This manuscript is the post-print of the following:

Al-Bdairi,N., Behnood, A., Hernandez, S., 2020. Temporal stability of driver injury severities in animal-vehicle collisions: A random parameters with heterogeneity in means (and variances) approach. Analytic Methods in Accident Research (**inPress**)

Temporal stability of driver injury severities in animal-vehicle collisions: A random parameters with heterogeneity in means (and variances) approach

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September 2019

Abstract

This study investigates the determinants of driver injury severity in animal-vehicle collisions while systematically accounting for unobserved heterogeneity in the data by using three methodological approaches: mixed logit model, mixed logit model with heterogeneity in means, and mixed logit model with heterogeneity in means and variances. Using the data from Washington state from January 1, 2012 to December 31, 2016, a wide range of factors that could potentially affect the injury severity of drivers were examined. Moreover, the temporal stability and transferability of the models were investigated through a series of likelihood ratio tests. Marginal effects were also used to study the temporal stability of the explanatory variables. Model estimation results show that many parameters can potentially increase the likelihood of severe injuries in Animal-vehicle crashes including freeways/expressways, daylight crashes, early morning crashes, dry road surface and clear weather condition. Moreover, the model estimation results show that accounting for the heterogeneity in the means (and variances) of the random parameters can improve the overall fit of the model. Some variables showed relatively similar marginal effects among different methodological approaches while some others showed different marginal effects upon the application of different methods. With regard to temporal stability of explanatory variables, the findings of this study show how underestimating the temporal stability concept may lead to inaccurate and unreliable conclusions.

Keywords: heterogeneity-in-means and variance; random parameters; unobserved heterogeneity; Animal-vehicle collision

1. Introduction

The highway system plays an important role in everyday life as it allows for transportation of people and goods to every corner of the country. In the United States, public highways constitute more than four million miles, of which about 74% (2,939,042 miles) are rural highways (U.S. Department of Transportation/Federal Highway Administration, 2016). Such highways, especially rural roadways, cross through the habitat of many wildlife animals. Therefore, the probability of vehicles colliding with a wild animal such as deer and elk is quite high in such locations. Animal-vehicle collisions (Animal-vehicle crashes) are a major safety concern to travelers, highway administrators, and environmentalists. In the U.S., more than 270,000 animal-vehicle collisions reported annually leading to more than 13,000 human injuries and about 200 fatalities (NHTSA, 2015). In addition to human injuries and fatalities, the Animal-vehicle collisions cause more than one billion dollars in property damage in the U.S annually (Huijser et al., 2009). The National Insurance Crime Bureau (NICB) also provided statistics regarding the animal-vehicle collisions in the U.S. with a total of 1,740,425 insurance claims between 2014 and 2017 (NICB, 2018). The majority of these claims (i.e., 584,165) involved deer-related collisions. Statewide, more than 2,500 Animal-vehicle collisions have been reported each year, with 167 human injuries and at least one human fatality by the Washington State Department of Transportation (WSDOT). Yet, these numbers are way below the actual Animal-vehicle collisions due to underreporting of such crashes.

Although there is an extensive body of knowledge on animal-vehicle collisions, a very limited understanding of the relationship between driver injury severity resulted from such collisions and how other factors, such as human-related, environmental conditions, roadway characteristics, crash characteristics, vehicle characteristics, and temporal characteristics can influence this relationship. A careful and thorough reviewing of the literature shows that injury severity sustained by drivers involved in the animal-vehicle collisions are highly overlooked because previous studies have mainly focused on crash frequency (Lao et al., 2011a, 2011b), temporal analysis (Hothorn et al., 2015), spatial analysis (Diaz-varela et al., 2011; Wilkins et al., 2019), countermeasures effectiveness (Hedlund et al., 2004; Knapp et al., 2003; Sullivan et al., 2004), predicting animal-vehicle collisions in urban areas (Found and Boyce, 2011), hotspot identification (Yang et al., 2019), driver behavior (Marcoux and Riley, 2010; Vanlaar et al., 2019).

In terms of injury severity analysis, Savolainen and Ghosh (2008) examined contributing factors to injury severity of drivers involved in deer-vehicle crashes occurred in Michigan state. However, their study did not account for unobserved heterogeneity in the crash data because they developed a multinomial logit model. Moreover, the previous studies assumed that the explanatory variables that impact injury severity are temporally stable (i.e., constant over time), which is not the case in the accident data analyses because the fundamental change of human behavior over time and the fact that a vehicle accident is a rare event. Above it all, the way that the crash data being aggregated over time (weeks, months or years) to obtain sufficient observations may arise concern with temporal instability in the crash data analyses (Mannering, 2018). Recently, several efforts have been made to remediate temporal instability in crash data analyses (Alnawmasi and Mannering, 2019; Behnood and Mannering, 2019, 2015, 2016; Mannering, 2018).

Given the sparse literature on injury severity of drivers involved in animal-vehicle collisions and the continuing rising of animal-vehicle crashes, there is a crucial need for decision makers and safety engineers to better understand the factors contributing to the animal-vehicle collisions and to identify the high-risk locations for mitigating the effects of these crashes through prioritizing appropriate countermeasures. Consequently, the current paper seeks to investigate injury severity sustained by drivers involved in animal-vehicle collisions in rural highways in Washington state.

To do so, an appropriate analysis approach needs to be utilized to overcome the limitations in the crash data, namely the unobserved heterogeneity (Mannering et al. 2016) and temporal instability (Mannering, 2018). In the current paper, a mixed logit model was used to capture any heterogenous effect in the determinants of driver injury severities involved in animal-vehicle collisions while capturing the heterogeneity in the means and variances of the random parameters. As such, this research contributes to our understanding of the animal-vehicle collisions in two ways: empirically and methodologically. In terms of empirical contribution, an extensive list of contributing factors that impact injury severity incurred by drivers involved in animal-vehicle collisions was used. Methodologically, to the best of the authors' knowledge, this is the first attempt to account for unobserved heterogeneity and temporal instability in crash data pertaining to animal-vehicle collisions as long as such collisions highly suffer from underreporting issues that if overlooked could lead to erroneous inferences. To achieve the overarching objective of this paper, five years of Washington state crash data of animal-vehicle collisions is used. This data includes Animal-vehicle collisions crashes involved deer and elk that occurred in rural highways in Washington state.

The rest of paper is organized as follows. Section 2 presents the methodological approach used in this study. Section 3 describes the data source and injury severity categorization. The temporal stability tests are presented in Section 4. The estimation results along with its interpretations are provided in Section 5. Finally, Section 6 concludes the paper and presents directions for future research.

2. Methodology

Police-reported crashes are the main sources of crash data in roadway safety studies. Such reports provide detailed information about the involved individuals, vehicles, roadways, and traffic and environmental factors. Still, these reports lack some determinants that could potentially affect the likelihood of a crash or its resulting injury severity. This could be attributed to the failure of police officers who collect the useful information about highway crashes at the crash scenes. In other words, some explanatory factors will not be available for the analyst. Mannering et al. (2016) provided detailed information about unobserved heterogeneity in the crash data and various methodologies to account for that. This shortcoming in the crash data needs to be addressed through using more comprehensive dataset as well as more advanced statistical and econometric approaches. By doing so, any biases and erroneous inferences would be significantly minimized, which could lead to implementing more effective countermeasures to reduce the crashes and their resulting injuries.

In light of the above discussion, numerous statistical approaches have been used to investigate injury severity of highway crashes while accounting for unobserved heterogeneity. For example, Al-Bdairi and Hernandez (2017), Al-Bdairi et al. (2018), Anderson and Hernandez (2017), Behnood and Mannering (2015), Behnood and Mannering (2017a), Cerwick et al. (2014), Gong and Fan (2017), Kim et al. (2013), and Liu and Fan (2020) have all estimated random parameters logit models (mixed logit models) of crash-injury severities. In other studies, Behnood et al. (2014), Behnood and Mannering (2016), Cerwick et al. (2014), Shaheed and Gkritza (2014), and Yasmin et al. (2014) have estimated latent class models. Many other methodological approaches have also been used to account for unobserved heterogeneity including bivariate/multivariate models with random parameters, correlated and grouped random parameter models, random thresholds random parameters ordered probability models, Bayesian random parameters models, grouped latent class models with class probability functions and others (Boggs et al., 2020; Eker et al., 2019; Fountas et al., 2019, 2018b, 2018a; Fountas and Anastasopoulos, 2018, 2017; Heydari et al., 2018; Huang et al., 2019; Marcoux et al., 2018; Shaheed et al., 2016; Venkataraman et al., 2014; Xiong and Mannering, 2013).

The main front line approaches to account for the unobserved heterogeneity include random parameters (mixed logit) approaches, latent class approaches, and the combination of both (Mannering et al., 2016). In random parameters approach, the heterogeneity of each estimated parameter across the observations should be statistically tested through specifying a parametric distribution (i.e., normal, lognormal, triangular, uniform, etc.). The latent class approach bypasses the distribution assumption in the mixed logit approach by accounting for the unobserved heterogeneity by identifying groups of observations (latent classes) with similar characteristics within each group (Behnood and Mannering, 2016; Mannering et al., 2016).

In the standard mixed logit model, the means and variances of the random parameters are assumed to be fixed across the observations. Having this assumption, the analyst will be unable to check whether the unobserved heterogeneity is a function of explanatory variables or not. Following the previous studies (Behnood and Mannering, 2017b; Seraneeprakarn et al., 2017), this research aims to compare the performance of three econometric models (i.e., mixed logit model, mixed logit model with heterogeneity in means, and mixed logit model with heterogeneity in means and variances) in analyzing the animal-vehicle crash injury severities.

