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Day-of-the-week variations and temporal instability of factors influencing pedestrian injury severity in pedestrian-vehicle crashes: A random parameters logit approach with heterogeneity in means and variances

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ABSTRACT

Using pedestrian-vehicle crash data in North Carolina from 2007 to 2018, this study explores the potential variation in the influence of factors affecting pedestrian injury severity in different time periods (weekday/weekend and three-year period). To capture unobserved heterogeneity, random parameters logit models with heterogeneity in means and variances are employed. In developing the model, several categories of factors are considered, including characteristics of the pedestrian, driver, crash, locality and roadway, time and environment, traffic control, and work zone. Transferability tests are conducted to examine the possible temporal instability of the estimation results between different time periods. According to the results, factors such as "ambulance rescue" and "curved roadway" produce temporally stable effects on pedestrian injury severity. However, strong temporal instabilities in effects on pedestrian injury severity are found for most factors across the three-year period and the weekday/weekend. In regard to structure, the model offers more insights by accounting for possible heterogeneity in the means and variances of the random parameters. Detailed policy-related recommendations are provided based on the analysis results. The findings of this work should be helpful to policymakers in future planning on safety improvements for pedestrians within the transportation system.

1. Introduction

Pedestrians are generally considered the most vulnerable traffic participants. According to the National Highway Traffic Safety Administration (NHTSA, 2017), on average, a pedestrian was killed every 88 min in traffic crashes in 2017. Two other recent reports from the Governors Highway Safety Association (Retting and Schwartz, 2019; 2020) noted a 53% increase in pedestrian fatalities in 2018 compared to 2009. Fig. 1 shows such changes over time, denoting an obvious increasing trend of pedestrian deaths in the USA after the Great Recession of 2008. Therefore, the safety and risk issues of pedestrians within the transportation system deserve more attention. To resolve the abovementioned issues, a myriad of studies have been

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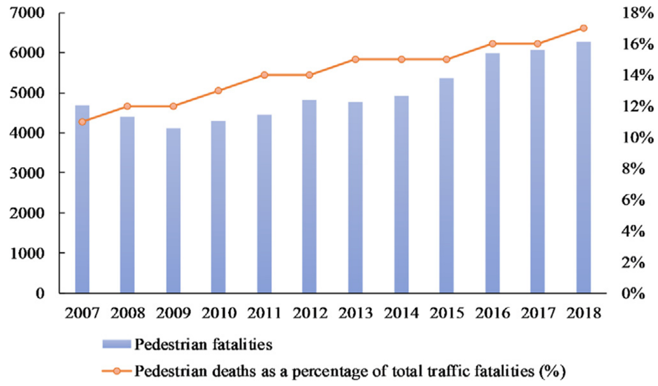

Fig. 1. Number of pedestrian fatalities and their percentages of total traffic fatalities in the USA.

conducted to explore the contributing factors influencing pedestrian injury severity, such as alcohol involvement, demographic features, at-fault operation, collision types, environmental characteristics, roadway and locality features, and time of day (Kim et al., 2008a, 2008b; 2010;; Dai, 2012; Chen and Fan, 2019; Li and Fan, 2019a; Mokhtarimousavi, 2019). However, relatively few studies have explored the temporal stability/instability of the factors affecting pedestrian injury severity in pedestrian-vehicle crashes.

According to Mannering (2018), several studies in the field of transportation safety research have provided strong evidence that issues of temporal instability need to be addressed in traffic crash analysis. Among all these issues, a critical one is temporal shifts in the effects of contributing factors from year to year. Such shifts may result from potential changes in many aspects over time (e.g., behavior, environment, and policy). In this context, Behnood and Mannering (2016) investigated crashes during the pre-recession, recession, and post-recession periods and found that pedestrian injury severity in pedestrian-vehicle crashes was unstable over time. Other traffic safety studies also argued for the need to study temporal instability from year to year (Alnawmasi and Mannering, 2019; Behnood and Mannering, 2019; Song et al., 2020). Hence, it is worth exploring this issue in analyses of pedestrian injury severity.

