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Modeling Severities of Gravel Road Crashes Using Random Parameters

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ABSTRACT

Gravel roads crashes are a roadway safety hazard and such crashes have higher probability of fatalities and serious injuries when compared to paved roads crashes. Previous studies investigated the contributing factors that affect gravel roads crash severities. There were widely range of contributory factors such as road conditions, weather conditions, vehicle type, driver behavior and characteristics, road geometric features, terrain, and environmental conditions that were investigated. However, no previous studies accounted for unobserved heterogeneity in the crash data while modeling gravel roads crash severities. This study employed random-parameter binary logit model also known as mixed logit model to model severity of gravel road crashes in Wyoming. Gravel roads crash data from Wyoming Department of Transportation from 2010 to 2019 were studied and analyzed. Both binary logistic regression model and mixed binary logistic regression model were developed. Mixed logistic binary regression model was found to be better fit the data in terms of goodness of fit statistics. The results showed that crashes involving motorcycles had the higher risk of fatalities and serious injuries. In addition, horizontal curves and male drivers were found to have significant effect on the gravel roads crash severities. Passenger cars were found as a random parameter from the results of mixed binary logistic regression model. In addition, existence of horizontal curve was found to be the most contributing factors increase the probability of having minor or possible injuries in gravel roads accidents. Furthermore, having a snow on the road surface was found to have significant effect on increasing the probability of resulting in property damage only accidents. The results found in this study will be helpful to identify effective countermeasures which will reduce gravel road crash severity. Thus, applied variable speed limits at the horizontal curves location and at snow falling time will enhance the gravel roads safety.

1. INTRODUCTION

Gravel roads form approximately 50% of the roadway network in the United States as reported by the Federal Highway Administration (1). These roads are mostly low volume roads with less than 2000 vpd (1). Due to their surface properties and degraded forms, these roads have high safety issues. Some distresses can cause loss of control such as: rutting and corrugation (1). In addition, Braking and negotiating horizontal curves can cause vehicle sliding and slippage especially on wet road surfaces. Furthermore, one of the major problems in gravel roads is the dust generating which reduce driver visibility (2, 3).

Gravel roads form about 90% of the local roads in the state of Wyoming (4). Thus, these roads are considered as one of the essential components in the transportation system in the state of Wyoming. Although the historical crash data in Wyoming shows that 0.7% of the crashes resulted in fatalities, the percentage of fatalities (1.3%) is significantly higher on gravel roads. This increment in the fatalities and serious injuries warranted the need for studying the factors that affect crash severities on gravel roads.

The state had 4,947 crashes on gravel roads, from 2008 to 2017, that led to 227 fatalities and severe injuries. Despite the gravel roads crashes accounted for 3.6% of the total crashes in Wyoming, 6.4% of the fatalities and severe injuries in Wyoming crashes occurred on gravel roads. Considering the low traffic volumes on gravel roads, the risk is higher than paved roads.

Several factor affect the gravel roads crash severities such as road geometric characteristics, crash characteristics, vehicle speed, road's terrain, weather circumstances, time of day, lighting condition, road surface condition, vehicle class and other factors (5, 6, and 7). Based on the crash data, the annual equivalent economic loss because of fatalities and severe injuries in gravel road crashes in Wyoming is about $21 million (1). There is a gap in the literature on gravel road crashes because those studies did not account for the unobserved heterogeneity effects while modeling gravel road crash severities. Since there is a significant number of factors affecting crash severities on gravel roads, previous studies could not identify the effect of all variables due to various difficulties such as data availability. Utilizing random parameters may compensate the ignored variables bias.

The main purpose of this study was to investigate the contributory factors that significantly affect gravel road crash severities in Wyoming while considering unobserved heterogeneity effects. Since random parameters were not considered before in gravel roads crash studies, this study provided a sophisticated and advance understanding for the crash severities on these roads.

2. LITERATURE REVIEW

Logistic regression or similar statistical methods are usually adapted in studying the association among a group of explanatory variables and crash severity. Explanatory factors that affect crash severities are usually categorized with reference to driver, road, environment, and vehicle. In addition, crash severity is basically classified based on severity level. Severity levels include property damage only (PDO), injury crashes, and fatal crashes. The nature of crash severity and related explanatory factors encouraged the researcher to use the logistic regression models in investigating the relationships among them.