The model estimation begins by introducing an injury severity function S_{in} that individual driver incurs injury severity level i (no injury, minor injury, and severe injury) in crash n as (Washington et al., 2011):

$$S_{in} = \boldsymbol{\beta}_i \boldsymbol{X}_{in} + \varepsilon_{in} \tag{1}$$

where S_{in} is an injury severity function determining the probability of injury severity level i in crash n, β_i is the vector of the estimable coefficients, $\boldsymbol{X}_{in}$ is the vector of explanatory variables (driver, vehicle, roadway and environmental attributes) that impact driver injury severity, and ε_{in} is the error term which is assumed to follow an independent and identically distributed extreme value (i.e., Gumbel type 1). To account for unobserved heterogeneity across crashes in the means and variances of random parameters, β_{in} in Eq. (1) should be formulated to be a vector of estimable parameters that varies across crashes as (Behnood and Mannering, 2017b, 2019; Seraneeprakarn et al., 2017):

$$\boldsymbol{\beta}_{in} = \boldsymbol{\beta} + \boldsymbol{\delta_{in}Z_{in}} + \sigma_{in}EXP(\boldsymbol{\omega}_{in}\boldsymbol{W}_{in})v_{in} \tag{2}$$

where β is the mean parameter, Z_{in} is a vector of explanatory variables that accommodate the heterogeneity in the mean, $\boldsymbol{\delta_{in}}$ is a corresponding vector of estimable parameters, $\boldsymbol{W}_{in}$ is a vector of explanatory variables that captures heterogeneity in the standard deviation σ_{in}, $\boldsymbol{\omega}_{in}$ is the corresponding parameter vector, and v_{in} is a randomly distributed term that captures unobserved heterogeneity across crashes.

The probability of injury severity *i* sustained by driver in crash *n*, $P_n(i)$, is written by allowing the vector $\boldsymbol{\beta}_{in}$ to have a continuous density function in the sense that *Prob* ($\boldsymbol{\beta}_n = \boldsymbol{\beta}$) = $f(\boldsymbol{\beta}|\boldsymbol{\varphi})$:

$$P_n(i) = \int \frac{EXP(\boldsymbol{\beta}_i\boldsymbol{X_{in}})}{\sum_{\forall I} EXP(\boldsymbol{\beta}_i\boldsymbol{X_{in}})} f(\boldsymbol{\beta}|\boldsymbol{\varphi})d\boldsymbol{\beta} \tag{3}$$

where $f(\boldsymbol{\beta}|\boldsymbol{\varphi})$ is the density function of $\boldsymbol{\beta}$ with $\boldsymbol{\varphi}$ referring to vector of parameters (mean and variance) of that density function, and all other terms are as previously defined.

A simulated maximum likelihood with 500 Halton draws is utilized for estimating the model (Mcfadden and Train, 2000). Normal, lognormal, triangular, and uniform were considered for the distribution of the random parameters. The best statistical fit was found when the distributions of the random parameters were assumed to be normal. Previous studies have also reported that normal distribution can provide the best statistical fit (Behnood and Mannering, 2017c, 2016; Milton et al., 2008; Moore et al., 2011). To further interpret the estimated results, marginal effects that represent the impact of a particular parameter on driver injury severity due to one-unit change were also calculated. In the present study, all the estimated parameters are indicator variables. Therefore, the marginal effects are computed as the difference in the estimated probabilities when the indicator variables change from zero to one.

3. Empirical setting

In this study, five-year single-vehicle crash data drawn from the Washington State Department of Transportation (WSDOT) on animal-vehicle collisions was used. This data includes the animal-vehicle collisions that occurred in rural highways in Washington state from January 1, 2012 to December 31, 2016. To test for the temporal instability, the crash data was split into three time periods: 2012-2013, 2014, and 2015-2016.

Injury severity levels sustained by drivers in animal-vehicle collisions are assessed by police officers at the crash scene into five-point ordinal scale: (1) no injury; (2) possible injury; (3) non-incapacitating injury; (4) incapacitating injury and (5) fatal injury. However, in this analysis injury severity levels are collapsed into three main groups: no injury, minor injury (by merging possible injury and non-incapacitating injury), and severe injury (by merging incapacitating injury and fatal injury). This is done to get a representative share for each injury severity level. The distribution of injury severity levels in the final data set in the four time periods (i.e., 2012-2013, 2014, 2015-2016, and 2012-2016) is provided in Table 1. Further, the final data set includes numerous variables that affect driver injury severity resulted from animal-vehicle collisions. The descriptive statistics of the explanatory variables are presented in Table 2.

Table 1 Crash injury frequency and percentage distribution by different time periods

Time period	Injury severity	Observations	Percent (%)
2012-2013	Severe injury	107	4.95%
	Minor injury	121	5.60%
	No injury	1,934	89.45%
	Total	2,162	100.00%
2014	Severe injury	63	5.08%
	Minor injury	56	4.52%
	No injury	1,121	90.40%
	Total	1,240	100%
2015-2016	Severe injury	107	4.35%
	Minor injury	128	5.21%
	No injury	2,223	90.44%
	Total	2,458	100%
2012-2016	Severe injury	277	4.73%
	Minor injury	305	5.20%
	No injury	5,278	90.07%
	Total	5,860	100.00%

Table 2 Descriptive statistics of the significant variables in the injury severity models

Variable	2012-2013		2014		2015-2016		2012-2016	
	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev
Driver characteristics								
Male (1 if the driver is male; 0 otherwise)	-	-	-	-	0.568	0.495	0.591	0.492
Young female driver (1 if driver is female with age between 16 and 30 years old; 0 otherwise)	0.099	0.299	-	-	-	-	-	-
Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise)	0.250	0.433	-	-	0.239	0.426	0.244	0.430
Insured (1 if driver was insured; 0 otherwise)	0.946	0.225	0.952	0.215	-	-	-	-
Sobriety (1 if driver is sober; 0 otherwise)	-	-			0.985	0.120	0.980	0.139
Driver restraint system (1 if no restraint system was used; 0 otherwise)	-	-	0.024	0.154	0.025	0.157	0.016	0.127
Driver restraint system (1 if lap and shoulder was used; 0 otherwise)			0.928	0.258				
Licensed driver (1 if licensed drivers; 0 otherwise)	-	-	-	-	0.945	0.229	-	-
Vehicle characteristics								
Passenger car (1 if vehicle type is passenger car; 0 otherwise)	0.497	0.500	0.462	0.499	0.439	0.496	0.465	0.499
Old vehicle (1 if vehicle model between 1960 and 1980; 0 otherwise)	0.006	0.074	-	-	-	-	-	-
Sedan 4 doors (1 if vehicle style is sedan 4 doors; 0 otherwise)	0.333	0.471	-	-	0.254	0.435	-	-
Pickup (1 if vehicle type is pickup; 0 otherwise)	0.449	0.497	0.482	0.500	-	-	-	-
Wagon 4 doors (1 if vehicle style is wagon 4 doors; 0 otherwise)	-	-	-	-	0.230	0.421	0.225	0.417
Truck tractor & semi-trailer (1 if vehicle type truck tractor & semi-trailer; 0 otherwise)	-	-	-	-	-	-	0.015	0.122
New vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise)	-	-	0.548	0.498	0.470	0.499	0.531	0.499
Roadway characteristics								
Speed limit (1 if speed limit is 55 mph, 0 otherwise)	-	-			0.234	0.424	0.415	0.493
Straight and grade (1 if roadway is straight and grade; 0 otherwise)	0.217	0.413			-	-	-	-
Rural freeways/expressways (1 if collision on rural freeways/expressways; 0 otherwise)	0.193	0.395			-	-	0.205	0.403
Two-way divided with median barrier (1 if collision is on two-way divided with median barrier road segment; 0 otherwise)	-	-			-	-	0.174	0.379
Roadway characteristic (1 if curve and grade; 0 otherwise)	-	-	0.073	0.259	-	-	-	-

Speed limit (1 if speed limit is 65 mph, 0 otherwise)	-	-	0.083	0.276	-	-	-	-
Traffic control device (1 if no traffic control; 0 otherwise)	-	-	0.990	0.102	-	-	-	-
Dry (1 if road surface condition is dry; 0 otherwise)	0.843	0.364	-	-	0.823	0.381	0.839	0.367
Crash characteristics								
Contributing circumstance (1 if "none"; 0 otherwise)	0.920	0.271	-	-	0.879	0.326	0.890	0.312
Straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise)	0.993	0.083	0.996	0.063	-	-	0.993	0.082
Airbag deployment (1 if combination of airbag deployed; 0 otherwise)	0.018	0.133	0.027	0.161	0.033	0.180	-	-
Ejection (1 if not ejected from vehicle; 0 otherwise)	0.964	0.186	-	-	-	-	0.972	0.166
Fixed object (1 if second harmful event is hitting a fixed object, 0 otherwise)	0.013	0.115	0.015	0.123	0.016	0.127	-	-
Distraction (1 if there is no distraction; 0 otherwise)	-	-	-	-	0.072	0.259	0.064	0.244
Overturn (1 if second harmful event is overturn, 0 otherwise)	-	-	-	-	0.009	0.096	0.009	0.095
Time-related attributes								
Night (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise)	0.464	0.499	-	-	0.463	0.499	0.470	0.499
Time of year (1 if fall, 0 otherwise)	0.417	0.493	0.410	0.492	-	-		
Time of year (1 if winter, 0 otherwise)	0.141	0.348	0.094	0.292	0.164	0.370	0.470	0.499
Early morning (1 if crash occurred between 12:00 am and 4:00 am, 0 otherwise)	-	-	-	-	-	-	0.080	0.271
Morning (1 if crash occurred between 4:00 am and 11:00 am, 0 otherwise)	-	-	-	-	0.266	0.442	-	-
Darkness and lighted (1 if darkness and lighted roadway are on; 0 otherwise)	-	-	-	-	-	-	0.035	0.184
Daylight (1 if light condition is daylight; 0 otherwise)	-	-	-	-	0.284	0.451	0.283	0.450
Environmental and weather characteristics								
Clear (1 if weather condition is clear; 0 otherwise)	-	-	0.779	0.415	-	-	0.739	0.439