In addition to temporal shifts by year, another critical issue is the variations arising from different days of the week. Such variations in the effects of contributing factors affecting crash injury severity between weekdays and weekends have also been clearly indicated by several studies using segmented data. Such studies have covered topics including heavy-vehicle driver injury severity (Song and Fan, 2020), single-vehicle crash injury severity (Adanu et al., 2018), and large-truck crash injury severity (Behnood and Al-Bdairi, 2020). On the other hand, as indicated in NHTSA (2017), the number of traffic fatalities on weekends increased by 5.9% in 2016 compared to 2015, and the number on weekdays increased by 5.3%. Furthermore, based on the recent NHTSA Fatality Analysis Reporting System (FARS) data, most pedestrian fatalities in 2018 occurred on Saturdays, with 1,031 in total, accounting for 16.41% of the total number of pedestrian fatalities. Moreover, Chen and Fan (2019) showed that the weekend factor impacts the injury severity of pedestrians in pedestrian-vehicle crashes. However, few research efforts have been devoted to assessing such day-of-the-week variations for pedestrians in pedestrian-vehicle crashes. In addition, the whole weekday dataset in this study shows a "two-peak" time-of-day pattern that is quite similar to the vehicle traffic on weekdays. This phenomenon should not be ignored since pedestrian injury severity in pedestrian-vehicle crashes is also strongly affected by traffic characteristics (e.g., traffic volume). Under such circumstances, it is necessary to conduct research on pedestrian injury severity by considering weekdays and weekends separately.

Despite the abovementioned issues, in police-reported crash data, some unobservable factors are either not reported by law enforcement agencies or cannot be collected from state crash records. Such unobservable factors may induce unobserved heterogeneity and have impacts on injury severity studies. Neglecting such unobserved heterogeneity might lead to biased estimation of parameters and therefore possibly improper inferences (Mannering and Bhat, 2014; Shaheed and Gkritza, 2014). Hence, this paper deploys a random parameters logit (RPL) approach with heterogeneity in means and variances for modeling pedestrian injury severity in pedestrian-vehicle crashes and exploring the possible contributing factors.

This study begins with a summary of findings from previous studies on pedestrian injury severity, the temporal instability of crash injury severity, and approaches used in modeling pedestrian injury severity in pedestrian-vehicle crashes. Then, descriptions of the data and the methodology are presented. Finally, detailed analysis results are provided, followed by suggestions for policy-related implementation and discussions of possible future research directions.

2. Literature review

Numerous studies have applied econometric and statistical techniques to examine contributing factors that determine pedestrian injury severity in pedestrian-vehicle crashes. Table 1 summarizes the literature on pedestrian injury severity by the order of the year of publication.

Table 1
A summary of the literature on pedestrian injury severity in pedestrian-vehicle crashes.

