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Research Article

Spatial Influence Analysis of Traffic Safety in Diverging Areas between Freeway Segments and Off Ramps

Cuiping Zhang,[1] Xuedong Yan,[1] Meiwu An,[2] and Hui Zhao[1]

[1] *MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Beijing 100044, China*
[2] *Saint Louis County Department of Transportation and Public Works, 1050 N. Lindbergh, St. Louis, MO 63132, USA*

Correspondence should be addressed to Xuedong Yan; xdyan@bjtu.edu.cn

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There tend to be more crashes occurring in freeway diverging segments due to increasing traffic conflicts between diverging vehicles and nondiverging vehicles. The diverging segments have a safety impact on the precedent basic segments and the following off ramps. It is always a challenge to accurately define the safety influential area of freeway diverging segments. In previous studies, fixed buffer in size is pregiven for crash frequency analysis in diverging segments, which lacks theoretical and practical support. In this study, the safety influential area was investigated from the statistical point of view. Data from a geocoded GIS crash database for Colorado Springs metropolitan area was used; the statistically significant factors associated with crash frequency were examined for the spatial influence of freeway diverging segments. Also, the generalized linear models with negative binomial link function were applied to predict the crash frequency for freeway diverging segments and off ramps based on the influential area. The results may give some insights into the causation of crashes on diverging segments and off-ramp intersections.

1. Introduction

Traffic crashes have caused substantial economic loss, injuries, and fatalities in our society. Traffic safety has become a serious concern among policymakers, engineers, and planners during transportation project planning and design. Many studies have been conducted to investigate contributing factors to the crashes and develop statistical models for prediction and analyses of traffic crashes. These studies have been performed at either an area level such as traffic analysis zones or a road level such as highway segments.

The area-level safety analyses are associated with traffic analysis zones (TAZs) which are typical units in transportation planning process. Since a TAZ is a geographic unit for inventorying socioeconomic data and estimating trip generation, the area-level crash analysis usually focuses on examining the relationship between crashes and both socioeconomic factors and network variables [1, 2]. The road-level safety analyses can be further categorized into segment level and intersection level. The segment-level safety analyses have concentrated on identifying the effects of traffic characteristics [3, 4], road design characteristics [5, 6], driver behavior [7], pavement conditions [8], and so forth, on crash frequency. For the intersection-level safety analyses, it is usually further classified into crash analysis of signalized intersections and unsignalized intersections. For the signalized intersections, a lot of researches have been conducted in the past decades which relate crashes with intersection geometry [9, 10], road environment [11], traffic-related variables [12], and so forth. What should be pointed out is that since the continuous increment of the unsignalized intersection crashes, more and more research attention has also been paid to this type of safety recently. For the unsignalized intersections related safety analysis, Haleem et al. [13] used a Bayesian reliability method to reduce level of uncertainty in predicting crashes at 3-leg and 4-leg unsignalized intersections. Several significant variables were identified, including traffic volume on major roads, existence of stop signs, number of right and/or left turn lanes, median type on major roads, and left/right shoulder widths. Abdel-Aty et al. [14] used multivariate adaptive

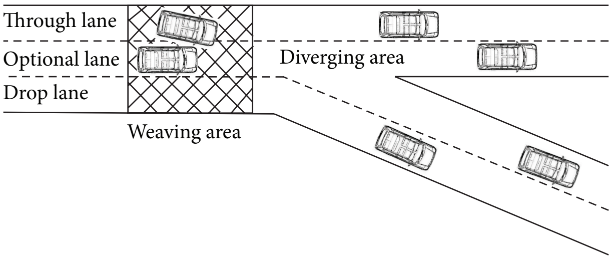


Figure 1: Junctions between freeway segments and off ramps.

regression spines (MARS) models to forecast angle crashes at unsignalized intersection. It was found that traffic volume on major roads, distance to the nearest signalized intersection upstream, distance between successive unsignalized intersections, median type on major roads, percentage of trucks on major roads, and size of intersection have important impacts on safety performance of unsignalized intersections.

The junction of a freeway diverging segment and an off ramp can be regarded as a special unsignalized intersection. A typical freeway diverging segment at an off ramp is illustrated in Figure 1. At the diverging area, a vehicle trying to leave freeway sometimes needs to make lane change to exit or even brake sharply to avoid missing exit if it is in the inside lane. Diverging areas are exposed to a relatively higher risk of crash compared to basic freeway segments. Several studies are conducted to investigate contributing factors for crashes at diverging areas [15–19]. It was found that weather condition, alcohol involvement, ramp ADT, ramp lengths, and speed-change lanes were strongly related to crash occurrence at diverging areas.