Researchers used the logistic regression method to study the characteristics of run-off-road crashes in Minnesota over a 15-years period (8). In another study, negative binomial generalized linear models were employed to investigate the effect of highway geometric characteristics on crash severities in Connecticut (9). Logistic regression was used to estimate the crash severities probabilities in Michigan and Illinois, the developed model was utilized to compare between severe and non-severe crash probabilities (10). In addition, applied ordered probit model was employed to study the effect of the contribution factors on the crash severities probabilities for various roadway functional classes (11). Moreover, the nested logit was used in various studies to estimate the probabilities of crash severity based on environmental conditions, highway geometric features, and accident type (12). Abdel-Aty and Abdelwahab developed a nested logit model to study the effect of several variables such as driver's age; gender, light condition, and speed on rear-end crashes severities (13).

Few traffic safety studies have considered the surface type of the low volume roads. A research study carried out in Minnesota, analyzed the low-volume roads crashes data. The study found that, several variables have significant effects on the low volume crash severities. Additionally, the study results showed that the driver characteristics have the highest effect on the low volume roads crash severities probabilities among other factors (14). Another study investigated the

crashes on low-volume rural roads in Kentucky and North Carolina. Quasi-induced exposure methods were employed to estimate the crash severities probabilities. The findings demonstrated that low-volume roads have similar crash trends as other types of roads. Moreover, this study highlighted the effect of driver's gender and age on the low-volume roads crash probabilities. In addition, old vehicles were found significantly increasing the probability of involving fatalities and serious injuries in the low volume roads crashes. (15). In a study carried out in North Carolina, safety performance factor model for low volume roads was developed using negative binomial regression (16). The analyzed data were collected from different road classes such as rural local road, urban local road, and urban local collector. Two models were developed for each road to estimate the crash occurrence probabilities, and the injury severity probabilities on low volume paved roads. The developed models were assessed using cumulative residual plots. The study findings demonstrated that the crashes have a significant correlation with the traffic volumes (16, 17). Recently, a research study was carried out to develop safety performance factors for rural low volume roads in Italy (18). Furthermore, researchers studied the gravel road crash data in Kansas. The study aimed to determine the significant factors that affecting the crash severity on gravel roads in Kansas. The study focused on studying the driver characteristics and their effect on the crash severities. The results of this study demonstrated that using seat belt and driving under influence of alcohol are the most significant factors effecting crash severities on gravel roads (19).

In general, the need of studying the traffic safety on gravel roads is significantly increasing. Developing gravel roads crashes and crash severities models are an essential part in studying the traffic road safety. However, only few studies investigated the relationship between crash severities on gravel roads and wide range of factors. Moreover, the uncovered heterogeneity effects on crash severities was not studied on gravel roads. Thus, this study aims to investigate gravel roads crash severities to identify the significant factor causing fatalities and serious injuries, while considering the unobserved heterogeneity effects. The study was carried out for Wyoming's statewide gravel roads crashes using crash data for ten years period. Binary logistic regression model and mixed binary logistic regression model were used to model the crash severities independently.

3. DATA PREPARATION

This study used crash data that were collected from Wyoming Department of Transportation (WYDOT). The data included gravel roads crash records for 10 year period from 2010 to 2019. Data for crashes on paved roads were not considered in this study. There were 4,947 crashes on Wyoming gravel roads in the study period. The data showed that the percentages of fatalities and serious injuries in gravel road was significantly higher than that of paved roads. Wyoming crash data showed that 318 crashes had fatalities or serious injuries on gravel roads in the study period, while there were 2,280 crashes that occurred on paved roads that involved fatalities or serious injuries. Figure 1 represents the percentage of fatalities and serious injuries on both gravel and paved roads. It can be seen in Figure 1 that the percentage of fatalities and serious injuries were 6.4% in gravel roads crashes, and only 2% in paved roads. The response variable was estimated based on whether the crash had fatalities or serious injuries, or not. Descriptive analysis was carried on the gravel roads crashes as shown in Table 1. However, the vast majority of of crashes on these roads were single vehicle crashes. Crashes with more than single vehicle form only 18% of the data. In addition, crashes with more than one involved vehicle had not lead to fatalities and only 0.4% of them caused a severe injuries. Because of that, only single vehicle crashes were investigated in this study.