Authors	Methodology	Location	Key findings
Zajac and Ivan (2003)	Ordered probit model	Rural Connecticut, USA	Factors contributing to pedestrian fatalities: clear roadway width, vehicle type, alcohol involvement of both driver and pedestrian, and older pedestrian (≥65).
Rifaat and Chin (2007)	Ordered probit model	Singapore	Factors contributing to severe injury of pedestrians: older pedestrian and nighttime.
Sze and Wong (2007)	Binary logit model	Hong Kong China	Factors contributing to severe injury of pedestrians: older pedestrian (≥65), head injury, crash at a crossing or within 15 m of a crosswalk, speed limit (≥50 mph), signalized intersection, and number of lanes (≥2).
Kim et al. (2008)	Multinomial logit (MNL) model	North Carolina, USA	Factors contributing to pedestrian fatalities: PM traffic peak, traffic signal control, curved roadways, inclement weather, crosswalk, and walking along the roadway.
Ulfarsson et al. (2010)	MNL model	North Carolina, USA	1) Pedestrian-at-fault factors: pedestrian crossing streets, pedestrian dash/dart-out, pedestrian age (≤12), drunk pedestrian; 2) Driver-at-fault factors: turning/merging/backing movement, speeding, drunk driver, and multiple pedestrians. 3) Other important factor(s): darkness.
Kim et al. (2010)	RPL model	North Carolina, USA	1) Factors contributing to pedestrian fatalities: dark unlighted roadway, truck, freeway, speeding, and drunk driver. 2) Heterogeneity in the means of random parameters: pedestrian gender (freeway and pedestrian-solely-at-fault collision indicators), and pedestrian age (traffic control [sign] and backing vehicle).
Tay et al. (2011)	MNL model	South Korea	Factors contributing to severe injury of pedestrians: heavy vehicles, drunk drivers, driver gender (male), driver age (≤65), pedestrian age (≥65), pedestrian gender (female), pedestrians in roadway, high speed limits, inclement weather conditions, nighttime, on road links, in tunnels, on bridges, and on wider roads.
Kwigizile et al. (2011)	Ordered probit model MNL model	Florida, USA	Comparisons of two model structures (ordered probit model vs. MNL model): effects of contributing factors are consistent on lowest and highest injury levels but inconsistent for some factors on intermediate injury levels.
Obeng and Rokonuzzaman (2013)	Ordered logit model	Greensboro, NC, USA	Factors contributing to crash injury severity in signalized intersections: female drivers and the presence of a sidewalk.
Zhou et al. (2013)	MNL model	Nanjing, China	Crossing behaviors of pedestrians at signalized intersections were investigated and contributing factors for different behavior groups identified: 1) late starters (arrival time, oncoming cars, and crosswalk length), 2) pedestrian with sneaking behavior (gender), and 3) pedestrian with partial sneaking behavior (age).
Aziz et al. (2013)	RPL model	New York City, NY, USA	1) Significant factors: number of lanes, grade, light condition, road surface, presence of signal control, type of vehicle, parking facilities, and commercial and industrial land use; 2) LR test indicated the necessity of separate models for different areas (boroughs).
Yasmin et al. (2014)	Ordered logit model	New York City, NY, USA	Factors contributing to fatality: older pedestrian (≥65).
Sasidharan et al. (2015)	Partial proportional odds (PPO) logit model	South Korea	Factors contributing to fatality: older pedestrian (≥75), pedestrian gender (male), dark unlighted roadways, and midblock crossing behavior of pedestrians.
Islam and Jones (2014)	RPL model	Alabama, USA	Pedestrian-at-fault accidents were analyzed, and obvious different effects on some variables were identified between urban and rural areas.
Haleem et al. (2015)	RPL model	Florida, USA	Factors contributing to severe injury: 1) At signalized intersections: higher AADT, higher speed limit, percentage of trucks, older pedestrians, at-fault pedestrians, rain, and darkness; 2) at unsignalized intersections: pedestrian walking along the roadway, middle-aged and older pedestrians, at-fault pedestrians, vans, darkness, and higher speed limit.
Behnood and Mannering (2016)	RPL model Latent-MNL model	Chicago, IL, USA	The results of the study mainly present the temporal instability of the determinants of pedestrian injury severity in motor vehicle crashes by using segmented datasets of pre-recession, recession, and post-recession periods.

(continued on next page)

Table 1 (*continued*)

Authors	Methodology	Location	Key findings
Pour et al. (2016)	PPO model	Melbourne metropolitan area, Australia	Midblock crashes of pedestrians were investigated, and factors contributing to severe injury of pedestrians were identified: higher speed limit, darkness, male pedestrian.
Tulu et al. (2017)	RPL model	Addis Ababa, Ethiopia	Factors contributing to fatality: higher speed limit, intersections, heavy vehicle, and less educated drivers.
Xin et al. (2017)	RP generalized ordered probit model with heterogeneity in means and variances	Florida, USA	Contributing factors: African American community, school zone, and bus-stop area (characteristics of the neighborhood and the built environment).
Kim and Ulfarsson (2019)	RPL model	USA	Factors contributing to severe injury of older pedestrians: crossing street, left/right turning movement, parking lot, minivan, and SUV.
Chen and Fan (2019)	MNL model	North Carolina, USA	Factors contributing to fatalities and disabling injuries: impaired driver, motorcycle and heavy truck, pedestrian age (26–65; ≥65), weekends, light condition (dawn, dusk, and dark), curved roadways, roadway surface with water, NC route, speed limit (35–50 mph; ≥50 mph).
Chen and Fan (2019)	RPL model	North Carolina, USA	Factors contributing to severe injuries of pedestrians (in both urban and rural areas): impaired driver, heavy trucks, darkness, speed limit (35–50 mph; ≥50 mph). Differences were also identified for some variables.
Li and Fan (2019b)	Latent class clustering (LCC) and PPO model	North Carolina, USA	Six submodels with different representing variables were developed, and heterogeneities existed among different classes. Some general major factors contributing to severe injury were identified: heavy vehicle, pedestrian crossing and dash/dart-out, and pedestrian age (≥55).