To make freeway diverging segments and off ramps safer, identifying contributing factors and implementing engineering countermeasures are critical. Accurately distinguishing the accidents on freeway diverging segments from off ramps is a vital precursor of safety related applications such as accident risk modeling, risk mapping, and accident hotspot identification [20]. In previous studies, intersection safety researches generally suggested that crashes associated with an intersection include all the crashes that occurred within a 250-foot length of two intersecting roads upstream and downstream from the intersection [21]. It was regarded as the safety influence area of an intersection. This practice is adopted in many state DOTs (Departments of Transportation) in the US since it is consistent with intersection functional area. Drivers start to perceive the intersection and begin maneuvers from a distance upstream. The process of maneuvers and deceleration might cause conflict and potential for crashes. Similarly, crashes that happened in freeway diverging areas might be relevant to driving maneuvers from a distance of freeway segments upstream or off ramp downstream. However, the 250-foot radii used for a typical intersection safety influence area will not apply on the junction of diverging segments and off ramps since traffic characteristics and driving behaviors on freeways are distinct from urban streets. Therefore, this paper aims to study safety influence area for the junction of freeway diverging segments and off ramps and examine statistically significant factors for crash frequency using the crash database provided by the Pikes Peak Area Council of Governments (PPACG). It is discussed that the predetermined influence area may not be suitable. The influence area should be investigated in a more comprehensive way and be determined specifically for the area studied.

The rest of the paper is organized into 4 sections. In the next section, methodology used in this paper, including buffer technique of GIS and negative binomial (NB) regression model, is briefly reviewed; in Section 3, regression results are presented and discussed in detail. Conclusions and extensions are included in Section 4.

2. Methodology

2.1. Data Preparation. Two freeways across the Pikes Peak metropolitan area in Colorado state of the United States are selected for this study. Geocoded crash data for the metropolitan planning region is provided by PPACG, together with traffic data and the road network data. All the three sets of data are prepared in GIS format. From the road network data, 72 freeway diverging segments at off ramps were identified in the area. Figure 2 illustrates a typical freeway diverging area at off ramp which is located on highway I-25 in the area.

All accident records in the crash dataset are categorized by types of accident: fatal, injury, and Property Damage Only (PDO). And each accident record involves at least one vehicle. Total accidents were counted from July 2006 to December 2010.

The crash frequency was set to be dependent variable. For the independent variables, they are identified from highway geometric design, traffic control and operation, traffic volume, and pavement condition data based on literature reviews and engineering judgments. The selection of independent variables in this study follows three rules listed below:

(1) Variables have a meaningful interpretation from the engineering perspective.
(2) Variables can be associated with an off ramp.
(3) There is a weak correlation among the selected variables.

It is worth noting that colinearity may exist among the independent variables. As is well known, the colinearity could lead to serious confounding problems and inflate variance in estimation. The misleading results could make it difficult to explain the relationships between crash frequency and the independent variables intuitively. After conducting colinearity analysis, 9 continuous variables and 6 nominal variables were finally selected. All the 15 variables represent unique aspects of the diverging area's characteristics and are listed in Tables 1 and 2.

2.2. Data Processing Using Buffer Technique of GIS. To estimate the proper size of safety influential area of freeway diverging segments at off ramps, buffers with gradually increasing size are utilized for the purpose of analysis. For a GIS-based traffic safety analysis, a buffer is useful for proximity identification of highway facilities. The buffer technique in

Table 1: Continuous variables description for diverging area analysis.

Variables	Description	Sum	Mean	Std. deviation	Maximum	Minimum
Ramp.Length	The length of a ramp in mile	11.67	0.16	0.10	0.54	0.03
Ramp_ADT	Average daily traffic of a ramp	361.82	5.03	4.18	14.73	0.02
Up_Interstate.Length	The length of up interstate in mile	33.10	0.46	0.54	2.78	0.01
Up_Interstate_ADT	Average daily traffic of up interstate	2689.53	37.35	14.92	64.08	11.78
Down_Interstate.Length	The length of down interstate in mile	19.73	0.27	0.17	0.79	0.03
Down_ADT	Average daily traffic of down interstate	2327.76	32.33	13.24	58.48	10.66
IRI	Pavement roughness in inches per mile	101.29	1.41	0.40	2.43	0.00
Median_Width	Median width in feet	524.30	7.28	7.15	18.30	0.00
Speed_Limit	Speed limit	4327.85	60.11	12.42	74.56	31.07

Notes: the number representing average daily traffic (ADT) is in thousand.

