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RESEARCH ARTICLE

How Expressway Geometry Factors Contribute to Accident Occurrence? A Binary Logistic Regression Study

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Abstract
Logistic regression and statistical method are combined to analyze accident data from "Traffic Accident Database System" (TADS) in order to find the relationship between expressway geometric factors and accident rate. A total of 2004 observations are used to illustrate the proposed model. A new concept mean angle of deflection (MAD) is also introduced to evaluate the effect of horizontal alignment. Accident rate (the dependent variable) in this study is a dichotomous variable, so a binary logistic regression is found suitable. Totally sixteen variables are proposed and fourteen are used in the model. Eight variables are found significantly associated with accident rate at the 0.05 significance. Each variable is interpreted with the results of SPSS 19.0 and the results provide the references for identifying unsafe locations and taking appropriate counteractive measures for expressways in mountainous areas.

Keywords
Accident rate, Logistic regression, Expressway, Curve, Variables

1 Introduction

During the past decades, the number of registered vehicles has witnessed a dramatic increase in China. By the end of 2013, according to the statistics by the Ministry of Public Security, the registered vehicles have risen from 9.6 million in 2003 to 2.5 billion in 2013. As a result, a great amount of traffic accident has occurred, especially on mountainous expressways. Number of deaths resulting from expressway accidents has increased by 10.2 times from 616 persons in 1995 to 6300 persons in 2010, and the average annual increase was 17.9 percent over the past 15 years (Zhao and Deng, 2012). Though expressway network comprises only 1.85 % of total road mileage, its reported traffic deaths are as large as 13.54 percent of all traffic fatalities. At present, some countermeasures have been implemented to enhance the traffic safety of expressways, especially for those in mountainous areas. Undoubtedly, these measures could bring a slight decrease in number of accidents, but the fatality rate is still alarming during the forthcoming years.

A large set of potential factors contributes to the occurrence of expressway accidents, including human behaviors, automobiles states, roadway geometrics and environmental conditions, etc (Lee et al., 2008; Gregoriades and Mouskos, 2013). Thus many previous studies have focused their emphasis on the likelihood of accidents with those factors, among which human factors from human skills (Sivak, 1981), driving fatigue (Di Milia et al., 2011) and age and gender (Bener et al., 2013) have been given considerable attention. Moreover, some have studied the weights and bumper of vehicles (Gattis et al., 1996; Matsui, 2005) and some have investigated the effects of weather conditions and traffic composition on the occurrence of accidents (Bergel-Hayat et al., 2013; Ramírez et al., 2009), but the important role of roadway geometric design is often neglected.

An unreasonable design of road alignment may lead to hazardous driving conditions. Actually, it is difficult to estimate and determine how much the expressway geometric factors contribute to the likelihood of accident occurrence because there is no valid, practical and simple instrument for traffic polices to examine effects of each individual factor on accidents.

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Therefore, how to determine the proportion of human, vehicle, roadway and environment becomes a worldwide concern. In New Zealand, roadway factors and over speeding behavior have been identified as two significant factors contributing to 35 % and 28 % of fatal and serious expressway accidents (source: NZ Transport Agency Research Report 371), respectively, and similar findings have also been observed in 8 mountainous expressways in China (Wang et al., 2010). Islam et al. (2014) considered the expected number of crash counts, traffic volume and roadway and roadside geometries such as number of lanes, shoulder width, and median type to establish safety performance functions (SPFs) so as to predict the single-vehicle and multivehicle crashes.

Many previous studies have indicated that curves witness a higher accident rate, so vertical and horizontal curvature have been recognized as two considerable factors associated with driving safety. For example, brake failure on huge grade segments accounts for quite a number of accidents, so the reduction of average gradient is more helpful to prevent accidents (Fu et al., 2011). For vertical and horizontal alignments, it is important to keep themselves continuous (Camacho-Torregrosa et al., 2013). Moreover, transitioned vertical curve is proposed to limit the length and gradient of vertical curve to ensure driving safety (Easa and Hassan, 2000). Sight distance is another key variable concerned in geometric design. Therefore, previous researches have used a great number of mathematical methods to analyze the relation between geometric design and likelihood of accident occurrence, such as binomial regression (Milton and Mannering, 1998), Poisson regression (Miaou et al., 1994), Bayesian hierarchical approach (Deublein et al., 2013), multivariate pobit regression and random-parameters pobit models (Anastasopoulos et al., 2012).