4. Temporal stability tests

A series of likelihood ratio tests were applied to statistically test if injury-severities in animal-vehicle collisions were significantly different across different time periods (2012–13, 2014, and 2015–16)[1]. To check the stability of the estimated parameters over time, the first log-likelihood ratio test can be written as (Washington et al., 2011):

$$\chi^2 = -2\left[LL\left(\beta_{k_2k_1}\right) - LL\left(\beta_{k_1}\right)\right] \tag{4}$$

where $LL\left(\beta_{k_2k_1}\right)$ is the log likelihood at the convergence of a model using the converged parameters of time period k_2 while using data from time period k_1, whereas $LL\left(\beta_{k_1}\right)$ is the log likelihood at the convergence of the model using k_1 data (without restricting the parameters). The test statistic χ^2 with degrees of freedom equal to the number of estimated parameters in $\left(\beta_{k_2k_1}\right)$ can provide the probability that the estimated models have different parameters and can be used to test if the null hypotheses that the estimated parameters are equal between the two time period data sets can be rejected. Table 3 provides the results of the first log-likelihood ratio test, which shows that the estimated parameters in the three time periods are different, meaning that the null hypotheses that any two time periods have the same parameters can be rejected with over 99% confidence. This means that estimating separate models for time periods (2012–13, 2014, and

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[1] Previous studies have shown that injury severity models developed using crash-related data are not temporally stable over different time periods. Several factors could be the reasons for temporal instability such as changes in individual behaviors, risk assessment, information processing, and safety attitudes that could be results of changes in information technologies, communication, and vehicles (Mannering, 2018). For example, in recent studies Behnood and Mannering (2016) and Alnawmasi and Mannering (2019) argued that the temporal instability resulted from the influence of economic recession and the long-term evolution of the factors affecting the injury severities. In other studies, Behnood and Mannering (2015) and Behnood and Mannering (2019) showed that long-term evolution of the factors affecting the injury severities resulted in significant temporal instability across different time periods. In this study, after extensive empirical testing for possible temporal instability over all time periods while keeping a meaningful number of observations in each time period, it was found that splitting the data into 2012-2013, 2014, and 2015-2016 provided the only statistically significant separation.

2015–16) is justified. Other researchers have also found that estimating separate models is warranted (Alnawmasi and Mannering, 2019; Behnood and Mannering, 2019, 2015, 2016). However, these studies did not investigate injury severity of animal-vehicle collisions.

Table 3 Likelihood ratio test results (degrees of freedom in parenthesis and confidence level in brackets)

k_1	k_2		
	2012-2013	2014	2015-2016
2012-2013	-	83.30 (15) [>99.99 %]	129.41 (20) [> 99.99 %]
2014	49.48 (18) [>99.99 %]	-	117.27 (20) [>99.99 %]
2015-2016	117.57 (18) [> 99.99 %]	122.50 (15) [>99.99 %]	-

The second log-likelihood ratio test that can be performed to further validate estimating separate models instead of a holistic one is written as (Washington et al., 2011):

$$\chi^2 = -2[LL(\beta_{2012-2016}) - LL(\beta_{2012-2013}) - LL(\beta_{2014}) - LL(\beta_{2015-2016})] \quad (5)$$

where $LL(\beta_{2012-2016})$ is the log-likelihood at convergence of the joint model (estimated with the data of 2012-2016), $LL(\beta_{2012-2013})$ is the log-likelihood at convergence of the model using 2012-2013 time period data, $LL(\beta_{2014})$ is the log-likelihood at convergence of the model using 2014 time period data, and $LL(\beta_{2014})$ is the log-likelihood at convergence of the model using 2015-2016 time period data. It should be noted that the same variables should be used in all models. The X^2 statistic is χ^2 distributed with degrees of freedom equal to the difference between the number of estimated parameters in joint model and the number of estimated parameters in the time periodspecific models. Again, this test shows that the null hypotheses that the parameters are the same can be rejected with over 99% confidence.

5. Discussion of estimation results

As discussed in previous section, the results of the temporal stability tests indicated that the null hypothesis that different time periods produced equal parameters rejected with over 99% confidence level. The model estimation results based on 2012-2016 data, 2012-2013 data, 2014 data, and 2015-2016 data are provided in Tables 4 to 7, respectively. It can be seen that although some of the explanatory variables are repeated across different models, there are significant differences in the model estimation results. The 2012-2016 model was the only model that produced significant heterogeneity in the variances of random parameters (Table 4). However, this model, due to the temporal instability of the explanatory variables, might be inaccurate and unreliable and might lead to incorrect conclusions[2]. As shown in Table 4, the mixed logit model that accounts for the heterogeneity in the means and variances of the random parameters provided betters statistical fit than the model that accounts for the heterogeneity only in the means of random parameters. Moreover, mixed logit models with heterogeneity in the means of the random parameters outperformed the standard mixed logit model in which the means of the random parameters are assumed to be fixed (Tables 4-7) [3]. This observation is in line with the findings of

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[2] The inaccuracy of the 2012-2016 model may result from the fact that the model is estimated using some old data that might not be valid anymore to address the safety concerns of the future. Although 2012-2016 might be inaccurate, because of containing some recent data, it might be more accurate than 2012-2013 and 2014 models. Among the estimated models, the most recent one (i.e., the model developed using 2015-2016 data) might be the most accurate model because of using most recent data. However, in this paper, a discussion has been made using the findings from all estimated models to show how temporal instability could affect the vector of estimable variables and the marginal effects of explanatory variables.

[3] It should be noted that in some data, heterogeneity in the means and/or variances of the random parameters might be statistically insignificant. These models simply converge to a standard mixed logit model. In other words, accounting for the heterogeneity in the means (and variances) of random parameters can potentially improve the overall model fit of any data; however, this improvement is more expected when developing a model for more heterogeneous data.

previous studies on the performance of random parameters models (Alnawmasi and Mannering, 2019; Behnood and Mannering, 2017b, 2017c, 2019).

As shown in Tables 4-7, a wide range of factors[4] were found to significantly affect the driver-injury severities in animal-vehicle collisions. In this study, these factors were classified as driver characteristics, vehicle characteristics, roadway characteristics, crash characteristics, time-related attributes, and environmental and weather characteristics. The corresponding marginal effects (averaged over the observation population) for 2012-2016, 2012-2013, 2014, and 2015-2016 models are given in Tables 8-11. The rest of this section provides a discussion of the model estimation results by variable classification and how temporal instability of the explanatory variables can affect the model estimation results.

5.1. Random parameters

Table 4 shows that in 2012-2016 time period, three variables were found to produce random parameters with normal distribution in the mixed logit model: an indicator variable for passenger car (1 if vehicle type is passenger car; 0 otherwise), an indicator variable for speed limit (1 if speed limit is 60 mph, 0 otherwise), and an indicator variable for night time (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise). Among these variables, the indicator variable for passenger car was not found to be statistically significant random parameter in the mixed logit models with heterogeneity in means (and variances). This explanatory variable in the mixed logit model defined for severe injury outcome and produced a mean of -2.857 and a standard deviation of 2.824. This implies that the involvement of passenger car in animal-vehicle collisions increases the likelihood of severe injuries for 15.58% of the observations and decreases the likelihood of severe injuries

[4] Some variables that are considered intuitively important should be retained in the model despite relatively low significance (e.g., curve and grade, speed limit, and traffic control device) (Kockelman and Kweon, 2002).

for 84.42% of the observations. The mean (standard deviation) of the indictor variable defined for speed limit[5] were obtained as -2.473 (2.795), -0.043 (5.547), and -0.125 (-1.08), in the standard mixed logit model, the mixed logit model with heterogeneity in means, and the mixed logit model with heterogeneity in means and variances, respectively. These numbers indicate that when the standard mixed logit model, the mixed logit model with heterogeneity in means, and the mixed logit model with heterogeneity in means and variances approaches are used, the speed limit of 60 mph increases the likelihood of severe injuries for 18.81%, 49.69%, and 54.61% of the observations, respectively. It can be seen that there is a considerable difference in the percentage of observations increasing the severe injuries when different approaches are used. With regard to the indicator variable defined for night, the mean (standard deviation) values were obtained as -2.568 (3.226), -2.091(2.723), and -2.179 (2.363), respectively, in the standard mixed logit model, the mixed logit model with heterogeneity in means, and the mixed logit model with heterogeneity in means and variances approaches. These distributional values imply that in the standard mixed logit model, the mixed logit model with heterogeneity in means, and the mixed logit model with heterogeneity in means and variances, animal-vehicle collisions during the night time increases the minor injuries for 21.30%, 22.13%, and 17.82% of the observations, respectively. Unlike the findings from the speed limit random parameter, there is not a considerable difference between various approaches in the percentage of observations increasing the minor injuries.

In 2012-2013 model (Table 5), two indicator variables were found to produce statistically significant random parameters when defined for minor injury outcome: an indicator variable for

[5] The heterogeneous effects of speed limit are attributed to some unseen important factors, such as roadway geometrics, driver behavior, and the difficulty to see animals at a higher speed that were not accounted for in the model. It should be noted that such higher speed limit has also been found to be random in previous studies (Shaheed et al., 2013; Yasmin et al., 2015).

“no contributing circumstance” and an indicator variable for having straight ahead movement prior to crash. The values of the mean (standard deviation) of the indictor variable defined for “no contributing circumstance” were obtained as -4.180 (4.935) and -2.358 (2.715) in the standard mixed logit model and the mixed logit model with heterogeneity in means, respectively. These numbers indicate that when the standard mixed logit model and the mixed logit model with heterogeneity in means are used “no contributing circumstance” increases the likelihood of minor injuries for 19.85% and 19.26% of the crashes, respectively. With regard to “straight ahead movement prior to crash”, the values of the mean (standard deviation) of this indictor variable were obtained as -4.950(4.996) and -2.714(2.935) in the standard mixed logit model and the mixed logit model with heterogeneity in means, respectively. These distributions imply that when the standard mixed logit model and the mixed logit model with heterogeneity in means are used the “straight ahead movement prior to crash” increases the likelihood of minor injuries for 16.03% and 17.76% of crashes, respectively.

As shown in Table 6, passenger car and straight ahead movement indicator variables were found as random parameters in 2014 data. The distribution of passenger car indicator variable shows that this variable increases the likelihood of severe injuries for 7.87% and 7.65% of the observations in in the standard mixed logit model and the mixed logit model with heterogeneity in means, respectively. The distribution of straight ahead movement indicator variable implies that this variable increases the probability of minor injuries for 8.52% and 10.08% of the observations when the standard mixed logit model and the mixed logit model with heterogeneity in means are used, respectively.