Table 2: Nominal variables description for diverging area analysis.

Variables	Descriptions	Values and meanings	Frequency	
			0	1
Ramp.Lanes	Number of lanes of a ramp	0, 1; 0 denotes 1 lane; 1 denotes 2 lanes	57	15
Up_Interstate.Lanes	Number of lanes of up interstate	0, 1; 0 denotes 1 and 2 lanes; 1 denotes 3 and 4 lanes	40	32
Down_Interstate.Lanes	Number of lanes of down interstate	0, 1; 0 denotes 1 and 2 lanes; 1 denotes 3 and 4 lanes	45	27
Median_Type	Median type (1 to 4 scale): 1 = curbed; 2 = positive barrier; 3 = unprotected; and 4 = none	0, 1; 0 refers to scale 1, scale 2, and scale 3; 1 refers to scale 4	43	29
PSR	Present serviceability rating (0 to 5 scale): 0 = extremely deteriorated pavement; 5 = pavement in excellent condition	0, 1; 0 denotes rating 3.5; 1 denotes rating 2.5, rating 3, rating 3.9, and rating 4.1	60	12
Truck_Percent	Percent truck related	0, 1; 0 denotes 4, 6, 7, and 9 percent; 1 denotes 11 percent	27	45

Figure 2: A typical diverging area at an off ramp along highway I-25.

GIS can be applied to accurately measure the target objects in units of distance. It can be seen that the bigger buffer size will lead to more crashes in the diverging area. However, much bigger buffer size might contain some crashes irrelevant to this diverging area. And smaller buffer size may not include all the crashes which are related to the diverging area. Therefore, a desirable buffer size is worth being investigated in order to better represent the related accidents. And gradually increasing buffer size in a certain distance unit can be used to explore the optimal safety influence area of the diverging area. Creating buffers at an interval of 50-foot increments may not result in a reasonable analysis by overrepresenting crashes while creating buffers at an interval of 1 foot may bring about overwhelming data processing and analysis. In this study,

Table 3: Summary statistic of crash frequency from 30 feet to 300 feet.

Variable	Mean	Std. deviation	Variance	Minimum	Maximum
Crash_30feet	0.61	2.17	4.69	0	15
Crash_60feet	2.69	7.54	56.78	0	61
Crash_90feet	4.38	10.19	103.79	0	70
Crash_120feet	5.75	13.02	169.57	0	96
Crash_150feet	7.96	17.77	315.79	0	134
Crash_180feet	10.04	23.98	574.94	0	190
Crash_210feet	13.13	27.08	733.29	0	199
Crash_240feet	14.78	27.91	778.88	0	208
Crash_270feet	16.69	29.23	854.55	0	218
Crash_300feet	18.99	29.96	897.39	0	221
Average	9.50	18.11	328.10	0	140

a series of buffers from 30-foot radius to 300-foot radius with an interval of 30-foot increments were created using ArcGIS 10 software.

To have deeper insights into the selected factors, for each buffer size, the influential factors were analyzed using NB regression model.

2.3. Negative Binomial Regression Model. In this study, the NB regression model was developed to identify the significant contributing factors to crash frequency and estimate the influential area of freeway diverging area [22, 23]. The basic formulation of Poisson regression is as follows:

$$P(y_i) = \frac{\lambda_i^{y_i} e^{-\lambda^i}}{y_i!}, \tag{1}$$

where $P(y_i)$ is the probability of y_i accidents occurring at a diverging area i per year. In this model, λ_i is both the mean and variance parameters of y_i. Therefore, λ_i is equal to the expected accident frequency $E(y_i)$ for diverging area i. Parameter λ_i is estimated by the following equation:

$$\lambda_i = e^{\beta x_i}, \tag{2}$$

where x_i is the independent variable and β is the coefficient of independent variable.

The structure of Poisson regression model is

$$\operatorname{Var}[y_i] = E[y_i], \tag{3}$$

where $\operatorname{Var}[y_i]$ is the estimated variance of the accident frequency and $E[y_i]$ is the estimated mean of the accident frequency.