Few studies, however, have focused on the specific conditions in China, especially in the mountainous areas. Therefore, the objective of this research is to (i) analyze the data collected in two typical mountain expressways (Taigan and Changjin Expressways) and measure the quantitative relationship between geometric design variables and the likelihood of accidents; (ii) find which factors among length, grade and radius contribute significantly to accidents, identify the combined influence of horizontal and vertical curves, and pick out some unsafe segments; and (iii) propose the corresponding safety improvement measures.

2 Method

2.1 Data collection

The traffic accident data in this study is collected from "Traffic Accident Database System" (TADS), which is published by Ministry of Public Security of the People's Republic of China and maintained by Jiangxi Transport Policy Bureau. This system provides accurate and detailed accident information including location, roadway conditions, number of vehicles involved, crash type and major causes, individual messages of driver involved, weather conditions, et al.

The original accident database contains 58131 officially reported observations occurring in Jiangxi, China over the period of 2008-2013, in which 14983 samples are collected from expressways. In this study, two typical sections of expressways are chosen among roadway networks in Jiangxi, including a 128km section of Taigan Expressway (G45) and a 128km section of Changjin Expressway (G065), as shown in Fig. 1, and 2004 valid accident samples are considered for further analysis from 2196 observations on these two expressway sections, accounting for 13.38 % of the total number in Jiangxi expressways.

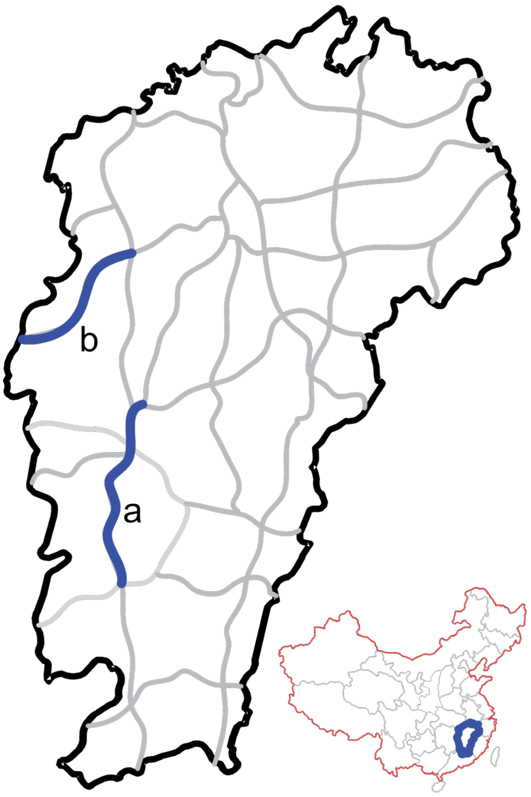

Fig. 1 Location of Taigan and Changjin Expressways in Jiangxi, China. a. Taigan Expressway, b. Changjin Expressway. Note: Jiangxi, also called "Gan" for short, is located in the southeastern part of Mainland China, on the southern bank of the Yangtze River, covering a total area of 166,900 sq km with a population of about 45.42 million by the end of 2014. Now, it has a total provincial road network of 155,515 km, divided in five administrative levels: 4,515 km of expressway (marked in grey lines), 1,902 km of a first-class highway, 9,941 km of a second-class highway, 10,619 km of a third-class highway, and an additional 101,315 km of a forth-class highway.