According to Table 1, previous studies have examined specific topics with unique segmentations of datasets, such as crashes at intersections/nonintersections and pedestrian-at-fault crashes. However, insufficient attention has been paid to the temporal instability of the determinants of pedestrian injury severity or particular segmentations based on temporal factors (e.g., day of the week). When referring to unobserved heterogeneity, the most commonly applied approach is the RPL model, and few research efforts have extended such a model with considerations of heterogeneity in means and variances to modeling pedestrian injury severity in pedestrian-vehicle crashes. Extensions of the random parameters approach can further capture unobserved heterogeneity by allowing the means and variances of the random parameters to vary across individuals, which has been demonstrated to be statistically superior to random parameters-only approaches (Mannering et al., 2016; Behnood and Mannering, 2017a; 2017b;; Seraneeprakarn et al., 2017; Waseem et al., 2019; Alnawmasi and Mannering, 2019; Yu et al., 2020; Al-Bdairi et al., 2020; Islam and Mannering, 2020).

3. Data Description and empirical setting

Twelve-year (2007–2018) pedestrian-vehicle crash data in North Carolina are utilized. The data were retrieved from the North Carolina Department of Transportation (NCDOT) Division of Bicycle and Pedestrian Transportation. The utilized data contain a total of 17,480 observations, and each observation involves only one pedestrian and one vehicle. There are five injury categories in the dataset: fatal, incapacitating, non-incapacitating, possible injury, and no injury. Fig. 2 displays the crash frequency of the five categories in each year, and Fig. 3 shows the distributions of crash frequency percentage over time of day on each day of the week. Fig. 3 also exhibits two quite different trends over time of day between weekdays and weekends.

Based on a careful examination of the annual distributions of the pedestrian crash data and accounting for the possible effects of the great recession shown in a previous work (Behnood and Mannering, 2016), the whole dataset is split into eight subsets: 2007–2009 weekdays, 2007–2009 weekends, 2010–2012 weekdays[1], 2010–2012 weekends, 2013–2015 weekdays, 2013–2015 weekends, 2016–2018 weekdays, and 2016–2018 weekends[2].

[1] Total crashes in 2012 are unusually high compared to adjacent years. The purpose of including the time period 2010-2012 in the analysis is to show the results in a consecutive and continuous manner.

[2] On the basis of examining the crash frequency distribution by year, the dataset is split into two parts (before and after 2012) considering that the total crash count was unusually high in 2012. Then, despite the time period of 2010-2012, a downward trend is observed in 2007-2009, and corresponding uptrends are observed in 2013-2015 and 2016-2018. Furthermore, the results of transferability tests and the marginal effects of most statistically significant variables show strong temporal instabilities among most 3-year-segmented datasets. Such results indicate that applying a longer period might ignore such temporal instabilities. In addition, there would be an inevitable issue with insufficient sample size of severe injury (fatality/incapacitating) if only the 1-year or 2-year-segmented datasets were used in this study. Therefore, 3 years is selected as the appropriate time period.

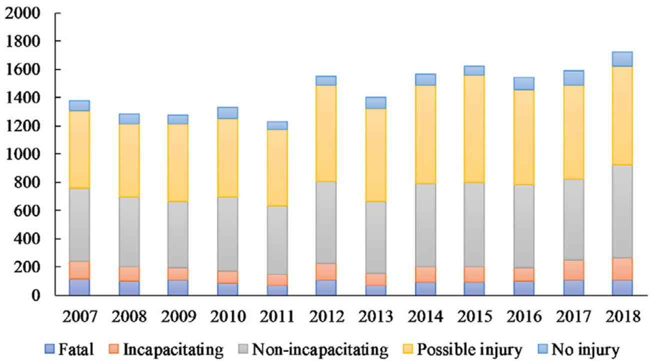

Fig. 2. Crash frequency distribution of injury severity category by year.

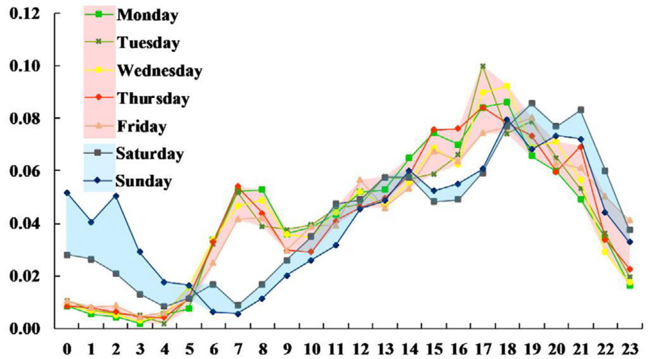

Fig. 3. Distributions of crash frequency percentage over time of day by day of the week.