It is noted that accident frequency often demonstrates overdispersion pattern, which may violate the assumption of Poisson regression model. Overdispersion may cause standard errors of the estimates to be underestimated (i.e., a variable may appear to be a significant predictor when it is in fact not significant). To confirm the pattern, basic statistical analysis is conducted and the results are shown in Table 3. As shown in Table 3, the variances of accident frequencies are greater than the means, which indicates that the crash frequency data are overdispersed. As Poisson regression is applicable under the assumption of equidispersion, that is, the mean is equal to the variance of the dependent variable, the Poisson model is no longer proper for analyzing the accident frequencies in this study. However, as an extension of Poisson regression, NB regression can be well used under the condition of overdispersion.

In the NB regression model, an error term ε_i is introduced to account for the bias caused by the overdispersion as shown in

$$\lambda_i = e^{\beta x_i} + e^{\varepsilon_i}, \tag{4}$$

where ε_i is a gamma distribution error with mean 1.0 and variance α^2. The resulting NB distribution equation is

$$P(y_i) = \frac{\lambda_i^{y_i} e^{-\lambda^i} e^{\varepsilon_i}}{y_i!}. \tag{5}$$

Separating ε_i out of this expression produces the unconditional distribution of y_i. The equation can be written as

$$P(y_i) = \frac{\Gamma(\theta + y_i)}{[\Gamma(\theta)\, y_i!]} u_i^{\theta} \left(1 - u^i\right)^{y^i}, \tag{6}$$

where $u_i^{\theta} = \theta/(\theta + \lambda_i)$ and $\theta = 1/\alpha$.

Since there is an additional parameter α in NB regression model, the model structure becomes

$$\operatorname{Var}[y_i] = E[y_i]\{1 + \alpha E[y_i]\}. \tag{7}$$

Parameter α relates the mean of the variance which is estimated using maximum likelihood estimation.

3. Results and Discussions

3.1. Regression Results. The NB model statistics analysis was conducted using the SPSS software package (Version 19.0). A stepwise method was applied for identifying the significant explanatory variables. The chi-square statistic ($p < 0.1$) was also used for understanding the statistical differences for the variables due to the relatively small sample size of this study.

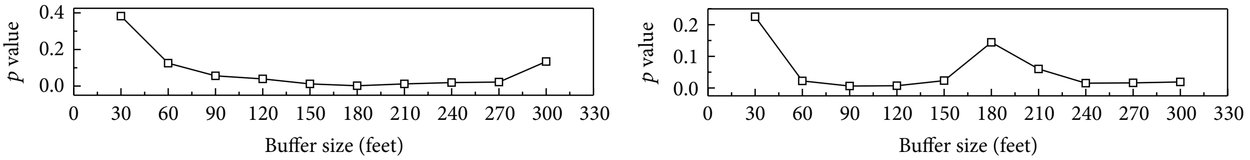
Table 4 summarizes the estimation results of the NB regression model with all the 15 variables for each buffer size.

Table 4: p value of variables for different buffer size.