2.2 Variables

Data pertaining to 6 years (2008-2013) are made available by the TADS from the system. For purpose of this study, the valid information are picked out and combined manually into one file. It contains location, horizontal alignment (radius of curve, length of curve, angle of deflection), vertical alignment (direction of grade, direction of grade) and *AADT* (annual average day traffic). Also in order to estimate the number of accidents, accident rate (*AR*) is determined as:

$$AR = \frac{N*10^8}{AADT*L*D}$$

where AR is number of accidents per 100 million vehicle-mile of travel, N is total number of accidents in the study period, L is length of each segment (km), and D is the days of study period.

Key variables in this paper include AR, N, R (radius of curve), L, MAD (mean angle of deflection) = N/L, PG (percent grade), DG (direction of grade) including line, concave and convex. Additionally, three distinct zones are defined as: (1) zone 1 (entrance zone): 100m before and after the entrance; (2) zone 2 (inside zone): between zone 1 and zone 3; (3) zone 3 (exit zone): 100m before and after the exit. TZ_1, TZ_2, TZ_3 and RZ_1, RZ_2, RZ_3 are the distinct zones (see Fig. 2) of tunnel and ramp. Statistical variables are presented in Table 1.

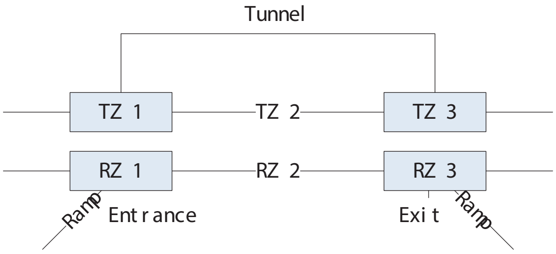

Fig. 2 Distinct zones of tunnel and ramp

Table 1 Key variables used for regression analysis

Variable	Min	Max	Mean	SD
R	0	6000.000	2122.031	1853.201
C	0	66.920	20.986	17.810
N	1.000	31.000	4.742	2.302
MAD	13.910	1641.970	182.147	247.408
L	0.010	1.850	0.223	0.215
PG	-4.000	3.900	0.039	1.937
AR	13.910	641.970	133.708	118.728
DG	line		***N***	910
	convex			426
	concave			665
Tunnel zone	TZ_1		***N***	92
	TZ_2			44
	TZ_3			88
Ramp zone	RZ_1		***N***	79
	RZ_2			24
	RZ_3			65

2.3 Logistic regression model

Binary logistic regression is well suitable for modeling a binomial outcome (takes the value 0 or 1 like having or not having a geometric feature) with one or more explanatory variables. The general form of logistic regression is given as:

$$\ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m \tag{1a}$$

$$P = \frac{\exp\left(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m\right)}{1+\exp\left(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m\right)} \tag{1b}$$

where x_i is the ith explanatory variable such that $x_i = 1$ if the variable satisfies the standard and $x_i = 0$ otherwise., β_0, β_1, …, β_m are the partial regression parameters to be estimated by maximizing the likelihood, and P refers to the probability of the occurrence of an accident.

The binary logistic regression model is introduced to quantify the contribution of each variable and the combined effects of several variables to accidents occurrence. 13 independent variables (Table 2) are selected and the average rate is chosen as the dependent variable.

Table 2 Change of variables depends on threshold

Variables	Value
AR_1	If $AR \leq 100$, $AR_1 = 0$ or $AR_1 = 1$
R_1	If $R > 3000$ $R_1 = 0$ or $R_1 = 1$
MAD_1	If $MAD \leq 300$, $MAD_1 = 0$ or $MAD_1 = 1$
PG_1	If $-1 \leq PG \leq 1$, $PG_1 = 0$ or $PG_1 = 1$
L_1	If $L \leq 0.5$, $L_1 = 0$ or $L_1 = 1$
L_2	If DG is line, $L_2 = 1$ or $L_2 = 0$
CC	If DG is concave, CC = 1 or CC = 0
CV	If DG is convex, CV = 1 or CV = 0
TZ_{11}	If accidents occur on TZ_1, $TZ_{11} = 1$ or $TZ_{11} = 0$
TZ_{21}	If accidents occur on TZ_2, $TZ_{21} = 1$ or $TZ_{21} = 0$
TZ_{31}	If accidents occur on TZ_3, $TZ_{31} = 1$ or $TZ_{31} = 0$
RZ_{11}	If accidents occur on RZ_1, $RZ_{11} = 1$ or $RZ_{11} = 0$
RZ_{21}	If accidents occur on RZ_2, $RZ_{21} = 1$ or $RZ_{21} = 0$
RZ_{31}	If accidents occur on RZ_3, $RZ_{31} = 1$ or $RZ_{31} = 0$

