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Investigating the effect of road characteristics on fatal crash count and crash severity; Case study: Birjand-Qayen route

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ABSTRACT: Motor vehicle crashes are currently among the ten major mortality factors all around the world. Iran follows a similar pattern and has a high annual rate of fatal crashes. The majority of these fatal crashes occur on rural routes, particularly on two-lane roads. In this study, the effective factors on the occurrence of accidents on Birjand-Qayen route (South Khorasan Province, Iran) is studied. In order to investigate the effects of being in two-lane segments, horizontal curves with more than 2% slope, and segments with insufficient lighting, on the fatal crash count and crash severity, standard Poisson regression model (fatal crash count per km as the dependent variable) and standard ordered logit model (severity of crashes as the dependent variable) were calibrated using the 2013-2016 data. Zero-inflated negative binomial and zero-inflated Poisson models were also applied to investigate the effect of true zero in fatal crash count modeling. Furthermore, a panel analysis of crash severity ordered logit model was carried out to consider the spatio-temporal effects. The results of the fatal crash count modeling showed that three or four-lane segments (compared to two-lane segments) reduce the number of fatal crashes, whereas curved segments with more than 2% slope (compared to straight segments) increase this number. Moreover, according to the crash severity model results, segments with sufficient lighting as well as three-lane or four-lane segments (compared to two-lane segments) reduce the severity of crashes; whereas crash severity in curved segments with more than 2% slope (compared to straight segments) is increased.

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1. INTRODUCTION

Motor vehicle crashes impose considerable socio-economic damages on the societies and transportation organizations across the world. In the US, the total losses caused by motor vehicle crashes in 2010 were \$242 billion, i.e. 1.6% of the country's GDP in 2010 [1]. Also in Iran, the cost of motor vehicle crashes in 2011 was equal to 8.5% of the country's GDP (approximately 520,000 billion Rials) [2], which demonstrates the considerable significance of accident prevention and execution of counteractions against the intensive factors. According to reports published by the Public Relations and International Affairs Department of Iranian Legal Medicine Organization, the number of deaths caused by vehicle crashes was almost 16,000 in 2017. Rural road crashes, particularly on two-lane routes, with approximately 11000 deaths, have the highest contribution [3]. In this regard, official reports demonstrate the 50-60% contribution of two-lane roads in total crashes occurring at rural routes [4]. Specifically, 68% of crashes leading to death and injury occurring from 2013 until 2017 along Birjand-Qayen route (South Khorasan Prov., Iran) took place on the two-lane segments of this road. Furthermore, screening of the route using the EPDO index and the sliding window method, by considering a 1-km scale (due to the submission of crash locations with the accuracy of 1-km by the Iranian traffic police Rahvar), revealed that the majority of accident-prone segments of this route are located at two-lane segments, curves with more than 2% slope, and segments with insufficient lighting at nights [5]. Accordingly, statistical models were employed to investigate the effects of these roadway characteristics (environmental factors) on the fatal crash count and crash severity along this route.

Many studies have been carried out to identify the factors affecting the frequency and severity of road crashes [6-9]. These factors can be classified into three main groups including driver-related factors (age, gender, skill level, fatigue, driving focus, sight, and experience), environmental factors (type of road pavement and its friction, number of lanes and their widths, geometrical characteristics of road, traffic control devices, traffic signs, climate, lighting, and visibility), and vehicle-related factors (weight, height, and vehicle type and also faults in design, manufacturing, brake system and handling). Meanwhile, driver-related factors are known as the most effective ones; yet, controlling or changing them is a very complicated process which requires an integrated procedure of legislation, culture-building, monitoring, and punishment.

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Moreover, the elimination of technical faults in vehicles mostly falls within the responsibility of car manufacturers. Therefore, the modification of road-related factors is commonly used to control and reduce the number and severity of crashes [10]. Accordingly, many studies have focused on the impact of road characteristics on the frequency and severity of crashes [11-14]. Regarding the mentioned reasons, the present study attempted to investigate the effect of road characteristics on the number of fatal crashes (due to their significant socio-economic impacts on families and the society) as well as crash severity along Birjand-Qayen road using statistical models. In the next section, the most related literature is reviewed. Next, research materials and the employed methods are presented. In the fourth section, after describing the applied data, model results were discussed. Finally, the obtained results are summarized and concluded.