Variables	30 feet		60 feet		90 feet		120 feet		150 feet		180 feet		210 feet		240 feet		270 feet		300 feet	
	Coef.	p-V	Coef.	p-V	Coef.	p-V	Coef.	p-V	Coef.	p-V	Coef.	p-V	Coef.	p-V	Coef.	p-V	Coef.	p-V	Coef.	p-V
(Intercept)	−3.887	0.486	−1.711	0.493	−4.794	0.044	−3.210	0.134	−4.157	0.024	−5.174	0.003	−3.103	0.077	−2.488	0.102	−1.837	0.221	−.817	0.583
[Ramp.Lanes = 0]	1.742	0.068	.396	0.517	.700	0.257	.733	0.189	.843	0.067	.981	0.025	.835	0.043	.893	0.016	.855	0.021	.419	0.251
[Up_Interstate.Lanes = 0]	−.643	0.512	−1.525	0.008	−.881	0.134	−.690	0.176	−.484	0.270	−.538	0.211	−.312	0.459	−.279	0.471	−.406	0.302	−.626	0.107
[Down_Interstate.Lanes = 0]	−.168	0.876	.713	0.309	.881	0.210	.995	0.106	1.363	0.012	1.646	0.001	.955	0.055	.887	0.051	.897	0.051	1.089	0.020
[PSR = 0]	1.435	0.196	.631	0.286	.542	0.408	.110	0.845	.245	0.595	.202	0.643	−.200	0.669	−.226	0.564	−.260	0.502	−.372	0.333
[Median_Type = 0]	−.699	0.618	−.605	0.428	−.597	0.411	−.529	0.419	−.894	0.112	−.562	0.304	.467	0.371	.320	0.502	.494	0.319	.613	0.203
[Truck_Percent = 0]	−1.602	0.365	−.355	0.699	1.393	0.093	1.336	0.076	1.377	0.043	1.558	0.019	1.084	0.101	1.208	0.045	1.352	0.026	1.134	0.064
Ramp.Length	−5.508	0.315	−5.080	0.086	−4.375	0.154	−3.381	0.188	−2.260	0.294	.160	0.932	.249	0.894	−.251	0.880	−.142	0.932	−.499	0.751
Ramp_ADT	−.019	0.860	−.137	0.207	−.068	0.325	−.040	0.471	.008	0.843	.017	0.677	−.009	0.828	.002	0.951	−.019	0.588	−.036	0.306
Up_Interstate.Length	.883	0.062	.798	0.060	.406	0.358	.397	0.306	.130	0.671	.185	0.544	.200	0.537	.204	0.475	.295	0.307	.043	0.871
Up_Interstate_ADT	.019	0.858	.137	0.206	.068	0.324	.040	0.469	−.008	0.846	−.017	0.680	.009	0.824	−.002	0.956	.020	0.584	.036	0.304
Down_Interstate.Length	−4.215	0.225	−.283	0.897	−.153	0.945	−.405	0.824	−.176	0.909	−.687	0.639	−1.328	0.372	−1.539	0.249	−1.728	0.202	−1.067	0.398
Down_Interstate_ADT	−.019	0.857	−.137	0.206	−.068	0.324	−.040	0.470	.008	0.845	.017	0.679	−.009	0.825	.002	0.954	−.019	0.585	−.036	0.305
IRI	.178	0.861	.324	0.588	.270	0.709	.015	0.982	.140	0.792	.373	0.455	−.145	0.793	−.280	0.522	−.347	0.420	−.528	0.226
Median_Width	.152	0.169	.001	0.983	.034	0.515	.024	0.625	.037	0.401	.020	0.646	−.058	0.165	−.037	0.334	−.041	0.305	−.066	0.085
SPEED_LIMI	.009	0.784	.010	0.510	.021	0.090	.012	0.245	.013	0.188	.013	0.139	.017	0.046	.013	0.078	.010	0.191	.013	0.094
α	.617	—	1.110	—	1.363	—	1.112	—	.830	—	.783	—	.766	—	.625	—	.659	—	.649	—

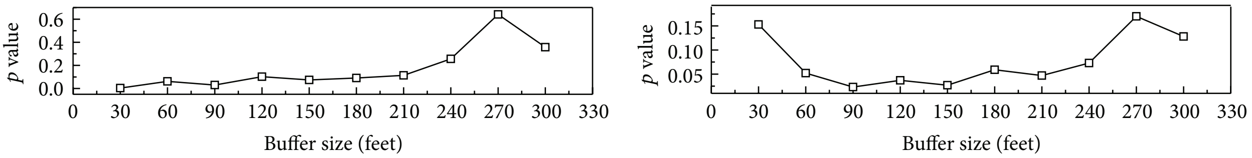
Table 5: p value of variables for different buffer size.

Variables	p value									
	30 feet	60 feet	90 feet	120 feet	150 feet	180 feet	210 feet	240 feet	270 feet	300 feet
Ramp.Lanes	0.382	0.125	0.056	0.039	0.012	0.002	0.012	0.019	0.022	0.134
Ramp.Length	0.225	0.022	0.006	0.007	0.023	0.144	0.060	0.015	0.016	0.019
Ramp_ADT	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Speed_Limit	0.004	0.062	0.030	0.102	0.074	0.091	0.114	0.256	0.641	0.358
Average	0.153	0.052	0.023	0.037	0.027	0.059	0.047	0.073	0.170	0.128



(a) Ramp.Lanes

(b) Ramp.Length



(c) Speed_Limit

(d) Average

Figure 3: p value distribution of independent variables for different buffer sizes.