Table 2 displays the frequency of pedestrian injury severity in each period. Considering the inherent degree of the injury and the sample size at each level, three categories are used as dependent variables: *severe injury* (fatality/incapacitating), *minor injury* (non-incapacitating), and *no/possible injury*. Additionally, Tables A1 and A2 provide a summary of the descriptive statistics of the variables used in the estimated models with six different categories in the weekday and weekend groups. The six different categories are *pedestrian characteristics*, *driver characteristics*, *crash characteristics*, *locality and roadway characteristics*, *time and environment characteristics*, and *traffic control characteristics and work zone*.

4. Methodology

In this study, the RPL model with heterogeneity in means and variances is deployed to model pedestrian injury severity in pedestrian-vehicle crashes. This method has been applied by several previous studies (Behnood and Mannering, 2017a; 2017b;; Seraneeprakarn et al., 2017; Waseem et al., 2019; Alnawmasi and Mannering, 2019; Yu et al., 2020; Al-Bdairi et al., 2020; Islam and Mannering, 2020). Three injury severity levels are used for modeling. The following injury severity function is defined to determine the specific injury severity$k$ (k = 1, 2, 3) for individual i:

Table 2
Pedestrian injury frequency and percentage distribution by period (numbers in parentheses).

Subgroup		Severe injury		Minor injury	No/possible injury		Total
		Fatal	Incapacitating	Non-incapacitating	Possible injury	No injury	
Weekdays	2007–2009	226 (7.48)	237 (7.85)	1128 (37.34)	1277 (42.27)	153 (5.06)	3021
	2010–2012	182 (5.77)	204 (6.46)	1205 (38.18)	1414 (44.80)	151 (4.78)	3156
	2013–2015	178 (5.02)	224 (6.31)	1286 (36.24)	1679 (47.31)	182 (5.13)	3549
	2016–2018	217 (5.72)	298 (7.86)	1420 (37.46)	1631 (43.02)	225 (5.94)	3791
Weekends	2007–2009	94 (10.30)	85 (9.31)	345 (37.79)	342 (37.46)	47 (5.15)	913
	2010–2012	81 (8.50)	70 (7.35)	384 (40.29)	366 (38.41)	52 (5.46)	953
	2013–2015	80 (7.71)	73 (7.04)	408 (39.34)	434 (41.85)	42 (4.05)	1037
	2016–2018	96 (9.06)	101 (9.53)	395 (37.26)	410 (38.68)	58 (5.47)	1060

$$U_{ki} = \beta_k \mathbf{x}_{ki} + \varepsilon_{ki} \tag{1}$$

where U_{ki} denotes the injury severity function of injury severity category k for individual i, $\mathbf{x}_{ki}$ represents the vector of explanatory variables in the observed data for individual i associated with injury severity level k, β_k is a vector of estimated parameters, and ε_{ki} is the error term.

Assuming that ε_{ki} follows an independent and identical Gumbel distribution that allows for parameters to vary across observations, the resulting RPL model can be shown as (McFadden and Train, 2000):

$$P_i(k) = \int \frac{\exp(\beta_k \mathbf{x}_{ki})}{\sum \exp(\beta_k \mathbf{x}_{ki})} f(\beta|\varphi) d\beta \tag{2}$$

where $P_i(k)$ is the probability of injury severity level k for individual i, $f(\beta|\varphi)$ is the density function of random vector β with φ, and φ is a vector of parameters describing this density function (mean and variance).

Following the work of Greene et al. (2006) and Seraneeprakarn et al. (2017), heterogeneity in the means and variances of random parameters can be modeled as:

$$\beta_{ki} = \beta + \boldsymbol{\delta_{ki}} \mathbf{z_{ki}} + \sigma_{ki} \exp(\boldsymbol{\omega_{ki}} \mathbf{w_{ki}}) v_{ki} \tag{3}$$

where β is the mean parameter estimate across all observations; $\boldsymbol{\delta_{ki}}$ is a vector of estimable parameters corresponding to $\mathbf{z_{ki}}$, the vector of characteristics capturing heterogeneity in the mean for injury severity level k; $\boldsymbol{\omega_{ki}}$ denotes a vector of estimable parameters associated with $\mathbf{w_{ki}}$, the vector of characteristics capturing heterogeneity in σ_{ki} (the standard deviation); and v_{ki} represents a disturbance term. With such a structure, characteristics (drivers, pedestrians, vehicles, crash characteristics, locality and roadway characteristics, or other possible sources) of heterogeneity may be contained in vectors $\mathbf{z_{ki}}$ and $\mathbf{w_{ki}}$. The model would be collapsed to one with heterogeneity in means only if no variable is found to be significant in $\mathbf{w_{ki}}$.