2. LITERATURE REVIEW

In the road safety improvement process, it is important to identify the effective factors on crashes. In this regard, many studies have investigated the impact of these factor on crash-related indices such as the Estimated Property Damage Only (EPDO) index, crash count, and crash severity [13-17]. The crash count was used in studies by Chen [7], Karlaftis [11], Hosseinpour [13], Ma [18], and Chimba [19] to evaluate the effect of different parameters on crash occurrence. In these studies, the impact of road factors on the number of crashes has been mentioned. As an example, Hosseinpour et al. (2014) investigated the effect of roadway characteristics on the frequency of head-on crashes occurred at five federal roads in Malaysia. The frequency of such crashes was modeled using Poisson models, standard negative binomial, random effect negative binomial, Hurdle Poisson, Hurdle negative binomial, zero-inflated Poisson, and zero-inflated negative binomial. Model results showed that the presence of a horizontal curve and expanding the shoulder width have both increasing and decreasing effects on the crash count, respectively. In this study, crash severity was also modeled using random-effect generalized ordered Probit. In this regard, the presence of horizontal curvature, undulating terrain, and high interference with roadside activities (such as parking and commercial areas) were identified as the road-related factors leading to severe crashes, and the presence of median, numerous intersections, and minor access points per km were expressed as road-related factors reducing crash severity [13].

To date, several studies have focused on factors affecting the crash severity, especially road-related and environmental factors [14, 20-23]. Chen et al. provided a descriptive analysis of crash severity using Decision Table/Naïve Bayes (DTNB) with focus on rear-end collisions. The results showed that two-lane rural roads would increase the probability of fatal crashes [24]. In another study, Jaafari Anarkooli et al. (2017) investigated the effective factors on the severity of single-vehicle rollover crashes in federal roads of Malaysia, according to a 6-year set of data (2007-2012), using random effect generalized ordered Probit and mixed logit models. The results of the study demonstrated increasing effects of insufficient lighting at nights, rainy weather, the presence of medians, and the unsafe condition of roadsides on crash severity [20]. Haghighi et al. (2018) also examined the impact of roadway geometric features on the severity of crashes occurred along rural two-lane roads in Illinois, US, since 2007 until 2009, using standard ordered logit and multilevel ordered logit models. The results reported reduced crash severity in cases of night time and narrow shoulder, and increased severity under inclement weather conditions [22]. However, investigating the previous literature in this section revealed the significant effect of roadway characteristics on the number of crashes and crash severity; the identified effective parameters were diverse and, in some cases, contradictory. Therefore, according to effective factors on crash occurrence which were identified in the previous study [5], these two indices were modeled in the present study to assess and analyze the impact of roadway characteristics on the fatal crash count and crash severity in Birjand-Qayen route.

3. MATERIALS AND METHODS

In this section, first, the Birjand-Qayen route and basic information about the crash data are presented. Then, the standard Poisson regression model is employed to assess the effective road-related factors on the number of fatal crashes, due to its countable nature. Furthermore, the standard ordered logit model was also employed to assess the effective road-related factors on crash severity, considering its ordered nature.

3.1 Data

The Birjand-Qayen route is a mountainous road that connects two populous cities in South Khorasan province, Iran. Crash reports are recorded at a length of 100 km along this road, between Birjand and Qayen. Modeling of the fatal crash count and crash severity at this rural road was carried out by excluding the crash data of the first two kilometers of each end from the total crash data, due to their vicinity to cities as well as differences in the driving behavior at the suburbs compared to the road. The crash data were acquired from the traffic police of South Khorasan province. The data were related to crashes recorded from April 2013 until February 2017 and included crash severity (injury and death), time of the crash (year, month, day, hour), and the crash location (relative distance from the start point of the road with 1 km accuracy). It is necessary to state that the traffic police have only recorded fatal or injury crashes. In this study, fatal crash was considered a crash leading to the death of at least one individual. According to the specification of the dataset, crashes other than the fatal ones are considered as injury crashes. Amongst 233 cases (total number of valid recorded crashes along 96 km), 68 crashes were fatal while others had only led to the injury.