It is noteworthy that the dispersion parameter α is significantly different from zero. This confirms the appropriateness of the NB model rather than the Poisson model. The coefficients of dependent variables interpret the degree to which the explanatory variables contribute to the crashes. Taking 30-foot buffer as an example, the positive coefficient of variable Up_Interstate_ADT implies that the frequency of crashes in the diverging area increases as the traffic amount increases. Other variables with a positive coefficient include Ramp.Lanes, PSR, Up_Interstate.Length, IRI, Median_Width, and Speed_Limit. In contrast, the variables with a negative sign imply that the increasing values of these variables can reduce the crash frequency. These variables include Median_Type, Ramp_ADT, Up_Interstate.Lanes, Down_Interstate.Lanes, Truck_Percent, Down_Interstate_ADT, Ramp.Length, and Down_Interstate.Length.

Using the stepwise regression approach, it is found that, among the 15 independent variables, Ramp.Lanes, Ramp.Length, Ramp_ADT, and Speed_Limit are the most statistically significant variables in determining accident likelihood from 30-foot buffer to 300-foot buffer. The p values of the significant independent variables are shown in Table 5. From the table, it can be seen that 90-foot buffer has the lowest p value on average in estimating the crash frequency.

To have an intuitive understanding of the relationship between crash frequency and the independent variables, a plot of p value distribution of independent variables for different buffer sizes is presented in Figures 3(a)–3(c). The p value of Ramp_ADT is rather small for all buffer sizes, which means the traffic amount has a strong influence on the crash frequency, no matter what size of the buffer we take. Besides, it can also be observed that p value distribution of the three variables, Ramp.Lanes, Ramp.Length, and Speed_Limit, varies monotonically with the buffer size. And all of the 4 different independent variables, Ramp.Lanes, Ramp.Length, Ramp_ADT, and Speed_Limit, have relatively low p values at the 90-foot buffer. Figure 3(d) also gives the average p value distribution of the 4 independent variables listed above for different buffers with a radius from 30 feet to 300 feet. It can be observed that the average p value of Ramp.Lanes, Ramp.Length, Ramp_ADT, and Speed_Limit decreases rapidly at first and reaches the lowest value at the 90-foot buffer; then it starts a rising trend and gets to the second lowest value at the 150-foot buffer. The average p value increases sharply from 180-foot buffer to 300-foot buffer and the possible reason may be that this area is highly influenced by interstate segment. Highlighted by the red circle, the lower p value indicates that the areas from 90 feet to 150 feet around the off-ramp intersections are dominant in terms of traffic safety.

3.2. The Result Analysis. Table 6 gives the parameter estimates for the significant variables from 30-foot buffer to 300-foot buffer. For example, the crash frequency at 90-foot buffer size can be predicted by

$$\begin{aligned} E(A) = \exp\bigl(&-1.391 + 0.819 \cdot \text{Ramp.Lanes} - 4.197 \\ &\cdot \text{Ramp.Length} + 0.195 \cdot \text{Ramp\_ADT} + 0.016 \\ &\cdot \text{Speed\_Limit}\bigr), \end{aligned} \tag{8}$$

where $E(A)$ denotes predicted crash frequency.

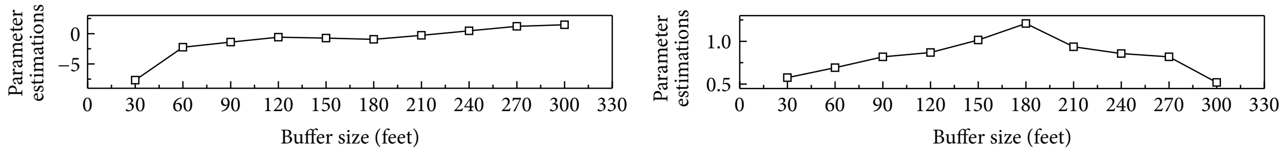
Table 6: Parameter estimates for the significant variables at different buffer size.

Parameter	(Intercept)	[Ramp.Lanes = 0]	[Ramp.Lanes = 1]	Ramp.Length	Ramp_ADT	Speed_Limit
Crash_30feet	−7.657	.5754	0[a]	−4.010	.313	.049
Crash_60feet	−2.233	.692	0[a]	−3.937	.251	.016
Crash_90feet	−1.391	.819	0[a]	−4.197	.195	.016
Crash_120feet	−.589	.869	0[a]	−4.052	.175	.012
Crash_150feet	−.729	1.015	0[a]	−3.327	.199	.012
Crash_180feet	−.940	1.208	0[a]	−1.704	.214	.012
Crash_210feet	−.280	.936	0[a]	−2.233	.214	.011
Crash_240feet	.457	.857	0[a]	−2.820	.191	.008
Crash_270feet	1.201	.819	0[a]	−2.799	.169	.003
Crash_300feet	1.469	.520	0[a]	−2.717	.143	.006

Dependent variables: Crash_30feet, Crash_60feet, Crash_90feet, Crash_120feet, Crash_150feet, Crash_180feet, Crash_210feet, Crash_240feet, Crash_270feet, and Crash_300feet.