3 Results and Discussions

3.1 Effects of horizontal curve on accident rate

The description of the length of all segments is shown in Table 3, which is divided into four intervals. It can be seen that over 80 % of curves are 1km or less with more than 90 % of accidents occurrence.

However, with the increase of length of curves, the ratio of total curves to the total accidents on curves also rises. So 0.5 is considered as the threshold.

Table 3 Description of segment length and number of accidents on curves

Length of curve (km)	% of total curves	% total accidents on curves	Ratio
0-0.5	39.985	49.333	0.811
0.5-1	45.529	41.333	1.102
1-1.5	9.682	6.667	1.452
1.5-2	4.804	2.667	1.802

Figure 3 displays the relationship between R and AR (mean AR = 0.351). Obviously, it shows the decrease of AR with the increase of R value. When R ranges between 1000m and 1500m, drivers are more likely to make mistakes that could result in accidents.

As shown in Table 1, the average radius of curves is 2122.031m. Also, when R is less than or greater than 2000m, AR is more than or less than 150m, respectively. Thus 2000m can be defined as the threshold. If $R < 2000$m, it is a dangerous curve that should be paid more attention.

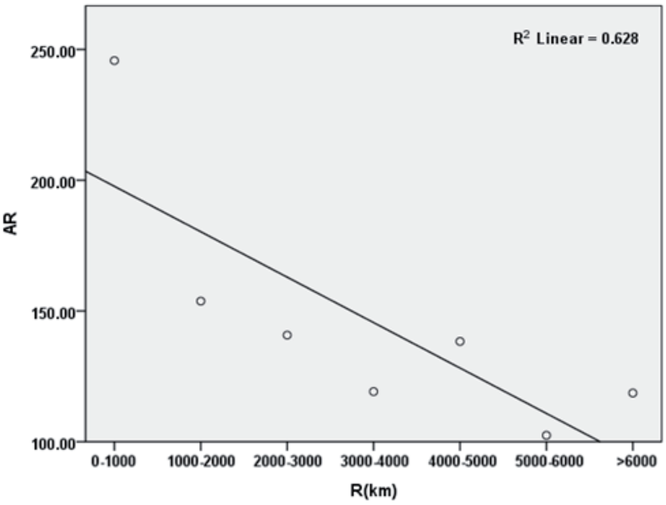

Fig. 3 The distribution of radius and accident rate

From Table 1, MAD of curves varies from 13.910° to 161.970°. And the values of MAD are significantly greater on curves is far higher in interval (700°, 800°), as displayed in Fig. 4. The trend line indicates that AR decreases with the increase of MAD. When the $MAD < 300°$, AR becomes stable relatively and the value of AR is lower. So $MAD = 300°$ is considered as the threshold.

3.2 Effects of vertical curve on accident rate

Figure 5 displays the distribution of PG and number of accidents. Obviously, the number of accidents increases as PG declines. When $PG = 0$, the number of accidents occurring on curves is lowest. Also, AR is relatively low among the interval −1° to 1° that can be considered as the threshold. Moreover, the amount of accidents occurring on descent curves is greater than that on ascent ones.