3.2 Method

As expressed at the beginning of this section, the standard Poisson regression and standard ordered logit models were

Table 1. Description of Standard Poisson model variables and frequency of segments

Dependent variable	Min	Max	Mean	Standard Deviation
Fatal crash	0	6	0.7083333	1.104218
Independent variable	Category of variable		Frequency of each Category	Percentage (%)
Number of lane	Two-lane		57	59.38
	Three-lane		12	12.50
	Four-lane		27	28.13
Alignment	Straight		57	59.38
	Curve with more than 2% slope		20	20.83
	Curve with less than 2% slope		19	19.79

used to assess the effectiveness of roadway characteristics on the fatal crash count and crash severity, respectively. A description of each model's methodology would be followed.

3.2.1 Poisson Regression Model

Modeling the number of fatal crashes at each segment is a numerical analysis since this dependent variable is positive and integer. In this regard, suitable numerical modeling techniques include Poisson regression, negative binomial, zero-inflated Poisson regression, and zero-inflated negative binomial [25]. In the Poisson model, the probability of φ_i (fatal crashes occurring at segment *i*) is expressed as Eq. 1.

$$P(\varphi_i) = \frac{\lambda_i^{\varphi_i} e^{(-\lambda_i)}}{\varphi_i!} \tag{1}$$

Where λ_i is the Poisson parameter attributed to segment *i*. This crash frequency parameter is defined through a linear-logarithmic function according to Eq. 2, where A is the vector of calculated parameters and X_i is the vector of independent variables related to each roadway characteristic at segment *i*. In the Poisson model, the related parameters of these variables are calculated using the maximum likelihood function [25].

$$\lambda_i = e^{A.X_i} \tag{2}$$

3.2.2 The Standard Ordered Logit Model

The standard ordered logit model is used to model crash severity due to the ordered nature of this model's dependent variable. In this model, the latent continuous variable of y_j^* is used to indicate the severity of crash *j*. This latent variable is considered related to the discrete variable of y_j for crash severity and is defined according to Eq. 3.

$$y_j^* = \beta X_j + \varepsilon_j \tag{3}$$

Where X_j is the vector of independent variables of each crash (*j*), occurred at a particular segment (with defined roadway characteristics), β is the vector of calculated coefficients for these independent variables (which are calculated using the maximum likelihood function), and ε_j is the error term which follows a logistic distribution. Next, the dependent variable of y_j is also determined based on variable y_j^* according to Eq. 4.

$$y_j = \begin{cases} 0, & if\ y_j^* \le \mu_0 \\ 1, & if\ y_j^* \ge \mu_0 \end{cases} \tag{4}$$

Where μ_0 is the threshold for crash severity categories including 0 (injury) and 1 (death). The probability for each of these categories can be calculated using Eqs. 5 and 6 [22].

$$P(y_j = 0) = 1 - \frac{e^{(\beta X_j - \mu_0)}}{1 + e^{(\beta X_j - \mu_0)}} \tag{5}$$

$$P(y_j = 1) = \frac{e^{(\beta X_j - \mu_0)}}{1 + e^{(\beta X_j - \mu_0)}} \tag{6}$$

4. DATA DESCRIPTION AND MODELLING

In this section, first, the data and variables used in modeling are described. Next, it is attempted to model the effective road-related factors on the number of fatal crashes and the severity of crashes occurred along this route using the data.