In 2015-2016 model (Table 7), indicator variables for “no contributing circumstance” and “night” were found to produce statistically significant random parameters in minor injury outcome.

The values of the mean (standard deviation) of the indictor variable defined for “no contributing circumstance” were obtained as -2.663 (2.021) and -2.453 (1.983) in the standard mixed logit model and the mixed logit model with heterogeneity in means, respectively. These numbers imply that when the standard mixed logit model and the mixed logit model with heterogeneity in means are used “no contributing circumstance” increases the likelihood of minor injuries for 9.38% and 10.8% of the crashes, respectively.

5.2. Heterogeneity in means (and variances)

All the explanatory variables in all models were tested for the possibility of significantly affecting the means and variances of the random parameters. The only model that produced significant heterogeneity in the variances of random parameters was the 2012-2016 model (Table 4). Using the 2012-2016 data, in the mixed logit model with heterogeneity in means, three variables were found to significantly affect the mean of the random parameters. An indicator variable for driver restraint system (1 if no restraint system was used; 0 otherwise) was found to increase the mean of speed limit, which is an indication of more severe injuries when restraint system is not used while speed limit is 60 mph. Another indicator variable for Ejection (1 if not ejected from vehicle; 0 otherwise) was found to decrease the mean of speed limit making severe injuries less likely. With regard to the random parameter “night”, an indicator variable for wagon 4 doors (1 if vehicle style is wagon 4 doors; 0 otherwise) increased its mean making minor injuries more likely. Using the 2012-2016 data, in the mixed logit model with heterogeneity in means and variances approach, three variables were found to have significant effects on the mean of the random parameters and three variables were found to have significant effects on the variances of the random parameters. All the explanatory variables that were found to significantly affect the mean of random parameters in the mixed logit model with heterogeneity in means approach had similar effects on the mean of random parameters in the mixed logit model with heterogeneity in means and variances approach. With regard to the explanatory variables that were found to affect the variances of the random parameters, overturn (1 if second harmful event is overturn, 0 otherwise) was found to increase the variances of “speed limit” and “night” while passenger car (1 if vehicle type is passenger car; 0 otherwise) was found to increase the variance of night only. An increase in the variances of the random parameters makes their distribution wider and increases their randomness.

Using the 2012-2013 data (Table 5), passenger car was sound as the only indicator variable that significantly affected the heterogeneity in the mean of random parameter that was defined for straight ahead movement. As shown in Table 5, passenger cars decreased the mean of straight ahead, which implies that they are making the likelihood of minor injuries less likely.

As shown in Table 6, in 2014 model, indicator variable for driver restraint system (1 if lap and shoulder was used; 0 otherwise) decreased the mean of random parameter for straight ahead movement, making minor injuries less likely.

In 2015-2016 model (Table 7), middle-age female drivers were found to decrease the mean of “night” random parameter, making minor injuries less likely while winter crashes increased the mean of “night”, making minor injuries more likely. Winter crashes were also found to have statistically significant effects on the mean of “no contributing circumstance” random parameter by decreasing its mean and making minor injuries less likely.

5.3. Driver characteristics

Table 4 shows that in 2012-2016 models, male drivers were involved in less minor injuries. As shown in Table 8, male drivers using the standard mixed logit model decreased the probability of minor injuries by -0.0119 and increased the likelihood of no and severe injuries by 0.0008 and

0.0111, respectively. Similar marginal effects were obtained while using the mixed logit models with heterogeneity in means (and variances). In 2015-2016 models (Table 11), using the standard mixed logit approach, male drivers increased the likelihood of severe injuries by 0.0109 and decreased the likelihood of minor and no injuries by -0.0004 and -0.0106, respectively. Similar marginal effects were obtained while using mixed logit model with heterogeneity in means. Male drivers were not found to be statistically significant factor affecting the driver injury severities in 2012-2013 and 2014 models. Overall, the model estimations results show that male drivers have temporally unstable behavior over different time periods. In crash injury severity analysis, gender has been found to have complicated effects on the injury severity of the roadway users, which can be attributed to various factors such as temporal and spatial instability, unobserved heterogeneity in the data, and variations in the methodological approaches (Behnood and Mannering, 2019, 2015).

In 2012-2016 models (Table 8), middle-age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise) and sobriety (1 if driver is sober; 0 otherwise) indicator variables were found to decrease the likelihood of severe injuries. The marginal effects of these two explanatory variables show relatively similar values in the mixed logit model with heterogeneity in means and the mixed logit models with heterogeneity in means and variances approaches. However, in the standard mixed logit model, these variables were associated with higher likelihood of no injuries than the other two models. Middle-age female drivers were also found as statistically significant factors in 2012-2013 models and 2015-2016 models. In these two time periods, middle-age female drivers increased the likelihood of minor injuries and decreased the likelihood of severe and no injuries. Overall, with the exception of 2014 models, middle-age female drivers show relatively stable effects on injury severities as they are always associated with decreased likelihood of severe injuries. This might be due to the combined effects of gender and age since both female and middle-age drivers have been reported to be cautious drivers in previous studies (Behnood et al., 2014; Behnood and Mannering, 2015). In 2015-2016 models, sobriety indicator variable was also found to increase the likelihood of severe injuries and decrease the likelihood of minor and no injuries. However, this variable was not found to significantly affect the injury severity outcomes in 2012-2013 and 2014 models.

As shown in Table 8, in 2012-2016 models, the indicator variable for driver restrained system (1 if no restraint system was used; 0 otherwise) was associated with more minor injuries and less no/severe injuries. The marginal effects of this variable show relatively similar values in all the methodological approaches. In 2014 models (Table 10) and 2015-2016 models (Table 11), although marginal effects of this variables were slightly different than those obtained in 2012-2016 models, driver restrained system showed similar effects on the injury severity outcomes. This variable was not found to be statistically significant factor affecting the injury severity outcomes in 2012-2013 models.

In 2012-2013 models (Table 9) and 2014 models (Table 10), insured drivers increase the probability of no injuries and decreased the probability of minor and severe injuries. In 2015-2016 models (Table 11), licensed drivers increased the probability of no injuries and decreased the probability of minor and severe injuries. None of these two variables (i.e., insured drivers and licensed drivers) were found to significantly affect the injury severity outcomes in 2012-2016 models.

5.4. Vehicle characteristics

In 2012-2016 models (Table 4), an indicator variable was defined for passenger cars and was found to be statistically significant determinant in the severe injury outcome of all methodological approaches. Only in the standard mixed logit model, this variable was found to be a significant random parameter. It is interesting to note that as shown in Table 8, in the mixed logit model with heterogeneity in means and the mixed logit model with heterogeneity in means and variances, this variable decreased the likelihood of severe injuries while in the standard mixed logit model, this variable increased the likelihood of severe injuries. As previously mentioned, passenger cars were found to increase the likelihood of severe injuries in a small portion (i.e., 15.58%) of the animal-vehicle collisions. By using the mixed logit models with heterogeneity in means (and variances) approaches, the role of passenger cars in increasing the likelihood of severe injuries of some animal-vehicle collisions can be reflected in the mean and variances of other random parameters. Passenger cars show relatively stable effects across different time periods as in most of the models they decreased the likelihood of severe injuries and increased the likelihood of minor and no injuries in 2012-2013 (Table 9) and 2015-2016 (Table 11) time periods. Interestingly, in 2014 models (Table 10), passenger cars showed inconsistent results as they increased the likelihood of severe injuries and decreased the likelihood of minor and no injuries.

In 2012-2016 models, indicator variables for “wagon 4 doors” and “truck tractor & semi-trailer” increased the likelihood of no injuries and resulted in less minor and severe injuries (Table 8). In the mixed logit model with heterogeneity in means and the mixed logit model with heterogeneity in means and variances, these variables showed relatively similar marginal effects. However, in the standard mixed logit model, “wagon 4 doors” resulted in lower likelihood of no injuries and “truck tractor & semi-trailer” resulted in higher likelihood of no injuries than the other two models. Interestingly, “Truck tractor & semi-trailer indicator variable” was not found to be a significantly affecting parameter in any of the 2012-2013, 2014, or 2015-2016 models. In 2015-2016 models, “wagon 4 doors” indicator variable showed similar effects as those observed in 2012-

2016 models. However, this variable was not found to be statistically significant factor in 2012-2013 and 2014 models.

In 2012-2016 models (Table 8), new vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise) resulted in less minor injuries and more no/severe injuries with relatively similar marginal effects obtained from all methodological approaches used in this study. In 2012-2013 models (Table 9), this variable did not significantly affect the injury severity outcomes while in 2014 models (Table 10) this variable resulted in less severe injuries and more minor and no injuries. In 2015-2016 models (Table 11), new vehicles increased the likelihood of no injuries and decreased the likelihood of minor and severe injuries.

An indicator variable for “sedan 4 doors” showed interesting effects on the injury severity outcomes across different time periods. In 2012-2013 models, this variable decreased the probability of minor injuries while in 2015-2016 model, this variable increased the probability of minor injuries. In 2012-2016 models and 2014 models, “sedan 4 doors” was not found to be a significant factor affecting the injury severity outcomes. The interesting behavior of “sedan 4 doors” show how affecting parameters on the injury severity outcomes can change their direction of effects over the time.

In 2012-2013 models, an indicator variable for old vehicles (1 if vehicle model between 1960 and 1980; 0 otherwise) and an indicator variable for pickups (1 if vehicle type is pickup; 0 otherwise) were found to significantly affect the injury severity outcomes. The former was found to increase the likelihood of severe injuries while the latter was found to decrease the likelihood of severe injuries. The variables were not found to be statistically significant factors affecting the injury severity outcomes 2015-2016 models and 2012-2016 models. In 2014 models, only pick up indicator variable significantly affected the injury severity outcomes with the similar effects observed in 2012-2014 models. This interesting behavior of how some significant factors in the past becomes insignificant shows the importance of temporal stability concept in crash-related studies.