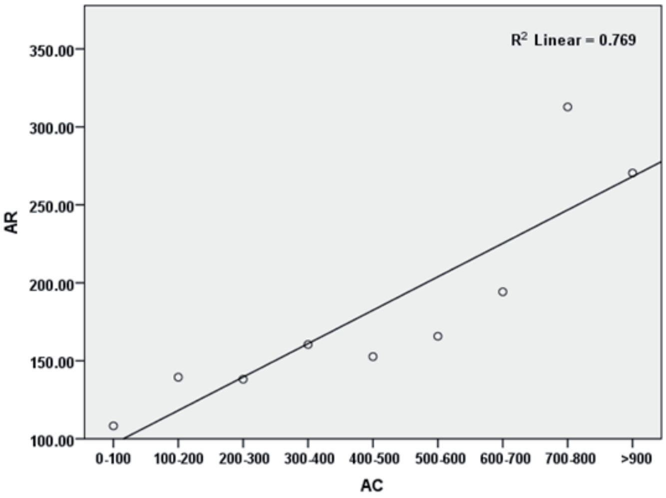

Fig. 4 Distribution of mean angle of deflection and accident rate

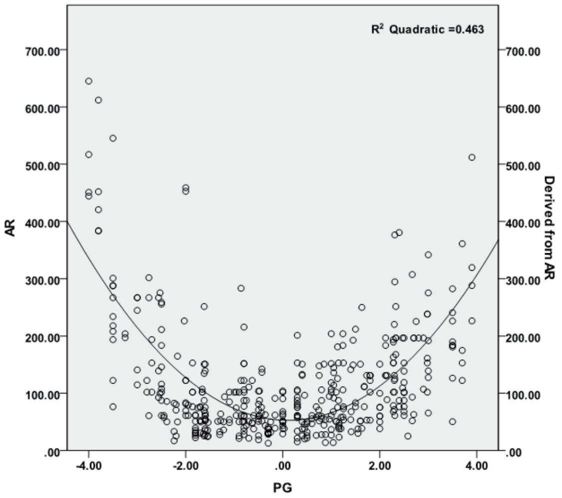

Fig. 5 Distribution of percent grade and accident rate

Table 1 shows that 1091 accidents, accounting for more than a half of total observations, occurred on curves. Figure 6 presents the relationship of direction of grade and number of accidents. The number of accidents occurring on curves with different DG varies significantly. The convex curve is prone to cause more accidents when PG is positive; otherwise, the concave curve tends to induce more injuries and fatalities if $PG < 0$. The number of accidents occurring on line curves is relatively stable with the change of PG.

3.3 Result of Logistic regression analysis

The logistic regression model is processed in SPSS 19 and the model's significant variables and goodness of fit are presented in Table 4. Additionally, Wald χ^2 test is used to determine the factors that affect the AR. Eight variables are found significantly at the 0.05 significance level in SPSS univariate analysis. B is the coefficient of each factor in the data analysis model.

Therefore, by the analysis result in Table 4, the regression model can be determined as:

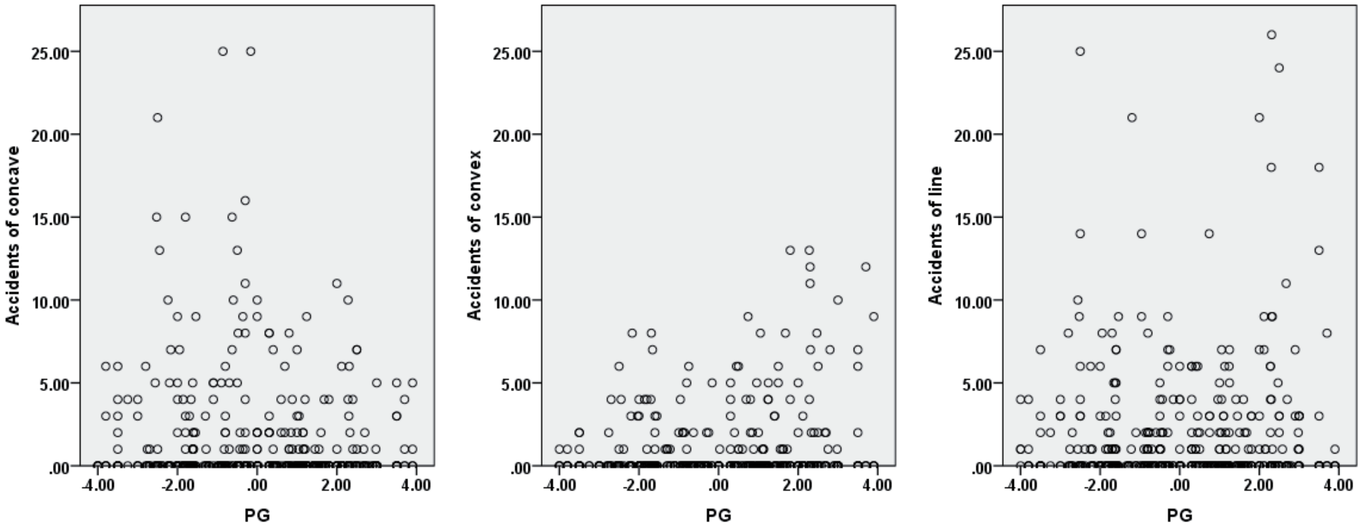

Fig. 6 Features of accidents among concave, convex and line

$$Z = -0.524R_1 + 1.240MAD_1 + 0.734PG_1 - 1.782L_1 - 0.09\mathrm{L}_2 - 0.639CC - 0.210CV + 1.331TZ_{11} - 2.395TZ_{21} + 1.265TZ_{31} + 0.865RZ_{11} - 0.463RZ_{21} + 0.407RZ_{31} - 0.337$$

$$P(AR > 100) = e\hat{\ }z/(1 + e\hat{\ }z)$$

Table 4 SPSS analysis results of logistic regression model

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
R_1	-0.524	0.266	3.894	1	0.048	0.592
PG_1	0.734	0.235	9.774	1	0.002	2.084
MAD_1	1.240	0.317	15.342	1	0.000	3.456
L_1	-1.782	0.500	12.717	1	0.000	0.168
L_2	-0.009	0.395	0.000	1	0.983	0.991
CC	-0.639	0.402	2.532	1	0.112	0.528
CV	-0.210	0.405	0.270	1	0.603	0.810
TZ_{11}	1.331	0.476	7.824	1	0.005	3.784
TZ_{21}	-2.395	0.510	22.099	1	0.000	0.091
TZ_{31}	1.265	0.502	6.341	1	0.012	3.542
RZ_{11}	0.865	0.413	4.384	1	0.036	2.375
RZ_{21}	-0.463	0.379	1.490	1	0.222	0.630
RZ_{31}	0.407	0.446	0.830	1	0.362	1.502
Constant	-0.337	0.400	0.708	1	0.400	0.714

This model shows the confounding effects and interactions between the factors from the univariate analysis. The S.E implies the stand deviation of the coefficient. The Exp(B) gives the degree of each factor contributing to the accident. With the increase of Exp(B) of each variable, it is more likely to cause accidents.

Since the B value of R_1 is −0.542, it indicates that with the increase of R_1, the likelihood of accidents occurring on curves will decrease. Moreover, driving on small radius curves is more risky for drivers due to nervous feeling and more frequent risky driving behaviors.

The results of *MAD* analysis indicate this variable is effective in describing the likelihood of accident occurrence. The model (Exp(B) = 3.456) shows that *MAD* has the most significant effect on the occurrence of accidents among all independent variables. As the *MAD* increases, the likelihood of accidents also rises because these segments produce centripetal and centrifugal forces. Also, the sight distance is not enough to ensure safety and efficient operation of vehicles.

PG_1 is also a significant risk factor and an increase in the percentage grade tends to induce the increase of accident rate. The empirical analysis reveals that vertical alignment influences accident rate until $PG > 1$. Similar results are also found that more accidents have occurred on descent curves than on ascent curves. In some developing countries, however, vehicle's overload contributes more to this type of accidents. The *DG* (L_1, L_2, *CC* and *CV*) is not a statistically significant risk factor. In particular, the results in Table 4 illustrate that line segments are more prone to cause accidents than convex and concave segments, and convex is more risky.