4.1 Describing Model Data

To model the number of fatal crashes at 1-km long segments along the route (since crashes are recorded with 1-km accuracy, examination at shorter distances was not possible) as well as the severity of crashes occurred at those segments, the road-related features of each segment including the lighting condition, number of lanes, and alignment of the road were obtained according to field observations along with an examination of the topographic maps of the segment. Importantly, since the traffic police do not record the location of crashes with an accuracy of less than 1 km, features associated with these 1-km segments and related crashes were based on their dominant feature.

4.1.1 Describing the Applied Data for Fatal Crash Count Modelling

In this model, the dependent variable of "fatal crash" represents the number of such crashes at each 1-km segment; according to Table 1, the average fatal crash occurrence per kilometer during these years is reported as approximately 0.7. The independent variables of this model are categorical

Table 2. Description of standard ordered logit model variables, crash severity, and frequency of crashes

Dependent variable	Category of variable	Frequency of each Category	Percentage (%)
Severity	Injury crashes	165	70.82
	Fatal crashes	68	29.18
Independent variable	Category of variable	Frequency of each Category	Percentage (%)
Condition	Daylight	143	61.37
	Night with sufficient lighting	34	14.59
	Night with insufficient lighting	56	24.03
Number of lane	Two-lane	153	65.67
	Three-lane	26	11.16
	Four-lane	54	23.18
Alignment	Straight	102	43.78
	Curve with more than 2% slope	60	25.75
	Curve with less than 2% slope	71	30.47

Table 3. The standard Poisson model on fatal crash count

Variable	Category of Variable	Coefficient	Standard Error	Z Test	P>[z]	95% Confident Interval	
Number of lane	Two-lane	-	-	-	-	-	-
	Three-lane	-1.789806	0.7215409	-2.48	0.013	-3.204	-0.3756118
	Four-lane	-0.9784289	0.3671116	-2.67	0.008	-1.697954	-0.2589034
Alignment	Straight	-	-	-	-	-	-
	Curve with more than 2% slope	0.1539873	0.3315131	0.46	0.642	-0.4957665	0.8037411
	Curve with less than 2% slope	0.9192685	0.278188	3.30	0.001	0.37403	1.464507
Constant		-0.3317873	0.2142644	-1.55	0.122	-0.7517379	0.0881633
Number of observation = 96			LL (Intercept Only) = -117.502			LL (Full Model) = -101.869	
McFadden's R2 (Intercept Only) = 0.1330				LR Chi2(4) = 31.26		Prob>Chi2= 0.0000	

variables including number of lanes and alignment; in the former, the reference condition is a two-lane segment, based on which the three- or four-lane segments are evaluated. In the latter, a straight segment is considered as the reference condition; subsequently, to indicate the relationship with fatal crashes occurring at the segment, the effect of horizontal curved segments with a less than 2% vertical slope and horizontal curves with a more than 2% vertical slope are evaluated against straight segments.

4.1.2 Describing the Applied Data for Crash Severity Modelling

In this model, the dependent variable of severity indicates the hurt impact of each crash (whether it led to injury or death). The defined categorical independent variables for describing the segment properties (that crash occurred) also include the number of lanes, alignment, and lighting condition; the reference conditions for these variables include two-lane, straight, and daylight, respectively. A description of the applied variables in this model is represented in Table 2. It should be noted that in this route, 33 kilometers are equipped with sufficient lighting at night while the remaining 63 kilometers lack proper lighting.

4.2 Modelling Results

In this section, the model results were discussed, and sensitivity analysis on variables in both the standard Poisson regression and standard ordered logit models were carried out.

4.2.1 Fatal Crash Count Model

The negative binomial model was employed to model the number of fatal crashes, as well as the Poisson regression model. Application of the latter was possible due to the similarity of variance and mean value of the fatal crashes count. In this regard, the proper fitness of the Poisson model was revealed. Additionally, according to the occurrence of no fatal crash in 58% of the segments, zero-inflated negative binomial and zero-inflated Poisson models were applied to investigate the effect of true zero in the model, distinguishing safe segments with zero crashes from other segments in which the number of crashes was zero due to other reasons. The results showed no significant improvement in models fitness compared to their corresponding standard models. Consequently, only the results of the standard Poisson model, as the superior model for the fatal crash count, were presented in Table 3.