5.5. Roadway characteristics

In 2012-2016 models (Table 8), among the roadway-associated characteristics, an indicator variable for speed limit (1 if speed limit is 60 mph, 0 otherwise) was found to increase the likelihood of severe injuries and decrease the probability of no/minor injuries. The marginal effects of this variable showed relatively similar effects among all the methodological approaches used in this study. Speed limit indicator variable showed similar effects on injury severity outcomes in 2015-2016 models (Table 11) and opposite effects in 2014 models (Table 10). This variable was not found to be statistically significant in 2012-2013 models.

In 2012-2016 models (Table 8), three other indicator variables were defined under the broad category of roadway characteristics: an indicator variable for rural freeways/expressways, an indicator variable for two-way divided with median barrier road segments, and an indicator variable for dry road surface condition. Indicator variable for rural freeways/expressways was found to be associated with less minor injuries. Similar effects were found with regard to rural freeways/expressways in 2012-2013 models (Table 9). However, they were not found to significantly affect the injury severity outcomes in 2014 and 2015-2016 models. The interesting behavior of rural freeways/expressways show that how underestimating the temporal stability concept may lead to inaccurate conclusions about the effects of explanatory variables and make a factor to appear as a significant factor in combined data (i.e., 2012-2016) while it was only significant in the past (i.e., 2012-2013) and not in recent years (i.e., 2014 and 2015-2016).

In 2012-2016 models (Table 8), the indicator variable for "two-way divided with median barrier road segments" was found to be associated with more minor injuries. This variable was not found to be a significant factor affecting the injury severity outcomes in any of the 2012-2013, 2014, and 2015-2016 models.

In 2012-2016 models (Table 8), the indicator variable for dry road surface condition increased the likelihood of severe injuries and decreased the likelihood of no and minor injuries. Dry road surface condition (with the exception of 2014 models) showed relatively stable effects across different time periods.

An indicator variable for "straight and grade" roadways decreased the probability of minor injuries in 2012-2013 models (Table 5). This variable was not found to significantly affect the injury severity outcomes in other models. Moreover, an indicator variable for "curve and grade" roadways decreased the likelihood of severe injuries in 2014 models (Table 6) while it was not a significant factor affecting the injury severity outcomes in other models.

5.6. Crash characteristics

With regard to the crash characteristics in 2012-2016 models, five indicator variables were found to significantly affect the minor injury output in the standard mixed logit model approach including the indicator variables for contributing circumstance (1 if "none"; 0 otherwise), distraction (1 if there is no distraction; 0 otherwise), ejection (1 if not ejected from vehicle; 0 otherwise), overturn (1 if second harmful event is overturn, 0 otherwise), and straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise). All these variables excluding the one for "distraction" were also found to significantly affect the minor injuries in the mixed logit models with heterogeneity in means (and variances approaches). The indicator variable for "overturn" was found to decrease the likelihood of minor injuries and resulted in more no/severe injuries while the other variables showed the opposite effects. None of the variables under crash characteristics category showed similar marginal effects among the methodological approaches. Contributing circumstance showed lower likelihood of minor injuries in the standard mixed logit model than the other two models while ejection showed higher likelihood of minor injuries in the standard mixed logit model than the other two models. In the standard mixed logit model and mixed logit models with heterogeneity in means, the indicator variable for overturn showed similar marginal effects while in the mixed logit models with heterogeneity in means, this variable showed lower probability of minor injuries than the other two models.

None of the above-mentioned parameters showed stable effects across different time periods. The indicator variable for “ejection” resulted in decreased likelihood of minor injuries (increased likelihood of no and severe injuries) in 2012-2016 models (Table 8) and 2012-2013 models (Table 9). This variable was not found to significantly affect the injury severity outcomes in 2014 and 2015-2016 models. The indicator variable for “straight ahead” resulted in decreased likelihood of minor injuries in 2012-2016 models (Table 8) and 2014 models (Table 10) and increased likelihood of minor injuries in 2012-2013 models (Table 9). This variable resulted in statistically insignificant effects on the injury severity outcomes in 2015-2016 models. The indicator variable for “overturn” decreased the likelihood of no injuries in 2012-2016 models and 2015-2016 models. This variable was not found as a statistically significant factor in 2012-2013 and 2014 models. The indicator variable for “distraction” was only found to be statistically significant in 2012-2016 models and 2015-2016 models and resulted in decreased likelihood of minor injuries (increased likelihood of no and severe injuries).

Hitting with fixed object decreased the probability of severe injuries in 2012-2013 models, decreased the likelihood of no injuries in 2014 models, and increased the likelihood of severe injuries in 2015-2016 models. This variable was not found to significantly affect the injury severity outcomes in 2012-2016 models. Again, this interesting behavior underscore the importance of temporal stability concept and how underestimating it may lead to inaccurate conclusions.

An indicator variable for airbag deployment (1 if combination of airbag deployed; 0 otherwise) was found to increase the likelihood of no injuries and decrease the likelihood of severe and no injuries in 2012-2013, 2014, and 2015-2016 models. Interestingly, this variable was not found as a statistically significant factor affecting the injury severities in 2012-2016 models.

5.7. Time-related attributes

In 2012-2016 models, night indicator (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise) resulted in more minor injuries and less no/severe injuries. The use of different methodological approaches did not lead to significant differences in the marginal effects of night indicator. This could be related to the sleeping and activity behavior of deer and elk during a day. These animals are less active during the night time, which decreases the likelihood of severe injuries. During the night time, these animals spend most of the time to hide themselves from the predators. Night indicator variable shows relatively stable effects across different time periods (with the exception of 2014).

In line with the findings from the night indicator, daylight and early-morning indicators resulted in more severe injuries and less no/minor injuries in 2012-2016 models and 2015-2016 models, which can again be attributable to the time-dependent sleeping and activity behavior of deer and elk. As shown in Table 8, early-morning indicator was found to produce consistent marginal effects among all the methodological approaches used in this study while daylight indicator resulted in higher likelihood of severe injuries in the standard mixed logit model than the other two models. In 2012-2016 models, an indicator variable for darkness and lighted condition was found to significantly affect the minor injury outcome and decreases the likelihood of minor injuries with relatively similar marginal effects among all the methodological approaches. This variable was not found as statistically significant factors in 2012-2013, 2014, and 2015-2016 models.

Animal-vehicle collisions during winter season consistently were found to increase the likelihood of no injuries and resulted in less severe/minor injuries across different time periods. Deer and elk spend more time bedded during winter and show less activity, which can lead to more no injuries. In addition, during winter, drivers may compensate for the winter-related weather (e.g., snowing) by reducing their speed, which can reduce the impact of hitting the animals. In 2012-2013 and 2014 models, animal-vehicle crashes during fall season, resulted in less severe injuries and more no and minor injuries.

5.8. Environmental and weather characteristics

An indicator variable for clear weather condition was found to increase the likelihood of severe injuries in 2012-2016 models. As shown in Table 8, in the standard mixed logit model, this variable resulted in higher likelihood of severe injuries than the mixed logit models with heterogeneity in means (and variances). Clear weather condition in 2014 models (Table 10) resulted in similar observations.

Table 4 Estimation results of the mixed logit models for animal-vehicle collisions severity - 2012-2016 time period (Note: [NI]: No injury; [MI] Minor injury; [SI]: Severe injury)

Variable	Mixed logit model with random parameters only		Mixed logit model with heterogeneity in means		Mixed logit model with heterogeneity in means and variances	
	Parameter estimate	t-stat.	Parameter estimate	t-stat.	Parameter estimate	t-stat.
Constant [SI]	-3.169	-5.69	-3.172	-5.96	-3.158	-6.55
Constant [MI]	1.637	2.29	1.387	1.95	1.528	2.53
Driver characteristics						
Male (1 if the driver is male; 0 otherwise) [MI]	-0.653	-4.06	-0.619	-3.93	-0.599	-3.79
Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise) [SI]	-0.836	-3.17	-0.612	-2.65	-0.620	-2.64
Sobriety (1 if driver is sober; 0 otherwise) [SI]	-1.003	-2.14	-0.705	-1.58	-0.713	-1.64
Driver restraint system (1 if no restraint system was used; 0 otherwise) [MI]	1.244	2.96	1.236	2.99	1.279	3.14
Vehicle characteristics						
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	-2.857	-1.97	-0.497	-2.99	-0.490	-2.83
Standard deviation of ''passenger car'' (normally distributed)	*2.824*	*2.65*	-	-	-	-
Wagon 4 doors (1 if vehicle style is wagon 4 doors; 0 otherwise) [NI]	0.700	4.17	0.852	4.61	0.855	4.56
Truck tractor & semi-trailer (1 if vehicle type truck tractor & semi-trailer; 0 otherwise) [NI]	2.193	2.77	2.158	2.41	2.049	2.21
New vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise) [MI]	-0.442	-2.87	-0.451	-3.00	-0.456	-2.93
Roadway characteristics						
Speed limit (1 if speed limit is 60 mph, 0 otherwise) [SI]	-2.473	-2.19	-0.043	-1.03	-0.125	-1.08
Standard deviation of ''speed limit'' (normally distributed)	*2.795*	*3.26*	*5.547*	*2.85*	*5.375*	*2.56*
Rural freeways/expressways (1 if collision on rural freeways/expressways; 0 otherwise) [MI]	-0.479	-2.22	-0.457	-2.21	-0.471	-2.21
Two-way divided with median barrier (1 if collision is on two-way divided with median barrier road segment; 0 otherwise) [MI]	0.398	2.07	0.419	2.27	0.410	2.12
Dry (1 if road surface condition is dry; 0 otherwise) [SI]	0.832	2.26	0.726	2.12	0.720	2.17
Crash characteristics						
Contributing circumstance (1 if "none"; 0 otherwise) [MI]	-0.986	-3.72	-0.648	-3.25	-0.671	-3.35
Distraction (1 if there is no distraction; 0 otherwise) [MI]	-0.676	-1.81	-	-	-	-
Ejection (1 if not ejected from vehicle; 0 otherwise) [MI]	-1.403	-4.36	-1.527	-4.79	-1.613	-5.45