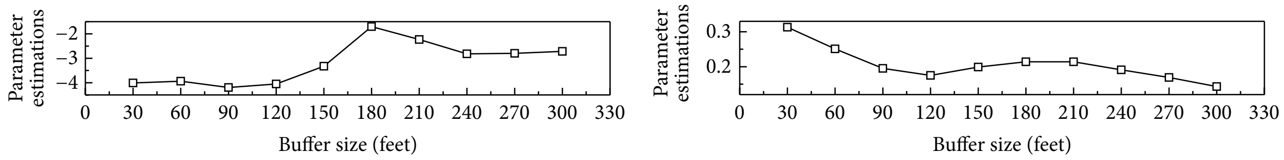
Model: (Intercept), Ramp.Lanes, Ramp.Length, Ramp_ADT, Speed_Limit.

[a] Set to zero because this parameter is redundant.



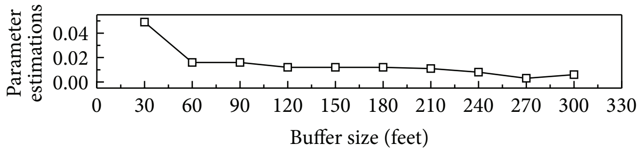
(a) Intercept

(b) [Ramp.Lanes = 0]



(c) Ramp.Length

(d) Ramp_ADT



(e) Speed_Limit

Figure 4: Parameter estimations of intercepts and independent variables for different buffer sizes.

For clarity, the estimated parameters are plotted in Figure 4 for all buffer sizes from 30 feet to 300 feet. From the figure, the positive sign of Ramp.Lanes' coefficient indicates that an increase in the number of lanes contributes to a higher crash frequency, presumably because a multilanes exit is more complicated than a one-lane exit. There are usually more lane-changing maneuvers at the multilanes exit, which could increase sideswipe accidents. The coefficient for the variable of Ramp_ADT is also positive, indicating that the number of crashes increases with the increase of traffic volume diverging into ramp. Moreover, the coefficient of speed limit shows that, as the speed limit increases, the risk of accidents increases. A previous study reported that, controlling the other factors, purely increasing operation speed in road segments by 1% would approximately result in 2% increment in injury crash rate and 4% increment in fatal crash rate [24]. The only negative sign in the regression equation is for the variable of ramp length. It indicates that fewer crashes would occur at longer ramp while controlling the other variables. The reduced accident likelihood for a longer ramp is consistent with previous findings [25–27]. The driving tasks of diverging from freeway segments into ramps require negotiating with other vehicles to change lanes, decelerating to exit from the main line, and accommodating the exiting traffic. A sudden change in speed and direction due to insufficient deceleration distance in a shorter ramp can raise the risks of both rear-end and sideswipe crashes.

As modeled in (8), when the ramp length was increased by 1 mile, the crash frequency would decrease by $e^{-4.197}$ times. To have a more intuitive illustration of the relationship, Figure 5 presents the accident frequencies under different ramp length conditions. The numbers of ramp lanes are set

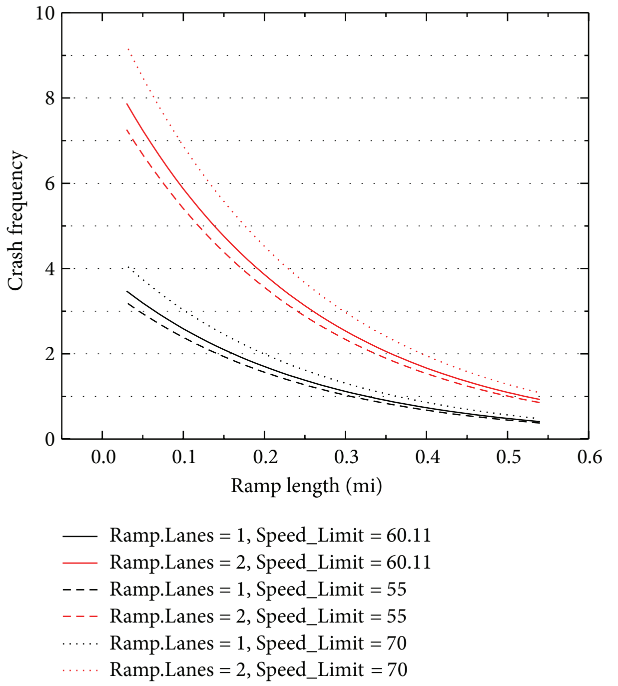


FIGURE 5: NB models for predicting accidents occurring under ramp length conditions.