The Exp(B) = 0.168 of L_1 is the low among all variables indicates length has a little effect on accidents. According to the B of length variable, as the length increases the accident rate decreases. This is inconsistent with the previous findings as the length of expressway segment increase so does the exposure to accident. Actually, this is an empirical finding with the regard to the effect of length on accident rate in mountainous area. In mountainous area there are few long straight lines and the geometric alignment is very complicated so in this paper the result is reasonable. But in plain the result may be different.

In mountainous areas, tunnel helps ensure the smooth-going of expressway alignment, but it increases the likelihood of an accident. The regression result also shows that the existence of tunnel has a significant effect on accident rate, which is significantly higher at the entrance and exit locations but relatively lower inside tunnel. Similar results have also been reported in previous studies (Jurado-Piña et al., 2010; Yeung and Wong, 2013). At these locations, the sudden change of environment has an adverse effect on driver's perception and judgment of environment information, which easily result in the significant increase of risky driving behaviors and probability of being involved in a crash. Inside tunnel, however, drivers have already adapted to the traffic environment and thus can pay more attention on the wheel, so the accident rate decreases greatly.

On the other hand, the entrance of ramp is also found to affect the accident rate significantly, which drivers also confront too complex traffic environment to acquire traffic condition or route diversion information, so drivers easily make driving errors or even cause fatal crashes (Sarhan et al., 2008). Particularly, Exp(B) of MAD_1 (3.456), TZ_{11} (3.784) and TZ_{31} (3.542) is much greater than that of other independent variables, so we can see the combination of these factors will increase the risk of driving greatly due to driver's heavy psychological load induced by nervousness and insufficient sight distance. More extremely, a segment with both high *MAD* and *PG* is also prone to cause accident.

4 Conclusions

Using the statistical traffic accident data from Taigan and Changjin Expressways in Jiangxi, China, this study examines the effects of geometric factors on accident rate and then uses a logistic regression model to determine the likelihood and assess the significant contributory factors to the accident rate. The Exp(B) given from the SPSS analysis results priorities the geometric factors in the process of expressway design so as to reduce the potential accidents. Also, it helps improve the overall safety performance through setting traffic signs and markings.

Following the analysis results of logistic regression, some recommendations are given as: 1) *MAD* should be given priority, which is strongly suggested to be no more than 300. If *MAD* > 600, driving speed should be seriously slowed down so as to ensure adequate reaction time and stopping distances at sharp turns; 2) *PG* should be limited between -2 and 2. Extension of vertical alignment can reduce traffic accidents, but it is too expensive to be widely used. Other safety improvement measures, such as setting emergency lane and climbing lane, may be more effective; 3) it should avoid curves with greater *MAD* and *PG*; 4) for the entrance and exit locations of tunnel and ramp, *MAD* and *PG* should be lowered; 5) in view of a sharp curve, driving speed should be limited with full consideration of geometric effects and driver's reaction requirement, and some effective signs can be used to guide driver's sight.

It is important to note that the combination of statistic method and logistical regression provides a superior statistic fit to assess the severity of traffic accidents, but it had some obvious methodological limitations. First, this study sample was not representative of all the expressways in China. Second, the traffic accident data may potentially contain inaccuracies and even not be reliable because of faulty records. Finally, a vast number of crashes and injuries are likely to go unreported, and consequently their correlation with geometric factors may be dramatically underestimated. These research findings can be seen as a contribution to the understanding of relationship between expressway geometric factors and risk of crash. The authors believe that this is an important topic that has not paid enough attention to scientific research. Therefore, further studies will rely on collecting the accurate accident data and evaluating the multiple effects of geometric factors on expressway's accident features. Also, it might also be helpful to explore potential policy initiatives and safety promotion strategies to increase driving safety on expressway.

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