Overturn (1 if second harmful event is overturn, 0 otherwise) [MI]	0.805	1.54	0.86	1.71	0.419	1.64
Straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise) [MI]	-1.588	-2.75	-1.567	-2.74	-1.607	-3.28
Time-related attributes						
Night (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise) [MI]	-2.568	-1.99	-2.091	-1.91	-2.179	-1.85
Standard deviation of ''night'' (Normally distributed)	*3.226*	*3.35*	2.723	*3.19*	*2.363*	*2.54*
Daylight (1 if light condition is daylight; 0 otherwise) [SI]	0.652	3.53	0.492	2.93	0.501	2.86
Early morning (1 if crash occurred between 12:00 am and 4:00 am, 0 otherwise) [SI]	0.626	2.34	0.647	2.66	0.656	2.65
Time of year (1 if winter, 0 otherwise) [NI]	0.577	2.94	0.517	2.71	0.537	2.81
Darkness and lighted (1 if darkness and lighted roadway are on; 0 otherwise) [MI]	-1.244	-1.84	-1.136	-1.85	-1.181	-1.72
Environmental and weather characteristics						
Clear (1 if weather condition is clear; 0 otherwise) [SI]	0.534	2.05	0.498	2.04	0.492	2.05
Heterogeneity in the means of the random parameters						
Speed limit: Driver restraint system (1 if no restraint system was used; 0 otherwise)	-	-	6.329	2.30	6.130	2.20
Speed limit: Ejection (1 if not ejected from vehicle; 0 otherwise)	-	-	-7.703	-2.77	-7.415	-2.47
Night: Wagon 4 doors (1 if vehicle style is wagon 4 doors; 0 otherwise)	-	-	0.874	2.44	1.355	3.40
Heterogeneity in the variances of the random parameters						
Speed limit: Overturn (1 if second harmful event is overturn, 0 otherwise)	-	-	-	-	0.877	2.16
Night: Overturn (1 if second harmful event is overturn, 0 otherwise)	-	-	-	-	0.767	1.67
Night: Passenger car (1 if vehicle type is passenger car; 0 otherwise)	-	-	-	-	0.239	1.94
Model statistics						
Number of observations	5860		5860		5860	
Log-likelihood with constants only	-2298.92		-2298.92		-2298.92	
Log-likelihood at convergence	-2116.90		-2081.81		-2072.79	
Akaike Information Criterion (AIC)	4293.8		4225.6		4213.6	
Bayesian Information Criterion (BIC)	4346.9		4280.4		4273.7	
McFadden Pseudo R-Squared	0.079		0.094		0.098	

Table 5 Estimation results of the mixed logit models for animal-vehicle collisions severity - 2012-2013 time period (Note: [NI]: No injury; [MI] Minor injury; [SI]: Severe injury)

Variable	Mixed logit model with random parameters only		Mixed logit model with heterogeneity in means	
	Parameter estimate	t-stat.	Parameter estimate	t-stat.
Constant [SI]	-0.665	-1.04	-0.675	-1.06
Constant [MI]	3.431	1.99	2.725	2.03
Driver characteristics				
Young female driver (1 if driver is female with age between 16 and 30 years old; 0 otherwise) [SI]	0.695	2.05	0.691	2.05
Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise) [MI]	2.364	2.52	1.544	2.84
Insured (1 if driver was insured; 0 otherwise) [NI]	1.014	3.13	0.997	3.17
Vehicle characteristics				
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	-2.461	-8.40	-2.485	-8.60
Old vehicle (1 if vehicle model between 1960 and 1980; 0 otherwise) [SI]	1.592	1.74	1.615	1.78
Sedan 4 doors (1 if vehicle style is sedan 4 doors; 0 otherwise) [MI]	-1.706	-2.35	-	-
Pickup (1 if vehicle type is pickup; 0 otherwise) [NI]	2.798	8.78	2.805	9.13
Roadway characteristics				
Straight and grade (1 if roadway is straight and grade; 0 otherwise) [MI]	-3.272	-2.55	-2.015	-2.64
Rural freeways/expressways (1 if collision on rural freeways/expressways; 0 otherwise) [NI]	0.774	2.33	0.762	2.53
Dry (1 if road surface condition is dry; 0 otherwise) [SI]	1.510	2.80	1.516	2.82
Crash characteristics				
Contributing circumstance (1 if "none"; 0 otherwise) [MI]	-4.180	-2.10	-2.358	-1.99
Standard deviation of ''contributing circumstance'' (normally distributed)	*4.935*	*2.76*	*2.715*	*2.40*
Straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise) [MI]	-4.950	-2.06	-2.714	-1.72
Standard deviation of ''straight ahead'' (normally distributed)	*4.996*	*2.76*	*2.935*	*2.62*
Airbag deployment (1 if combination of airbag deployed; 0 otherwise) [MI]	6.866	2.76	4.308	3.03
Ejection (1 if not ejected from vehicle; 0 otherwise) [MI]	-3.807	-2.28	-1.791	-1.72

Fixed object (1 if second harmful event is hitting a fixed object, 0 otherwise) [NI]	-2.382	-4.55	-2.405	-4.78
Time-related attributes				
Night (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise) [SI]	-0.447	-1.95	-0.447	-1.96
Time of year (1 if fall, 0 otherwise) [SI]	-0.679	-2.74	-0.669	-2.72
Time of year (1 if winter, 0 otherwise) [NI]	0.752	2.12	0.728	2.23
Heterogeneity in the means of the random parameters				
Straight ahead: Passenger car (1 if vehicle type is passenger car; 0 otherwise)	-	-	-2.094	-4.35
Model statistics				
Number of observations	2162		2162	
Log-likelihood with constants only	-886.01		-886.01	
Log-likelihood at convergence	-762.40		-760.00	
Akaike Information Criterion (AIC)	1568.8		1564.0	
Bayesian Information Criterion (BIC)	1598.2		1593.4	
McFadden Pseudo R-Squared	0.140		0.142	

Table 6 Estimation results of the mixed logit models for animal-vehicle collisions severity - 2014 time period (Note: [NI]: No injury; [MI] Minor injury; [SI]: Severe injury)

Variable	Mixed logit model with random parameters only		Mixed logit model with heterogeneity in means	
	Parameter estimate	t-stat.	Parameter estimate	t-stat.
Constant [SI]	1.593	1.78	1.630	1.81
Constant [MI]	5.025	1.28	5.477	1.29
Driver characteristics				
Insured (1 if driver was insured; 0 otherwise) [NI]	1.970	3.59	1.954	3.52
Driver restraint system (1 if no restraint system was used; 0 otherwise) [MI]	5.810	2.19	6.344	1.98
Driver restraint system (1 if lap and shoulder was used; 0 otherwise) [SI]	-1.951	-3.83	-1.946	-3.78
Vehicle characteristics				
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	-4.823	-2.15	-4.855	-2.18
Standard deviation of ''passenger car'' (normally distributed)	*3.412*	*2.29*	*3.398*	*2.28*
Pickup (1 if vehicle type is pickup; 0 otherwise) [NI]	1.783	3.46	1.855	3.53
New vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise) [SI]	-0.759	-1.87	-0.787	-1.93
Roadway characteristics				
Curve and grade (1 if curve and grade; 0 otherwise) [SI]	-1.420	-1.56	-1.419	-1.56
Speed limit (1 if speed limit is 65 mph, 0 otherwise) [SI]	-1.394	-1.42	-1.400	-1.43
Traffic control device (1 if no traffic control; 0 otherwise) [MI]	-5.363	-1.63	-5.482	-1.47
Crash characteristics				
Straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise) [MI]	-8.639	-2.07	-9.029	-1.88
Standard deviation of ''straight ahead'' (normally distributed)	*6.303*	*2.77*	*7.069*	*2.40*
Airbag deployment (1 if combination of airbag deployed; 0 otherwise) [MI]	4.209	2.49	3.501	1.99
Fixed object (1 if second harmful event is hitting a fixed object, 0 otherwise) [NI]	-3.830	-4.34	-3.890	-4.35
Time-related attributes				
Time of year (1 if winter, 0 otherwise) [NI]	1.706	1.88	1.762	1.90
Time of year (1 if fall, 0 otherwise) [SI]	-0.924	-1.99	-0.926	-1.98

Weather characteristics				
Weather condition (1 if clear; 0 otherwise) [SI]	1.145	1.73	1.157	1.74
Heterogeneity in the means of the random parameters				
Straight ahead: Driver restraint system (1 if lap and shoulder was used; 0 otherwise)	-	-	-2.569	-1.72
Model statistics				
Number of observations	1240		1240	
Log-likelihood with constants only	-474.28		-474.28	
Log-likelihood at convergence	-379.26		-375.88	
Akaike Information Criterion (AIC)	796.5		791.8	
Bayesian Information Criterion (BIC)	817.3		813.6	
McFadden Pseudo R-Squared	0.200		0.207	

Table 7 Estimation results of the mixed logit models for animal-vehicle collisions severity - 2015-2016 time period (Note: [NI]: No injury; [MI] Minor injury; [SI]: Severe injury)