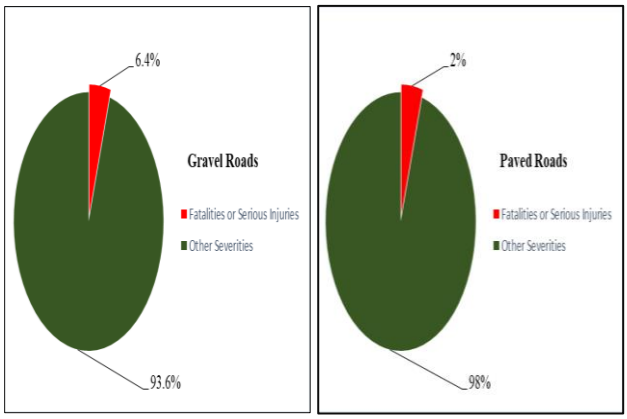

Figure 1: Comparison between Crashes Severities

Table 1: Gravel Road Crash's Descriptive Statistics

Variable	Description	Frequency	Percentage (%)
Response			
Severe Crash	Severe crash:1 if yes or 0 otherwise	318	6.42
Possible Injury Crash	Possible injury crah:1 if yes or 0 otherwise	1198	24.22
Property Damage Only Crash	Property damage only:1 if yes or 0 otherwise	3431	69.36
Environmental Characteristics			
Daylight	Daylight: 1 if yes or 0 otherwise	2,997	60.58
Darkness Lighted	Darkness lighted: 1 if yes or 0 otherwise	137	2.77
Darkness Unlighted	Darkness unlighted: 1 if yes or 0 otherwise	1,414	28.58
Adverse weather	Snowing, raining, blowing snow: 1 if yes or 0 otherwise	500	10.1
Roadway Characteristics			
Wet	wet road surface: 1 if yes or 0 otherwise	230	4.65
Snow	snow on the road surface: 1 if yes or 0 otherwise	1,109	22.42
Dry	dry road surface: 1 if yes or 0 otherwise	2,601	52.58
Physical or visual obstruction	existence of obstruction: 1 if yes or 0 otherwise	159	3.21
Level	Level (no grade): 1 if yes or 0 otherwise	3,204	67.77
Downgrade	downgrade or sag: 1 if yes or 0 otherwise	1,129	22.82
Upgrade	upgrade or crest: 1 if yes or 0 otherwise	550	11.1
Horizontal Curve	crash on horizontal curve: 1 if yes or 0 otherwise	1,652	33.39
Speed	speed exceed the speed limit: 1 if yes or 0 otherwise	1,511	30.55
Driver Characteristics			
Young driver	driver age 29 years or below: 1 if yes or 0 otherwise	2,383	48.17
Middle age driver	driver age between 30 and 59 years: 1 if yes or 0 otherwise	1,837	37.13
Elderly driver	driver age 60 or above: 1 if yes or 0 otherwise	727	14.7
Commuter driver	driver live in the crash city or within 25 miles from the crash scene: 1 if yes or 0 otherwise	2,853	57.67
Gender	Gender: 1 if male or 0 otherwise	3,351	67.73
Vehicle Characteristics			
Passenger	passenger car: 1 if yes or 0 otherwise	1,275	25.77
SUV	SUV or Pick up: 1 if yes or 0 otherwise	2,853	57.67
Motorcycle	motorcycle or ATV: 1 if yes or 0 otherwise	196	3.96

4. RESEARCH METHODOLOGY

Logistic regression and mixed binary logistic regression techniques were used to model the gravel road crash severities. The response variable in both models was whether the gravel road crash is fatal or severe injury crash, or not. In the logistic regression method, the probability (πi) of having a severe crash can be expressed in Equation 1 (20).

$$\Pi i = \exp[(\beta 0+ \beta 1\ Xi1+\cdots+ \beta p\ Xpi] /(1+\exp[(\beta 0+ \beta 1\ Xi1+\cdots+ \beta p\ Xpi]) \quad (1)$$

Where X is the explanatory variable, and β is the explanatory variable coefficient. The term βi Xi represents the effect of the explanatory variable on the response. Model evaluation can be carried out using several measurements. This study used twice negative the log-likelihood (-2LL), log-likelihood ratio, and AIC to evaluate and test the goodness of fit of the developed models. The log-likelihood ratio test was calculated to test whether the model parameters influence gravel roads crash severity. In order to calculate log-likelihood ratio a null model, with only constant, b0, was generated and it's (-2LL) was calculated. The log-likelihood ratio can be calculated as shown in Equation (2).

$$\text{Log-likelihood ratio} = -2LL - -2LL\text{at zero} \quad (2)$$

AIC is an expression for the number of parameters in the model. AIC was used to test the model fit and was calculated as expressed in Equation 3 (20).