In this study, all models are estimated by the simulated maximum likelihood approach with 500 Halton draws considering both accuracy and efficiency (Waseem et al., 2019; Yu et al., 2020). The normal distribution is selected for model estimation since it has been proven to be more suitable than other distributions (Milton et al., 2008; Moore et al., 2011; Waseem et al., 2019). Additionally, marginal effects are calculated to interpret the impacts of significant variables on outcomes of pedestrian injury severity.

5. Transferability test

Another main purpose of this study is to statistically examine whether there are significant differences between different periods in the effects of factors on pedestrian injury severity in pedestrian-vehicle crashes. From this perspective, the following transferability test is conducted (Washington et al., 2020):

$$X^2 = -2\left[LL(\beta_{m_2 m_1}) - LL(\beta_{m_1})\right] \tag{4}$$

where $LL(\beta_{m_2 m_1})$ is the log likelihood at convergence of a model using the converged parameters from time m_2 (with only m_2 data) on the data of time m_1 (with the parameters restricted to the estimated parameters of time m_2) and $LL(\beta_{m_1})$ is the log likelihood at convergence of the model with data of time m_1 (without restricting the parameters to the estimated parameters of time m_2). This test is also reversed by using $LL(\beta_{m_1 m_2})$ and $LL(\beta_{m_2})$. The X^2 statistic is χ^2 distributed (with degrees of freedom equal to the number of parameters) and can be used to determine the confidence level at which the null hypothesis that the parameters are equal in times m_1 and m_2 can be accepted or rejected (Alnawmasi and Mannering, 2019).

Table 3 presents the results of the transferability tests for all period pairs. It shows that only 13 out of 56 tests produced confidence levels of less than 95%. This implies fairly high confidence that the model specifications and estimated parameters are temporally unstable over most period combinations. Although some of the confidence levels do not reach 95%, they are still reasonably high to reject the null hypothesis that the parameters are the same (e.g., the 2010–2012 weekend parameters run on the 2007–2010 weekday data, which gives a 90.50% confidence level). The overall results indicate the importance of examining the temporal instability of factors affecting pedestrian injuries by considering different periods (e.g., time of day and season of year). Additionally, these results agree to some extent with the findings in Behnood and Mannering (2016).

6. Results and discussion

The model estimation results are presented in Tables B1–B8 for each period by showing all three RPL approaches (random parameters only, random parameters with heterogeneity in means, and random parameters with heterogeneity in means and variances). The RPL model is established for each period as the base model for further investigating potential heterogeneity in the means and variances of the random parameters. All variables in Tables A1 and A2 were evaluated by heterogeneity tests. It should be noted that heterogeneity in the means of significant random parameters is found to be significant in all periods; however, heterogeneity in the variances of the random parameters is found to be significant only on 2010–2012 weekdays and 2013–2015 weekdays. Additionally, marginal effects for each significant contributing factor of each model are calculated and displayed in Tables 4–11.

Table 3
Likelihood ratio test results between different period pairs based on the RPL model with heterogeneity in means (χ^2 values with degrees of freedom in brackets and confidence level in parentheses; cells in ***bold italics*** are the null hypothesis of temporal stability that cannot be rejected at the 95% confidence level [13 out of 56]).