Variable	Mixed logit model with random parameters only		Mixed logit model with heterogeneity in means	
	Parameter estimate	t-stat.	Parameter estimate	t-stat.
Constant [SI]	-1.190	-1.88	-1.218	-1.93
Constant [MI]	-1.489	-3.14	-1.672	-3.41
Driver characteristics				
Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise) [MI]	0.925	2.52	1.332	3.19
Sobriety (1 if driver is sober; 0 otherwise) [SI]	-1.118	-2.08	-1.110	-2.07
Driver restraint system (1 if no restraint system was used; 0 otherwise) [MI]	2.744	3.68	2.718	3.48
Licensed driver (1 if licensed drivers; 0 otherwise) [NI]	1.047	3.83	1.053	3.84
Male (1 if the driver is male; 0 otherwise) [SI]	0.457	1.94	0.455	1.93
Vehicle characteristics				
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	-0.521	-2.28	-0.514	-2.25
Wagon 4 doors (1 if vehicle style is wagon 4 doors; 0 otherwise) [NI]	0.673	2.54	0.648	2.46
New vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise) [NI]	0.384	2.14	0.366	2.06
Sedan 4 doors (1 if vehicle style is sedan 4 doors; 0 otherwise) [MI]	0.921	2.54	0.933	2.54
Roadway characteristics				
Speed limit (1 if speed limit is 55 mph, 0 otherwise) [SI]	0.517	2.32	0.520	2.34
Dry (1 if road surface condition is dry; 0 otherwise) [SI]	0.784	2.23	0.789	2.25
Crash characteristics				
Contributing circumstance (1 if "none"; 0 otherwise) [MI]	-2.663	-2.40	-2.453	-2.12
Standard deviation of ''contributing circumstance" (normally distributed)	*2.021*	*2.27*	*1.983*	*2.06*
Airbag deployment (1 if combination of airbag deployed; 0 otherwise) [MI]	1.433	2.16	1.414	2.17
Fixed object (1 if second harmful event is hitting a fixed object, 0 otherwise) [SI]	2.208	4.83	2.196	4.80
Distraction (1 if there is no distraction; 0 otherwise) [MI]	-1.752	-2.57	-1.705	-2.53
Overturn (1 if second harmful event is overturn, 0 otherwise) [NI]	-2.386	-4.52	-2.391	-4.49
Time-related attributes				

Night (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise) [MI]	-2.159	-1.32	-1.427	-1.06
Standard deviation of ''night'' (normally distributed)	*3.577*	*2.58*	3.095	2.45
Time of year (1 if winter, 0 otherwise) [NI]	0.589	2.10	0.484	1.52
Morning (1 if crash occurred between 4:00 am and 11:00 am, 0 otherwise) [SI]	-0.973	-3.35	-0.976	-3.36
Daylight (1 if light condition is daylight; 0 otherwise) [SI]	0.521	2.27	0.523	2.28
Heterogeneity in the means of the random parameters				
Night: Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise)	-	-	-1.426	-1.97
Night: Time of year (1 if winter, 0 otherwise)	-	-	1.714	1.82
Contributing circumstance: Time of year (1 if winter, 0 otherwise)	-	-	-1.117	-1.42
Model statistics				
Number of observations	2458		2458	
Log-likelihood with constants only	-937.0		-937.0	
Log-likelihood at convergence	-846.8		-842.6	
Akaike Information Criterion (AIC)	1741.6		1739.2	
Bayesian Information Criterion (BIC)	1775.0		1776.7	
McFadden Pseudo R-Squared	0.096		0.100	

Table 8 Averaged marginal for animal-vehicle collisions injury severity effects over all crash observations – 2012-2016 time period (Note: Bold values indicate the injury severity output for which the explanatory variable was defined)

Variable	Mixed logit model with random parameters only			Mixed logit model with heterogeneity in means			Mixed logit model with heterogeneity in means and variances		
	Severe injury	Minor injury	No injury	Severe injury	Minor injury	No injury	Severe injury	Minor injury	No injury
Driver characteristics									
Male (1 if the driver is male; 0 otherwise) [MI]	0.0008	**-0.0119**	0.0111	0.0008	**-0.0118**	0.0110	0.0008	**-0.0114**	0.0106
Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise) [SI]	**-0.0035**	0.0002	0.0033	**-0.0027**	0.0002	0.0025	**-0.0027**	0.0002	0.0026
Sobriety (1 if driver is sober; 0 otherwise) [SI]	**-0.0309**	0.0018	0.0292	**-0.0219**	0.0013	0.0206	**-0.0221**	0.0013	0.0208
Driver restraint system (1 if no restraint system was used; 0 otherwise) [MI]	-0.0007	**0.0023**	-0.0016	-0.0007	**0.0022**	-0.0015	-0.0008	**0.0023**	-0.0016
Vehicle characteristics									
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	**0.0097**	-0.0005	-0.0091	**-0.0063**	0.0003	0.0060	**-0.0062**	0.0003	0.0059
Wagon 4 doors (1 if vehicle style is wagon 4 doors; 0 otherwise) [NI]	-0.0038	-0.0037	**0.0075**	-0.0037	-0.0052	**0.0089**	-0.0037	-0.0054	**0.0090**
Truck tractor & semi-trailer (1 if vehicle type truck tractor & semi-trailer; 0 otherwise) [NI]	-0.0006	-0.0002	**0.0008**	-0.0004	-0.0002	**0.0006**	-0.0004	-0.0002	**0.0006**
New vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise) [MI]	0.0004	**-0.0075**	0.0071	0.0004	**-0.0079**	0.0075	0.0004	**-0.0079**	0.0075
Roadway characteristics									
Speed limit (1 if speed limit is 60 mph, 0 otherwise) [SI]	**0.0101**	-0.0004	-0.0096	**0.0109**	-0.0007	-0.0101	**0.0107**	-0.0007	-0.0100
Rural freeways/expressways (1 if collision on rural freeways/expressways; 0 otherwise) [MI]	0.0001	**-0.0027**	0.0026	0.0001	**-0.0027**	0.0027	0.0001	**-0.0028**	0.0027
Two-way divided with median barrier (1 if collision is on two-way divided with median barrier road segment; 0 otherwise) [MI]	-0.0001	**0.0029**	-0.0028	-0.0002	**0.0032**	-0.0030	-0.0001	**0.0031**	-0.0030
Dry (1 if road surface condition is dry; 0 otherwise) [SI]	**0.0245**	-0.0015	-0.0231	**0.0216**	-0.0014	-0.0202	**0.0214**	-0.0014	-0.0200
Crash characteristics									
Contributing circumstance (1 if "none"; 0 otherwise) [MI]	0.0015	**-0.0300**	0.0285	0.0011	**-0.0206**	0.0195	0.0011	**-0.0212**	0.0200

Distraction (1 if there is no distraction; 0 otherwise) [MI]	0.0001	**-0.0019**	0.0018	-	-	-	-	-	-
Ejection (1 if not ejected from vehicle; 0 otherwise) [MI]	0.0017	**-0.0466**	0.0449	0.0020	**-0.0534**	0.0514	0.0021	**-0.0559**	0.0538
Overturn (1 if second harmful event is overturn, 0 otherwise) [MI]	-0.0001	**0.0006**	-0.0005	-0.0001	**0.0007**	-0.0006	-0.0001	**0.0003**	-0.0002
Straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise) [MI]	0.0029	**-0.0569**	0.0540	0.0031	**-0.0587**	0.0556	0.0032	**-0.0598**	0.0566
Time-related attributes									
Night (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise) [MI]	-0.0009	**0.0251**	-0.0241	-0.0008	**0.0257**	-0.0248	-0.0008	**0.0252**	-0.0244
Daylight (1 if light condition is daylight; 0 otherwise) [SI]	**0.0079**	-0.0006	-0.0073	**0.0058**	-0.0005	-0.0054	**0.0060**	-0.0005	-0.0055
Early morning (1 if crash occurred between 12:00 am and 4:00 am, 0 otherwise) [SI]	**0.0023**	-0.0001	-0.0021	**0.0025**	-0.0002	-0.0024	**0.0026**	-0.0002	-0.0024
Time of year (1 if winter, 0 otherwise) [NI]	-0.0016	-0.0020	**0.0036**	-0.0014	-0.0018	**0.0032**	-0.0015	-0.0019	**0.0033**
Darkness and lighted (1 if darkness and lighted roadway are on; 0 otherwise) [MI]	0.0001	**-0.0008**	0.0007	0.0001	**-0.0007**	0.0006	0.0001	**-0.0007**	0.0006
Environmental and weather characteristics									
Clear (1 if weather condition is clear; 0 otherwise) [SI]	**0.0143**	-0.0009	-0.0135	**0.0135**	-0.0009	-0.0126	**0.0133**	-0.0009	-0.0124

Table 9 Averaged marginal for animal-vehicle collisions injury severity effects over all crash observations - 2012-2013 time period (Note: Bold values indicate the injury severity output for which the explanatory variable was defined)

Variable	Mixed logit model with random parameters only			Mixed logit model with heterogeneity in means		
	Severe injury	Minor injury	No injury	Severe injury	Minor injury	No injury
Driver characteristics						
Young female driver (1 if driver is female with age between 16 and 30 years old; 0 otherwise) [SI]	**0.0036**	-0.0001	-0.0035	**0.0036**	-0.0001	-0.0035
Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise) [MI]	-0.0005	**0.0118**	-0.0113	-0.0006	**0.0126**	-0.0120
Insured (1 if driver was insured; 0 otherwise) [NI]	-0.0344	-0.0131	**0.0475**	-0.0332	-0.0207	**0.0539**
Vehicle characteristics						
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	**-0.0449**	0.0010	0.0439	**-0.0454**	0.0016	0.0438
Old vehicle (1 if vehicle model between 1960 and 1980; 0 otherwise) [SI]	**0.0009**	-0.0001	-0.0008	**0.0009**	-0.0001	-0.0008
Sedan 4 doors (1 if vehicle style is sedan 4 doors; 0 otherwise) [MI]	0.0004	**-0.0083**	0.0079	-	-	-
Pickup (1 if vehicle type is pickup; 0 otherwise) [NI]	-0.0326	-0.0141	**0.0467**	-0.0325	-0.0240	**0.0564**
Roadway characteristics						
Straight and grade (1 if roadway is straight and grade; 0 otherwise) [MI]	0.0004	**-0.0054**	0.0050	0.0005	**-0.0055**	0.0050
Rural freeways/expressways (1 if collision on rural freeways/expressways; 0 otherwise) [NI]	-0.0032	-0.0017	**0.0049**	-0.0032	-0.0025	**0.0057**
Dry (1 if road surface condition is dry; 0 otherwise) [SI]	**0.0575**	-0.0016	-0.0559	**0.0578**	-0.0029	-0.0549
Crash characteristics						
Contributing circumstance (1 if "none"; 0 otherwise) [MI]	-0.0003	**0.0130**	-0.0127	-0.0005	**0.0051**	-0.0046
Straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise) [MI]	-0.0006	**0.0064**	-0.0058	-0.0021	**0.0190**	-0.0169
Airbag deployment (1 if combination of airbag deployed; 0 otherwise) [MI]	-0.0004	**0.0057**	-0.0053	-0.0004	**0.0058**	-0.0054
Ejection (1 if not ejected from vehicle; 0 otherwise) [MI]	0.0026	**-0.0520**	0.0494	0.0022	**-0.0397**	0.0375
Fixed object (1 if second harmful event is hitting a fixed object, 0 otherwise) [NI]	0.0047	0.0006	**-0.0053**	0.0045	0.0011	**-0.0056**
Time-related attributes						
Night (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise) [SI]	**-0.0064**	0.0002	0.0062	**-0.0064**	0.0002	0.0062
Time of year (1 if fall, 0 otherwise) [SI]	**-0.0078**	0.0002	0.0076	**-0.0077**	0.0004	0.0073
Time of year (1 if winter, 0 otherwise) [NI]	-0.0028	-0.0012	**0.0040**	-0.0027	-0.0017	**0.0045**