$$AIC = -2LL + 2np \quad (3)$$

The mixed binary logistic regression model is close to the logistic regression model except that it must have at least one random parameter (21). In this study, the coefficients, β's, distribution assumed to follow the normal distribution. Probability of gravel roads crash severities, using the mixed binary logistic regression, can be expressed as shown in Equation 4 (22, 23)

$$Pim = \int [(\exp(\beta Xi))/(1+ \exp(\beta Xi))\ f(\beta/\theta)d\beta] \quad (4)$$

Where X is crash severity contribution factors, β is the factor coefficient, f (β/θ) is the random parameter density function normal distribution. Based on that, the log-likelihood in the mixed binary logistic regression is defined as follow (24, 25).

$$LL = \sum_{i=1}^{n} [yi\ ln[(Pi]^m)+(1-yi)\ ln[(1-]][Pi]^m) \quad (5)$$

The mixed logistic regression method provide an estimation for each coefficient to calculate the crash severity probabilities (26, 27). The model can be used regardless the data were randomly selected or not (28).

5. EMPIRICAL ANALYSIS

Both binary logistic regression model and mixed binary logistic regression model were developed using R studio 4.1.0. The forward stepwise model building method was employed to determine the significant factors and omit the non-significant factors. The stepwise method produce a model with the best goodness of fitness (29, 30). Several attempts were conducted to determine the random parameters. The effect of heterogeneity of all factors were checked.

6. Serious or Fatal Injury

The results showed that only passenger cars was identified as a random parameter for the fatal and severe injury accident. The parameter was considered random in this study when its standard deviation was different from zero at the 95th percentile confidence interval. The binary logistic regression model results and the mixed binary logistic regression model summary are shown in Table 2. The results are discussed in the following content. All explanatory variables were interpreted while assuming all else was unchanged.

Table 1: Serious or Fatal Injury Models Summary

Variable	Binary Logistic Model		Mixed Binary Logistic Model	
	Coefficient Estimate	P-value	Coefficient Estimate	P-value
Intercept	-2.335	< 2 (10^{-16})	-2.359	< -2 (10^{-6})
Environmental Characteristics				
Darkness Lighted (other lighting condition in reference)	-1.992	0.049	-2.0929	0.054
Roadway Characteristics				
Snow (all other road condition in reference)	-1.268	1.97 (10^{-7})	-1.3429	2.7 (10^{-7})
Level (terrain in reference)	-0.265	0.040	-0.2699	0.049
Horizontal Curve (straight in reference)	0.404	0.002	0.4879	6.100 (10^{-4})
Speed (speed higher than the speed limit in reference)	0.410	0.002	0.462	7.9 (10^{-4})
Driver Characteristics				
Commuter Driver (not commuter drover in reference)	-0.305	0.017	-0.281	0.038
Gender (female in reference)	0.309	0.034	0.284	0.067
Vehicle Characteristics				
Passenger (all other vehicle types in reference)	-1.009	6.09 (10^{-6})	-5.117	0.049
SUV (all other vehicle types in reference)	-0.654	1.590 (10^{-4})	-0.680	9.65 (10^{-5})
Motorcycle (all other vehicle types in reference)	1.870	< 2 (10^{-16})	1.866	< -2 (10^{-6})
Model Fit Statistics				
AIC	2,031.835		2,027.724	
-2 Log Likelihood	2,009.836		2,004	
-2 Log Likelihood at zero	2,354.4994		2,360	
Log-likelihood ratio x2	344.6634		356	

The results showed that the mixed binary logistic regression model provided a better performance in terms of goodness of fit measurements. This can be concluded since the mixed binary logistic regression had lower AIC value and higher log-likelihood (31, 32, and 33). Thus, the mixed binary method was considered to make inferences about the crash severities. The odds ratios were calculated for mixed binary logistic regression model. Table 3 represents the odds ratios results for serious and fatal injury. The analysis represented that, as shown in Table 2, the passenger car was found as a random parameter. However, as shown in Table 2, there are eleven significant model parameters, including the model constant. Ten of these parameters were fixed, while one of them, passenger cars, was random. The odds ratio is the probability of the gravel road crash to have fatalities or serious injuries considering the effect of only the relative parameter. The odds ratios usually calculated with neglecting the interaction effects (21, 34, and 35). Utilizing the odds ratios in making inferences about the factors and their contribution on the gravel roads crash severities is one of the most important outcome of this study. The odds ratio based