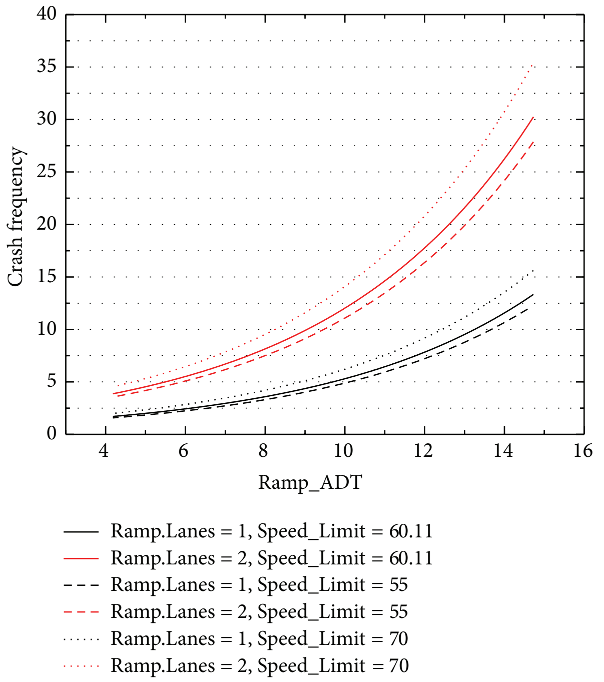


FIGURE 6: NB models for predicting accidents occurring under ramp ADT conditions.

as 1 and 2. Since Colorado has one of the highest speed limits in the United States, which are 75 mph for rural freeways, 65 mph for urban freeways, and 35 mph for off ramps, here we set the value of the variable "Speed_Limit" as 65 and 75 and the mean as 60.11. As is reported, shorter ramps yield higher crash risk for accident prediction. Furthermore, greater impact on the crash frequency could also be expected for the number of ramp lanes.

For predicting the accident frequency, the relationship between ramp ADT and crash frequency could be illustrated in Figure 6. As shown in the figure, when the ramp ADT was increased by 1 unit, the crash frequency would increase by $e^{-0.195}$ times. Greater impacts of the number of ramp lanes on crash frequency could also be observed.

4. Conclusions and Extensions

The primary objective of this study was to explore the safety influence area of diverging areas between freeway segments and off ramps and the contributing factors of traffic crash frequencies in the areas. The data were collected at 72 diverging areas from the two freeways across the Pikes Peak region, Colorado, US. The NB models were developed to identify the relationships between crashes and explanatory variables. The analysis yielded some interesting results on the relationship between crash frequency and ramp-related variables at different buffer sizes ranging from 30 feet to 300 feet with a 30-foot increment.

The main results could be listed as follows:

(1) Different from many previous studies, the generally increasing buffer sizes of the diverging area are adopted. The 4 statistically significant factors including Ramp.Lanes, Ramp.Length, Ramp_ADT, and Speed_Limit according to the deferent buffer sizes are reported.

(2) Based on different size of influential area, the relationship between the number of ramp lanes, length of the ramp, ramp ADT, and the speed limit and the crash frequency is reported in Table 6. Specifically, the number of ramp lanes, ramp ADT, and the speed limit are positively correlated to the crash frequency, while the length of the ramp is negatively correlated to the crash frequency.

The findings of this study are expected to be beneficial to transportation engineers in addressing safety concerns and improving safety performances at off-ramp areas on freeways. From the results of the study, it can be found that key factors have different influence on crashes with buffer sizes changing. That is to say, the safety influence area of the diverging areas should be considered comprehensively. And the size of the influence area should be determined according to the area studied, rather than a fixed value. It is recommended that similar methodology of changing buffer size would be applied in identifying the traffic safety influence areas for freeway diverging areas and other types of intersections in road networks.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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