Table 10 Averaged marginal for animal-vehicle collisions injury severity effects over all crash observations - 2014 time period (Note: Bold values indicate the injury severity output for which the explanatory variable was defined)

Variable	Mixed logit model with random parameters only			Mixed logit model heterogeneity in means		
	Severe injury	Minor injury	No injury	Severe injury	Minor injury	No injury
Driver characteristics						
Insured (1 if driver was insured; 0 otherwise) [NI]	-0.0422	-0.0233	**0.0655**	-0.0417	-0.0205	**0.0622**
Driver restraint system (1 if no restraint system was used; 0 otherwise) [MI]	-0.0037	**0.0060**	-0.0023	-0.0037	**0.0058**	-0.0021
Driver restraint system (1 if lap and shoulder was used; 0 otherwise) [SI]	**-0.0373**	0.0008	0.0365	**-0.0370**	0.0008	0.0362
Vehicle characteristics						
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	**0.0020**	-0.0001	-0.0019	**0.0015**	-0.0001	-0.0014
Pickup (1 if vehicle type is pickup; 0 otherwise) [NI]	-0.0199	-0.0082	**0.0281**	-0.0204	-0.0076	**0.0280**
New vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise) [SI]	**-0.0087**	0.0003	0.0083	**-0.0090**	0.0002	0.0088
Roadway characteristics						
Curve and grade (1 if curve and grade; 0 otherwise) [SI]	**-0.0020**	0.0001	0.0019	**-0.0021**	0.0001	0.0020
Speed limit (1 if speed limit is 65 mph, 0 otherwise) [SI]	**-0.0015**	0.0001	0.0014	**-0.0014**	0.0001	0.0013
Traffic control device (1 if no traffic control; 0 otherwise) [MI]	0.0064	**-0.0712**	0.0648	0.0062	**-0.0650**	0.0588
Crash characteristics						
Straight ahead (1 if vehicle maneuver prior to the crash is straight ahead; 0 otherwise) [MI]	0.0015	**-0.0183**	0.0168	0.0018	**-0.0142**	0.0124
Airbag deployment (1 if combination of airbag deployed; 0 otherwise) [MI]	-0.0002	**0.0038**	-0.0036	-0.0001	**0.0029**	-0.0028
Fixed object (1 if second harmful event is hitting a fixed object, 0 otherwise) [NI]	0.0054	0.0012	**-0.0066**	0.0055	0.0010	**-0.0065**
Time-related attributes						
Time of year (1 if winter, 0 otherwise) [NI]	-0.0020	-0.0013	**0.0033**	-0.0020	0.0012	**0.0032**
Time of year (1 if fall, 0 otherwise) [SI]	**-0.0064**	0.0003	0.0061	**-0.0064**	0.0003	0.0061
Weather characteristics						
Weather condition (1 if clear; 0 otherwise) [SI]	**0.0273**	-0.0013	-0.0261	**0.0274**	-0.0012	-0.0262

Table 11 Averaged marginal for animal-vehicle collisions injury severity effects over all crash observations for 2015-2016 time period (Note: Bold values indicate the injury severity output for which the explanatory variable was defined)

Variable	Mixed logit model with random parameters only			Mixed logit model with heterogeneity in means		
	Severe injury	Minor injury	No injury	Severe injury	Minor injury	No injury
Driver characteristics						
Male (1 if the driver is female; 0 otherwise) [SI]	**0.0109**	-0.0004	-0.0106	**0.0109**	-0.0004	-0.0105
Middle age female driver (1 if driver is female with age between 30 and 65 years old; 0 otherwise) [MI]	-0.0002	**0.0078**	-0.0076	-0.0003	**0.0116**	-0.0113
Sobriety (1 if driver is sober; 0 otherwise) [SI]	**-0.0410**	0.0018	0.0392	**-0.0407**	0.0019	0.0389
Driver restraint system (1 if no restraint system was used; 0 otherwise) [MI]	-0.0012	**0.0060**	-0.0048	-0.0012	**0.0062**	-0.0050
Licensed driver (1 if licensed drivers; 0 otherwise) [NI]	-0.0327	-0.0259	**0.0586**	-0.0329	-0.0270	**0.0599**
Vehicle characteristics						
Passenger car (1 if vehicle type is passenger car; 0 otherwise) [SI]	**-0.0074**	0.0003	0.0071	**-0.0073**	0.0003	0.0070
Wagon 4 doors (1 if vehicle style is wagon 4 doors; 0 otherwise) [NI]	-0.0040	-0.0029	**0.0068**	-0.0039	-0.0029	**0.0068**
New vehicle (1 if vehicle model between 2000 and 2010; 0 otherwise) [NI]	-0.0055	-0.0043	**0.0098**	-0.0053	-0.0043	**0.0096**
Sedan 4 doors (1 if vehicle style is sedan 4 doors; 0 otherwise) [MI]	-0.0004	**0.0092**	-0.0088	-0.0004	**0.0096**	-0.0092
Roadway characteristics						
Speed limit (1 if speed limit is 55 mph, 0 otherwise) [SI]	**0.0064**	-0.0004	-0.0061	**0.0065**	-0.0004	-0.0061
Dry (1 if road surface condition is dry; 0 otherwise) [SI]	**0.0270**	-0.0013	-0.0257	**0.0272**	-0.0013	-0.0259
Crash characteristics						
Contributing circumstance (1 if "none"; 0 otherwise) [MI]	0.0012	**-0.0157**	0.0144	0.0011	**-0.0151**	0.0139
Airbag deployment (1 if combination of airbag deployed; 0 otherwise) [MI]	-0.0002	**0.0028**	-0.0026	-0.0002	**0.0028**	-0.0026
Fixed object (1 if second harmful event is hitting a fixed object, 0 otherwise) [SI]	**0.0049**	-0.0004	-0.0046	**0.0049**	-0.0003	-0.0046
Distraction (1 if there is no distraction; 0 otherwise) [MI]	0.0002	**-0.0033**	0.0031	0.0002	**-0.0033**	0.0031
Overturn (1 if second harmful event is overturn, 0 otherwise) [NI]	0.0026	0.0014	**-0.0040**	0.0025	0.0014	**-0.0039**
Time-related attributes						
Night (1 if crash occurred between 6:00 pm and 12:00 am, 0 otherwise) [MI]	-0.0012	**0.0266**	-0.0254	-0.0013	**0.0273**	-0.0260
Time of year (1 if winter, 0 otherwise) [NI]	-0.0020	-0.0021	**0.0042**	-0.0018	-0.0016	**0.0034**
Morning (1 if crash occurred between 4:00 am and 11:00 am, 0 otherwise) [SI]	**-0.0065**	0.0003	0.0062	**-0.0065**	0.0003	0.0062
Daylight (1 if light condition is daylight; 0 otherwise) [SI]	**0.0069**	-0.0004	-0.0065	**0.0069**	-0.0004	-0.0065

6. Summary and conclusions

Animal-vehicle collisions are a major safety concern to roadway users, highway administrators, and environmentalists. Using the data on Animal-vehicle collisions in Washington state from January 1, 2012 to December 31, 2016, this paper applied three methods including a standard mixed logit model, a mixed logit model with heterogeneity in means, and a mixed logit model with heterogeneity in means and variances to explore the determinants of driver-injury severities in animal-vehicle collisions. With three possible injury severity outcomes of severe injury, minor injury, and no injury, a wide range of factors potentially affecting the driver-injury severities such as driver characteristics, vehicle characteristics, roadway characteristics, crash characteristics, time-related factors, and environmental and weather characteristics were considered in this research. The temporal stability of the affecting factors was also evaluated in this study. The estimation results showed that although some explanatory variables have relatively stable effects on the injury severity outcomes, some others are temporally instable. For example, male drivers were not found to significantly affect the injury severity outcomes in the models estimated for 2012-2013 and 2014. However, they significantly affected the injury severity outcomes of the models estimated for 2015-2016. Several factors could be the reasons of temporal instability such as changes in individual behaviors, risk assessment, information processing, and safety attitudes that could be the results of changes in information technologies, communication, and vehicles. The results of a series of likelihood ratio tests showed that estimated models were instable over time.

Based on the results obtained from this study, it can be concluded that accounting for heterogeneity in the means and variances of the random parameters allows new insights and enhances the overall model fit. Some explanatory variables showed relatively similar marginal effects among all the methodological approaches while there were a few variables showing slightly different marginal effects. With regard to the determinants of driver-injury severity in animal-vehicle collisions, various factors were found to increase the likelihood of severe injuries including freeways/expressways, daylight crashes, early morning crashes, dry road surface and clear weather condition. Several factors were also found to increase the probability of no injuries including wagon 4 doors, truck tractor & semi-trailer, and crashes during winter.

The findings of this research underscore the importance of temporal stability of the affecting factors on injury severity outcomes. Underestimating the temporal stability concept may lead to inaccurate conclusions. The findings of this paper show the differences between the three version of the mixed logit models and emphasize on fully accounting for the unobserved heterogeneity in the data by taking into account the unobserved heterogeneity in the means and variances of the random parameters. The results of this paper should be useful for highway administrators and environmentalists to decrease the probability of severe injuries in animal-vehicle collisions.

Acknowledgements

The authors would like to acknowledge and thank the Washington Department of Transportation for their time and effort regarding the crash data used for this study.

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