on the mixed logistic binary regression are shown in Table 3. Interpreting the model estimates; snow, is a negative fixed parameter. Thus, having snow on the road surface decreased the probability of fatalities or serious injuries on gravel roads crashes by 0.261 times on average. This can be explained by the fact that drivers reduce speed and take extra caution while driving in snowy road surface. Driver commuter, is a negative fixed parameter, so being a commuter driver would reduce the probability of having a fatal or serious injury crash by 0.755 times. This was most likely because of that commuter drivers were at less risk of encountering unexpected scenarios while driving. Speed was a positive fixed variable, indicating that exceeding the speed limits significantly increase the probability of involving fatalities or serious injuries in the gravel roads crash by 1.588 times on average. For the positive fixed variable, gender, being a male increased the probability of involving fatalities or serious injuries for the gravel roads crashes. This was most likely because males tended to be more aggressive drivers than females. The probability of gravel road crashes being severe increased by an estimated odds of 1.328 times on average when male drivers were involved in crashes. SUV was a negative fixed parameter, indicating that SUV vehicles were less likely to have fatalities or serious injuries for gravel roads crashes. While the positive fixed variable motorcycle, indicated that motorcycle increased the probabilities of having fatalities or serious injuries on gravel roads. The odds ratio for motorcycle suggested that when they were involved in gravel road crashes, the probability of severe crashes increased by an estimated odds of 6.46 times on average. The level grade is a negative fixed parameter, meaning that having a crash at level terrain reduced the probabilities of fatalities and serious injuries for gravel roads crashes. Horizontal curve was a positive fixed variable, meaning gravel road crashes that took place in horizontal curve increased the crash severity. Gravel road crashes that took place in horizontal curves had the probability of being severe by an estimated odds of 1.628 times on average. The risk of severe crashes at horizontal curves can be explained by the risk of drivers losing control on the curved sections of the roads (36, 37). While darkness lighted was negative fixed parameter, indicating that lighting the gravel roads at night reduces the probability of fatalities or serious injuries by an estimated odds of 0.123 on average. This is most likely because lighted roads will increase the driver visibility which led to better ability in preventing severe crashes. The mean and standard deviation of the variable passenger car was found -5.1174 and 3.673, respectively. This suggested that for 91.8% cases, having a passenger vehicle involved in the gravel road crash reduced the probability of fatalities or serious injuries. The probability of gravel road crashes being severe decreased by an estimated odds of 5.117 times on average when gravel road crash involved passenger vehicle. For the remaining 8.2% cases, having passenger vehicle increased the probability of fatalities or serious injuries in the gravel roads. Finally, the results showed that snow, commuter drivers, SUV, level road, darkness and lighted were less likely to cause fatalities or serious injuries in the gravel roads crashes. Unobserved heterogeneity effect was found in the passenger vehicle. 26% of the gravel road crashes have a passenger vehicle as a part of the crash. The heterogeneity in passenger vehicle factor related to the significant variability in the drivers behavior of this category.

Table 2: Average Odds Ratio Results for the Mixed Binary Logistic Regression Model for Fatal and Serious Injury

Variable	Average odds ratio
Snow	0.261
Commuter driver	0.755
SUV	0.507
Motorcycle	6.46
Level	0.765
Horizontal Curve	1.628
Darkness Lighted	0.123
Speed	1.588
gender	1.328

7. Minor or Possible Injury

The results showed that only passenger cars were identified as a random parameter for the minor and possible injury crashes. The parameter was considered random in this study when its standard deviation was different from zero at the 95th percentile confidence interval. Both logistic regression model and mixed binary logistic model results are shown in Table 4. The results are discussed in the following content. All explanatory variables were interpreted while assuming all else was unchanged.