According to Table 3, three and four-lane segments could result in less fatal crashes compared to two-lane

Table 4. The average marginal effect of variables in fatal crash count Poisson model

Variable	Category of Variable	*dy/dx*	Standard Error	Z Test
Number of lane	Two-lane	-	-	-
	Three-lane	-0.8062734	0.1743287	-4.63
	Four-lane	-0.6040694	0.1819751	-3.32
Alignment	Straight	-	-	-
	Curve with more than 2% slope	0.0860597	0.1819751	0.45
	Curve with less than 2% slope	0.779278	0.2716133	2.87

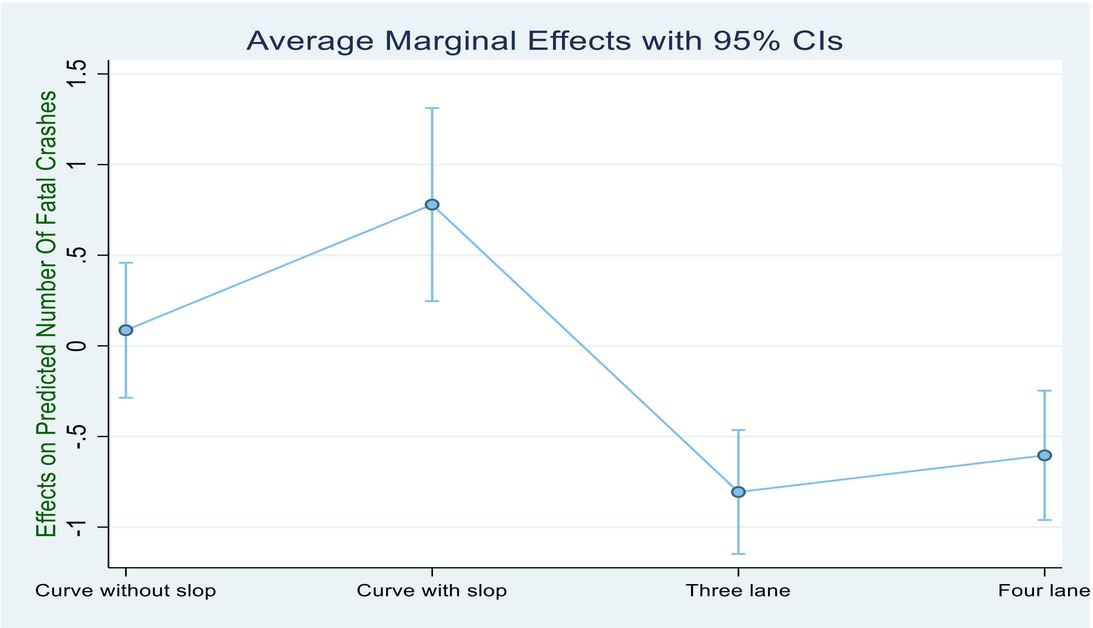

Fig. 1. The average marginal effect of variables in fatal crash count Poisson model

segments. Moreover, segments with curves and a more than 2% slope increase the number of fatal crashes compared to straight segments; while, the number of fatal crashes was not significantly increased in segments with curves and a less than 2% slope (compared to straight segments). Next, the marginal effect of each variable on the fatal crash count in this Poisson model was evaluated using the average marginal effect (AME) method (Table 4).

The marginal effect of variables in fatal crash count Poisson model denotes the alteration a single-unit change of a variable would result in the frequency of fatal crashes. To calculate the marginal effect for a particular variable using the AME method, first the marginal effect of that variable is calculated in every observation of the dataset. Average of these obtained values represent the average marginal effect for that particular variable. Although the marginal effect at the mean (MEM) method (calculation of marginal effect when the entire variables are fixed at their mean values) is more prevalent, many researchers believe that the AME method has more functionality [26, 27]. For instance, according to Table 4, segments with four lanes (compared to two-lane one) lead to a 0.60 decrease in the fatal crash count. On the other hand, curved segments with more than 2% slope compared to a straight one lead to a 0.77 increase in fatal crash count. The average marginal effect of each variable on altering the number of fatal crashes in this model is presented in Fig. 1.

