas located on the left side of the freeway lanes compared to those on the right. For diverging areas, about 2.26 times more crashes are likely to occur near diverging areas on the left compared to those diverging on the right side of the freeway. In addition, adverse pavement conditions (such as wet pavement, snow, and ice), adverse light conditions (such as darkness and glare), and presence of work zone were found to be significant variables in the occurrence of crashes.

1. Introduction

Traffic crashes occurring on transportation facilities continue to be major socio-economic concerns due to the large number of lives, bodily injuries and loss of property claimed by these crashes. Consequently, transportation agencies are exerting considerable amount of effort and resources to improve these facilities as countermeasures in an attempt to alleviate these losses. The causes of traffic crashes can be categorized into classes of variables such as geometric design elements, human/driver-related factors, traffic and environmental factors. The arrangement of lanes and ramps in urban freeways at merging and diverging areas are important geometric factors for safe and efficient use of these facilities. Due to considerably greater demand for access to freeways as they pass through urban central business areas (CBDs) and the limited right-of-way

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available compared to suburban and rural areas, configurations of on- and off-ramps are sometimes erratically provided both on the left- and right-sides of the mainline freeway lanes in order to make them as accessible as possible.

Therefore, this paper explores the effects of geometric characteristics by comparing the location of left-side ramps versus right-side ramps by developing two separate models for merging and diverging areas. In addition, other factors such as driver's age, traffic volume on mainlines, environmental factors (i.e., roadway pavement conditions, lighting conditions, weather conditions), and presence of construction work zones at the time of crash were also explored. For this study, the negative binomial distribution was used to predict the effect of these variables on crash frequency.

A number of efforts have studied and modeled safety issues and factors affecting crash frequency in the vicinity of freeway junctions over the past several years. Because left-side junctions are generally rare, most of these studies have concentrated with the more typical, the right side junctions. A study by Bauer and Harwood (1998) indicated that ramp annual average daily traffic (AADT), area type, ramp type, ramp configuration, and ramp length to be significant factors affecting crash frequency. Bared et al. (1999) evaluated the safety effects of acceleration and deceleration lanes and found that off-ramps (on diverging areas) were more prone to traffic crashes than on-ramps (on merging areas) and the crash frequency at ramps is affected by freeway's AADT.

McCartt et al. (2004) studied crashes that occurred on urban interstate ramps in northern Virginia. Most of the crashes (about 50%) occurred at exit (off) ramps and they were mostly run-off road type of crashes. Several studies (Chen et al., 2009; Chen and Lu, 2009; Pan et al., 2010) evaluated the safety impacts of arrangement and number of lanes on freeways on diverging areas in Florida. Mergia et al. (2013) explored factors contributing to injury severity at freeway merging and diverging areas in Ohio by developing separate models for merging and diverging areas. However, it is noteworthy to mention that so far all of the above discussed studies did not consider left-side merging and diverging areas. Studies by Zhou et al. (2010), Zhao and Zhou (2011) and Chen et al. (2011) studied safety and operational effects of left-side exits at freeway diverging areas in Florida. All these Florida studies conclude that left-side diverging areas have higher crash frequency as compared to those located on the right side of the mainlines. It is regrettable that these studies did not include merging areas.

Since left-side junctions are not as common as right-side junctions on most freeways, their impacts on freeway safety have not been adequately studied. The studies by Zhou et al. (2010), Zhao and Zhou (2011) and Chen et al. (2011) evaluated the effect of diverging areas only as mentioned above and the junctions studied are located over a relatively larger geographical area. Therefore, a study of the occurrence frequency of crashes at left-side and right-side junctions in urban areas of relatively higher ramp/junction density and a comparison thereof would be of paramount significance in the management, planning and safe and efficient operation of urban freeways. Accordingly, the present study utilized a short section, 6.5 miles (10.5 km) long of Interstate 75 that passes through downtown Dayton that includes interchanges at US-35, SR 4 and SR 48, which have been named among the nation's malfunctioning junctions due to the high number of traffic crashes occurring on this short stretch of I-75. This section is characterized by uncommon geometric designs such as left side on- and off-ramps, weaving sections, and varying number of lanes.

2. Methodology

Crash frequency modeling involves counting crashes that are related to a certain specific set of explanatory variables of interest. Therefore, crash frequency data is basically a count data that is commonly modeled assuming Poisson and negative binomial distributions (Shankar et al., 1995; Milton and Mannering, 1998; Chang, 2005; Lord et al., 2005; Xie and Zhang, 2008; Lee and Abdel-Aty, 2009; Moon and Hummer, 2009; Liu et al., 2010).

A unique characteristic of the Poisson distribution is the assumption of equality between the mean and variance of the expected number of crashes. However, there are many instances where this assumption may not be valid for traffic crash count data (Lord et al., 2005; Hauer, 2001). Due to this limitation, model prediction using the Poisson distribution could lead to biased and erroneous parameter estimates and hence incorrect inferences. As a result, for an over-dispersed crash data the negative binomial distribution becomes a better choice (Poch and Mannering, 1996; Hauer, 2002). The probability distribution for the negative binomial is modeled as shown in Eqs. (1)–(4) (Simonoff, 2003):

$$f(Y_i : \mu_i, v) = \frac{\Gamma(Y_i + v)}{Y_i!\Gamma(v)} \left(\frac{v}{v + \mu_i}\right)^v \left(\frac{\mu_i}{v + \mu_i}\right)^{Y_i} \tag{1}$$

$$\mu_i = E(Y_i) = \exp(\beta X_i) \tag{2}$$

$$Var(Y_i) = \mu_i(1 + \alpha_i \mu_i) \tag{3}$$

$$\alpha = 1/v \tag{4}$$

where:

β and α = coefficients estimated using maximum likelihood techniques
Γ = Gamma function,
Y_i = the observation i; $i = 1, \ldots, n$