Table 4: Minor and Possible Injury Models Summary

Variable	Binary Logistic Model		Mixed Binary Logistic Model	
	Coefficient Estimate	**P-value**	**Coefficient Estimate**	**P-value**
Intercept	-1.071	$<10^{-16}$	-1.129	$< (2)10^{-16}$
Roadway Characteristics				
Snow (all other road condition in reference)	-0.790	4.28 (10^{-16})	-0.946	4.44 (10^{-11})
Level (terrain in reference)	-0.338	3.31 (10^{-16})	-0.407	2.74(10^{-5})
Horizontal Curve (straight in reference)	0.265	3.09 (10^{-4})	0.327	1.6 (10^{-4})
Speed (speed higher than the speed limit in reference)	0.308	2.2 (10^{-5})	0.373	8.56 (10^{-5})
Wet (all other road condition in reference)	N/A	N/A	-0.562	9.9 (10^{-4})
Driver Characteristics				
Elderly Driver (other ages in reference)	-0.709	2.9 (10^{-8})	-0.853	22(10^{-7})
Younger Driver (other ages in reference) (considered random parameter)	0.279	1.67 (10^{-4})	0.317	0.034
Gender (female in reference) (considered random parameter)	N/A	N/A	-0.449	0.038
Vehicle Characteristics				
Motorcycle (all other vehicle types in reference)	1.040	7.58 (10^{-12})	1.369	2.34 (10^{-9})
SUV (all other vehicle types in reference)	N/A	N/A	0.166	0.0634
Model Fit Statistics				
AIC	5192.5		5190.986	
-2 Log Likelihood	5174.428		5164.986	
-2 Log Likelihood at zero	5476.744		5476	
Log-likelihood ratio x2	302.316		311.014	

The results showed that the mixed binary logistic regression model provided a better performance in terms of goodness of fit measurements. This can be concluded since the mixed binary logistic regression had lower AIC value and higher log-likelihood (31, 32, and 33). Thus, the mixed binary method was considered to make inferences about the crash severities. The odds ratios were calculated for mixed binary logistic regression model. Table 5 represents the odds ratios results for minor and possible injuries. The analysis represented that, as shown in Table 4, gender and young age driver were found as random parameters. However, as shown in Table 4, there are eleven significant model parameters, including the model constant. Nine of them were fixed parameter, while two of them, gender and younger driver, were random. The odds ratio is the probability of the gravel road crash to have minor or possible injury considering the effect of only the relative parameter. The odds ratios usually calculated with neglecting the interaction effects (21, 34, and 35).

Table 5: Average Odds Ratio Results for the Mixed Binary Logistic Regression Model for Minor and Possible Injury

Variable	Average odds ratio
Snow	0.388
Wet	0.570
Level	0.666
Horizontal Curve	1.387
Speed	1.452
Elderly Age Driver	0.426
SUV	1.181
Motorcycle	3.931

Interpreting the model estimates; snow, is a negative fixed parameter. Thus, having snow on the road surface decreased the probability of minor and possible injuries on gravel roads crashes by 0.388 times on average. This inference is mostly related to the slippage potential on the snowy road surfaces, which makes drivers be more careful. Wet, is a negative fixed parameter. Thus, having wet road surface decreased the minor and possible injuries probability on gravel roads crashes by 0.57 times. This inference is mostly related to the slippage potential on the wet road surfaces that makes driver being more careful. Level is a negative fixed parameter. Based on that, having a crash on level terrain will decrease the probability of minor and possible injuries by 0.666 times on average. Horizontal curve is a positive fixed parameter. So, having crashes at horizontal curve locations will increase the probability of having minor or possible injuries by 1.39 times on average. This is expected since the horizontal curve is one of the most high-risk spot in any road. Speed is another positive fixed parameter. Thus, having a crash on gravel roads while driving with a speed higher than the speed limit increased the probability of minor or possible injuries by 1.452 times on average. The higher speed lead to higher collision that increases the injury severity. Elderly drivers is also a negative fixed parameter. So, when elderly drivers are involved in gravel road crashes, the probability of minor or possible injuries decreased by 0.426 times on average. SUV is a positive fixed parameter. Having SUV vehicle involved in gravel road crashes increased the probability of minor or possible injuries by 1.18 times on average. This influence due to the common behavior of SUV drivers, since they feel safe while driving such cars. While the positive fixed variable motorcycle, indicated that motorcycle increased the probabilities of having minor or possible injuries on gravel roads. The odds ratio for motorcycle suggested that when they were involved in gravel road crashes, the probability of having minor and possible injury increased by an estimated odds of 3.931 times on average. The mean and standard deviation of the variable gender was found -0.449 and 0.038, respectively. This suggested that for 62.2% cases, having a female driver involved in the gravel road crash reduced the probability of minor and possible injuries. The probability of gravel road crashes being severe decreased by an estimated odds of 0.449 times on average when gravel road crash involved female driver. For the remaining 37.8% cases, having female driver increased the probability of minor or possible injuries on the gravel roads. The mean and standard deviation of the variable younger drivers was found 0.317 and 0.327, respectively. This suggested that for 82.6% cases, having younger drivers involved in the gravel road crash increased the probability of minor and possible injuries. The probability of gravel road crashes being minor or possible increased by an estimated odds of 0.317 times on average when gravel road crash involved younger drivers. For the remaining 17.4% cases, having younger drivers decreased the probability of minor or possible injuries in the gravel roads. Finally, the results showed that snow, wet, level road, and elderly drivers were less likely to influence minor or possible injuries in the gravel roads crashes. While motorcycle has the highest probability to be in minor or possible injury.