4.2.2 Crash Severity Model

The standard ordered logit model was used to examine the effect of roadway characteristics on the severity of crashes. A panel analysis of crash severity ordered logit model was also employed to consider the spatiotemporal effect. Although, the result of an LR test between this model and the standard ordered logit model was equal to zero. Consequently, only the results of the standard ordered logit model were presented (Table 5).

Based on the results, regarding the lighting condition variable, the severity of crashes increases in segments without sufficient lighting at nights compared to daytime. Furthermore, no significant difference was observed between crash severity at segments with sufficient lighting at nights and daytime crashes, both of which denotes the importance

Table 5. The standard ordered logit model on crash severity

Variable	Category of Variable	Coefficient	Standard Error	Z Test	P>[z]	95% Confident Interval	
Condition	Daylight	-	-	-	-	-	-
	Night with sufficient lighting	-0.1054993	0.5367516	-0.20	0.844	-1.157513	0.9465144
	Night with insufficient lighting	1.685028	0.3669817	4.59	0.000	0.9657571	2.404299
Number of lane	Two-lane	-	-	-	-	-	-
	Three-lane	-1.716405	0.7861816	-2.18	0.029	-3.257292	-0.1755171
	Four-lane	-1.211382	0.4884781	-2.70	0.007	-2.090383	-0.3323815
Alignment	Straight	-	-	-	-	-	-
	Curve with more than 2% slope	-0.3231721	0.4286542	-0.75	0.451	-1.163319	0.5169746
	Curve with less than 2% slope	0.8101318	0.3924526	2.06	0.039	0.0409387	1.579325
μ_0		1.171471	0.3229121			0.5385745	1.804367
Number of observation = 233		LL (Intercept Only) = - 94.266			LL (Full Model) = -117.476		
McFadden's R2 (Intercept Only) = 0.1650			LR Chi2(6) = 46.42		Prob>Chi2 = 0.0000		

Table 6. The average marginal effect of variables in crash severity ordered logit model

Variable	Category of Variable	*dy/dx*	Standard Error	Z Test
Condition	Daylight	-	-	-
	Night with sufficient lighting	-0.0157073	0.0784667	-0.20
	Night with insufficient lighting	0.3357744	0.0726643	4.63
Number of lane	Two-lane	-	-	-
	Three-lane	-0.2514448	0.0803559	-3.13
	Four-lane	-0.1974677	0.0627039	-3.15
Alignment	Straight	-	-	-
	Curve with more than 2% slope	-0.0485595	0.0633854	-0.77
	Curve with less than 2% slope	0.1448994	0.0695897	2.08