8. Property damage only

The results showed that speed and gender are identified as random parameters for the property damage only crashes. Both logistic regression model and mixed binary logistic model summaries are shown in Table 6. All explanatory variables were interpreted while assuming all else was unchanged.

Interpreting the model estimates, daylight is a positive fixed parameter. So, having crashes in daylight will increase the probability of property damage only crashes by 1.77. This can be explained by that daylight give more vision which decrease the probability of having more severe injuries. Snow is a positive fixed parameter. Thus, having snow on the road surface increased the probability of property damage only crashes on gravel roads crashes by 3.865 times on average. This inference is mostly related to the slippage potential on the snowy road surfaces. Wet is

a positive fixed parameter. Thus, having wet road surface increased the probability of property damage only crashes on gravel roads crashes by 2.235 times on average. This inference is mostly related to the slippage potential on the wet road surfaces. Dry surface is a positive fixed parameter. Based on that, having a dry road surface will increase the probability of property damage only crashes by 1.212 times on average. This can be related to that, on dry road surface, crashes tend to be less severe. Level is a positive fixed parameter. Based on that, having crashes on level terrain will increase the probability of property damage only crashes by 1.462 times on average. It can be explained by that level areas have less risk than up hills or down hills. Horizontal curve is a negative fixed parameter. So, having accident at horizontal curve location will decrease the probability of having property damage only accident by 0.8 times. This is expected since the horizontal curve is one of the most high risk spot in any road, so most crashes there tend to be more severe. Younger driver is another positive fixed parameter. Thus, having crashes on gravel roads while younger drivers is involved will increase the probability of property damage only crashes by 1.708 times on average. Middle age driver is a positive fixed parameter. So, involving a middle driver in gravel road crashes increased the probability of property damage only crashes by 1.71 times on average. Commuter driver is a positive fixed parameter. Having commuter driver involved in crashes increased the probability of property damage only crashes by 1.988 times on average. This influence due to that commuter driver are familiar with the roads so they are less likely have more sever crashes. In addition, the passenger vehicle is a positive fixed parameter, where the results showed that having passenger vehicle involve in gravel road crashes increase the probability of property damage only crashes by 1.584 times on average. While the negative fixed variable motorcycle, indicated that motorcycle decreased the probability of property damage only crashes on gravel roads. The odds ratio for motorcycle suggested that when they were involved in gravel road crashes, the probability of property damage only crashes decreased by an estimated odds of 0.013 times on average. The mean and standard deviation of the variable gender was found 0.937 and 2.069, respectively. This suggested that for 67.5% cases, having a female driver involved in the gravel road crash increased the probability of property damage only crashes. For the remaining 32.5% cases, having female driver decreased the probability of property damage only in the gravel roads. The mean and standard deviation of the variable speed was found -0.649 and 1.230, respectively. This suggested that for 70.0% cases, having crashes on the gravel roads with higher speed than the speed limit decreased the probability of property damage only crashes. For the remaining 30% cases, having high speed increased the probability of property damage only crashes in the gravel roads.

Table 6: Property Damage Only Models Summary

Variable	**Coefficient Estimate**	**P-value**	**Coefficient Estimate**	**P-value**
Intercept	-1.237	$< 2\ (10^{-16})$	-1.591	$3.97(10^{-13})$
Environmental Characteristics				
Daylight (other lighting condition in reference)	0.418	$1.32\ (10^{-10})$	0.571	$3.95\ (10^{-9})$
Roadway Characteristics				
Snow (all other road condition in reference)	1.001	$< 2\ (10^{-16})$	1.352	$< (10^{-16})$
Wet (all other road condition in reference)	0.572	$5\ (10^{-4})$	0.804	0.0006
Dry (all other road condition in reference)	0.125	0.118	0.192	0.090
Level (terrain in reference)	0.273	$6.7\ (10^{-5})$	0.380	0.00013
Horizontal Curve (straight in reference)	-0.207	0.003	-0.223	0.021

Speed (speed higher than the speed limit in reference)	-0.518	2.17 (10^{-14})	-0.649	1.54 (10^{-9})
Driver Characteristics				
Commuter Driver (not commuter drover in reference)	0.403	1.16 (10^{-9})	0.687	3.82 (10^{-11})
Middle Age Driver (all other ages in references)	0.596	1.55 (10^{-9})	1.030	2.16 (10^{-11})
Gender (female in reference)	0.476	5.28 (10^{-12})	0.937	1.19 (10^{-9})
Young age driver (all other ages in references)	0.220	0.022	0.535	9.31 (10^{-5})
Vehicle Characteristics				
Passenger (all other vehicle types in reference)	0.716	1.57 (10^{-10})	0.460	1.07 (10^{-5})
Motorcycle (all other vehicle types in reference)	-2.627	< 2 (10^{-16})	-4.377	< (10^{-16})
Model Fit Statistics				
AIC	5861.9		5859.192	
-2 Log Likelihood	5831.9		5828	
-2 Log Likelihood at zero	6852.9		6584	
Log-likelihood ratio x2	1021		756	

Table 3: Average Odds Ratio Results for the Mixed Binary Logistic Regression Model for Property Damage Only

Variable	Average odds ratio
Day Light	1.770
Snow	3.865
Dry	1.212
Wet	2.235
Level	1.462
Horizontal Curve	0.800
Young age Driver	1.708
Middle age Driver	2.801
Commuter driver	1.988
Passenger	1.584
Motorcycle	0.013

9. CONCLUSIONS

Gravel roads safety is one of the essential issues in gravel roads management. Crashes that occurred on gravel roads have higher probabilities of fatalities or serious injuries. Previous studies were carried out to investigate the relationship between the gravel roads crash severities and the influencing factors. They found that there is a widely range of contribution factors such as road conditions, weather conditions, vehicle type, driver behavior and characteristics, road geometric features, terrain, and environmental conditions. This study adapted a novel technique that was not employed before in modeling the severity of gravel roads crashes. The unobserved heterogeneity effects were employed and investigated in this research work. Gravel roads crash data from WYDOT in the period from 2010 to 2019 were studied and analyzed. The outcome of this study was modeled for all degrees of crash severities. Two models were developed, for each severity level: binary logistic regression and mixed binary logistic regression. The mixed logistic binary regression model was found to have better performance in both: investigating the factors influencing gravel road crash severities; and estimating the gravel roads crash severities probabilities.

The results of this study found that motorcycle crashes on gravel roads had the highest risk of having fatalities and serious injuries. In addition, vehicle type in terms of passenger vehicle has a mixed effect on the crash severities. Other contributory factors such as driver characteristics and surface condition in terms of having snow were less likely to cause fatalities or serious injuries. On the other hand, some factors such as the existence of horizontal curve and male drivers increased the severity of gravel roads crashes. While, minor injuries found to be most affected by having horizontal curve on the gravel road crashes, such road characteristics increased the minor injury probability significantly. In addition, property damage only crashes were found to be more probable if the road surface was snowy.

The importance of employing random parameters in gravel roads crash studies was highlighted in this study. The random parameters have the capabilities of compromise the bias resulted from the omitted and neglected contributory factors. In general, the omitted variables bias produce a misleading estimates that affect the accuracy of the results interpretation. Additionally, using random parameter is a cost effective solution replace the need of building a database with numerous factors.

10. RECOMMENDATIONS

Since the finding of the study highlighted the high risk encountered the motorcycle on gravel roads, more studies should be conducted to investigate the factors that increase the risk of having fatalities and serious injuries among the motorcycle crashes on gravel roads. In addition, as the horizontal curves affect the crash severity positively, widening at the curves tangents are suggested to reduce the possibility of loss of control. Moreover, the results of this study indicated the significant effect of speed on the crash severities. Thus, awareness campaigns are suggested to increase the society understanding about the risk of exceeding the posted speed limits.

The promising results of this study should encourage the researchers to carry out more researches on gravel roads crashes with employing more advance techniques such as the artificial neural network or the mixed generalized ordinal probit model. In addition, the effect of interaction can be studied and investigated. The high percentage of fatalities and serious injuries on gravel roads crashes should raise the need of developing comprehensive safety manuals for gravel roads.

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12. AUTHOR CONTRIBUTION

The authors confirm contribution to the paper as follows: study conception and design: OA, UR, KK; data collection: KK; analysis and interpretation of results: OA; draft manuscript preparation: OA, UR, KK. All authors reviewed the results and approved the final version of the manuscript.

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