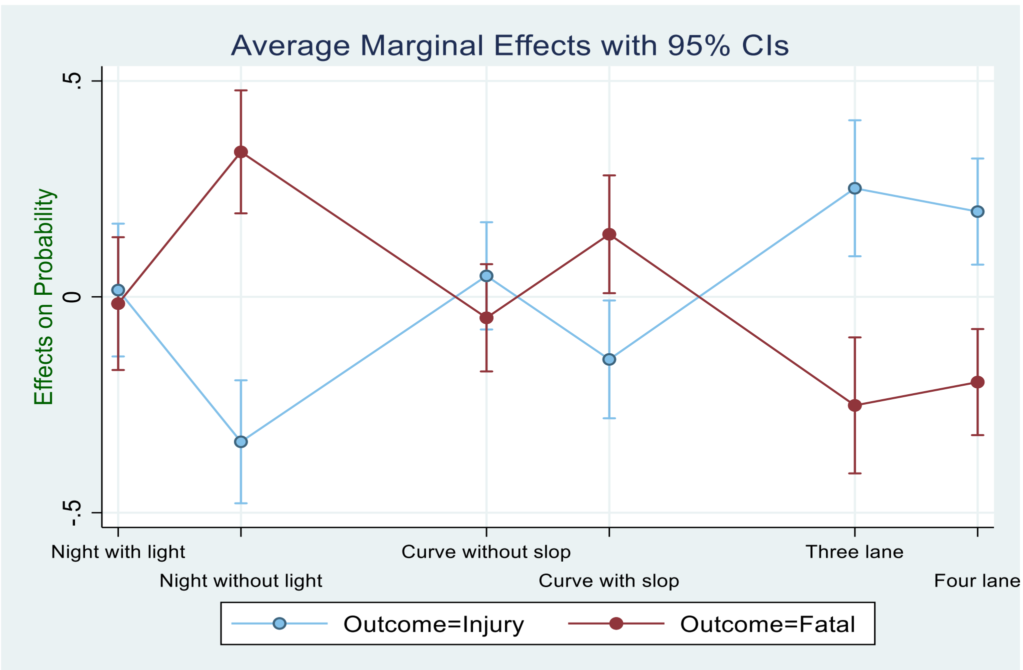

Fig. 2. The average marginal effect of variables in crash severity ordered logit model

of installing proper lighting with the aim of reducing crash severity. Moreover, changing the number of lanes to three and four-lane segments reduces the crash severity compared to two-lane segments. Ultimately, investigating the results on the alignment variable also shows that crash severity increases in curves with more than 2% slope compared to straight segments. In this regard, no significant difference was observed between curved segments with less than 2% slope and straight segments. Next, the marginal effects of each variable on crash severity in the standard ordered logit model calculated by using the AME method are presented in Table 6.

The average marginal effect in crash severity ordered logit model represents the average impact of a single unit change of a variable on altering each of the fatal and injury crash occurrence probability when other variables remain fixed at their observed values. In this regard, it can be seen that the presence of four-lane segments would reduce the probability of fatal crashes by 19.7%. Furthermore, curved segments with more than 2% slope have a higher probability of fatal crash occurrence by 14.4%. The average marginal effect of each variable on altering the probability of each fatal and injury crash occurrence computed by the AME method is shown in Fig. 2.

5. CONCLUSION

The present study investigated the effect of roadway characteristics on the fatal crash count and crash severity by using statistical models. Applied crash data was related to Birjand-Qayen road (South Khorasan province, Iran) since 2013 until 2017. With regards to crash count modeling, the standard Poisson regression model resulted in a better fitness compared to the standard negative binomial model. Meanwhile, zero-inflated negative binomial and zero-inflated Poisson models also did not show much superiority over the corresponding standard models. Consequently, only the results obtained from the standard Poisson model were reported. Results of the sensitivity analysis of standard Poisson model revealed that the number of fatal crashes reduces by 0.8 and 0.6 at three and four-lane segments, respectively, compared to two-lane segments. Furthermore, the fatal crash count would increase by 0.77 at curved segments with more than 2% slope, compared to straight ones. Accordingly, roadway characteristics significantly affect the fatal crash count. Next, the standard ordered logit model was employed to examine the effect of roadway characteristics on the severity of crashes along this route. A panel analysis of crash severity ordered logit model was also employed to consider the spatiotemporal effect; while, the result of LR test between this model and the standard ordered logit model was equal to zero (no significant difference). Subsequently, results of the standard ordered logit model showed that the crash severity effectively reduces at the presence of sufficient lighting. Accordingly, crash occurrence in segments with no sufficient lighting at night increased the probability of fatal crashes by 33.5% compared to daytime crashes. Furthermore, crashes occurred at curved segments with more than 2% slope increased the fatal crash probability by 14.4%, compared to straight segments. Also, three and four-lane segments respectively resulted in 25.1% and 19.7% reduction in the probability of fatal crash occurrence compared to two-lane segments, demonstrating the notable effect of roadway characteristics on crash severity. For future studies, it is suggested to include more possible variables, in case they are available, such as roadside access and the presence of rural residential areas around the road on the crash count and crash severity. It is also recommended that the predictions are made using different models such as probit.

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