m1	m2 2007–2009 [Weekdays]	2007–2009 [Weekends]	2010–2012 [Weekdays]	2010–2012 [Weekends]	2013–2015 [Weekdays]	2013–2015 [Weekends]	2016–2018 [Weekdays]	2016–2018 [Weekends]
2007–2009	[Weekdays]	–	77.42 [24] (>99.99%)	68.53 [29] (>99.99%)	130.50 [31] (>99.99%)	85.84 [30] (>99.99%)	107.56 [22] (>99.99%)	111.71 [38] (>99.99%)
68.98 [24] (>99.99%)								
2007–2009	[Weekends]	45.53 [29] (97.39%)	–	54.96 [29] (99.75%)	***41.70 [31] (90.50%)***	***37.19 [30] (82.83%)***	49.14 [22] (99.92%)	68.79 [38] (99.84%)
26.23 [24] (65.85%)								
2010–2012	[Weekdays]	69.04 [29] (>99.99%)	89.08 [24] (>99.99%)	–	139.69 [31] (>99.99%)	113.05 [30] (>99.99%)	61.03 [22] (>99.99%)	101.05 [38] (>99.99%)
76.11 [24] (>99.99%)								
2010–2012	[Weekends]	***34.07 [29] (76.33%)***	***16.40 [24] (12.69%)***	***36.51 [29] (84.08%)***	–	***17.72 [30] (3.71%)***	45.38 [22] (99.76%)	72.01 [38] (99.93%)
24.02 [24] (53.95%)								
2013–2015	[Weekdays]	73.62 [29] (>99.99%)	128.60 [24] (>99.99%)	101.80 [29] (>99.99%)	156.83 [31] (>99.99%)	–	125.93 [22] (>99.99%)	75.96 [38] (99.98%)
111.21 [24] (>99.99%)								
2013–2015	[Weekends]	42.72 [29] (95.17%)	46.78 [24] (99.64%)	***27.97 [29] (48.05%)***	73.69 [31] (>99.99%)	***39.03 [30] (87.49%)***	–	***42.80 [38] (72.73%)***
25.66 [24] (62.94%)								
2016–2018	[Weekdays]	71.96 [29] (>99.99%)	186.22 [24] (>99.99%)	125.11 [29] (>99.99%)	320.85 [31] (>99.99%)	83.02 [30] (>99.99%)	170.46 [22] (>99.99%)	–
124.36 [24] (>99.99%)								
2016–2018	[Weekends]	52.29 [29] (99.49%)	42.84 [24] (98.96%)	53.20 [29] (99.60%)	87.62 [31] (>99.99%)	65.30 [30] (99.98%)	46.92 [22] (99.85%)	***45.31 [38] (80.66%)***
–								

Based on both the model estimation results and the LR test results, variations in the effects of the significant factors (with random effects and heterogeneous effects in means and variances of random variables) exist between different periods (across three-year periods and between weekdays and weekends). The rest of this section presents a detailed discussion of the modeling results. The main focus is on the temporal instability of significant factors in the most recent periods (2016–2018 weekdays and weekends) to help further improve pedestrian safety.

6.1. Human characteristics

6.1.1. Effects of alcohol-impaired pedestrians

The factor of pedestrians under the influence of alcohol ("alcohol-impaired pedestrian") is statistically significant in all periods, as illustrated in Fig. 4. According to its marginal effects, this factor increases the risk of pedestrians being severely injured in pedestrian-vehicle crashes all the time but shows temporal instability over time. In fact, much greater marginal effects of this factor on severe injury are observable on 2013–2015 weekends and 2016–2018 weekends (marginal effects: 0.0392 and 0.0447, respectively). Additionally, the marginal effects of this factor affecting severe injury are larger on weekends than on weekdays for most of the three-year periods (except 2010–2012), which supports the segmentation of the data over different time periods (day of week and three-year period).

In all periods except 2010–2012 weekends and 2013–2015 weekdays, the marginal effects on severe injury considering potential heterogeneity in means are larger than when using RPL only (e.g., marginal effects on 2016–2018 weekends:

Table 4
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2007–2009 weekdays).

Variable	RPL model			RPL model with heterogeneity in the mean		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics						
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise)	**0.0200**	−0.0067	−0.0133	**0.0196**	−0.0064	−0.0132
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	**0.0085**	−0.0028	−0.0057	**0.0082**	−0.0026	−0.0056
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	0.0093	0.0012	−0.0106	0.0098	0.0011	−0.0108
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise)	0.1153	0.0635	−0.1788	0.1179	0.0623	−0.1802
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	0.0156	0.0201	**−0.0357**	0.0160	0.0204	**−0.0364**
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.0064	0.0164	−0.0229	0.0066	0.0163	−0.0228
Midblock (1 if crash happened when pedestrian is crossing at mid-block location; 0 otherwise)	0.0003	0.0020	−0.0022	0.0003	0.0020	−0.0022
Multiple-threat (1 if crash is a multiple-threat crash; 0 otherwise)	0.0023	0.0031	**−0.0054**	0.0023	0.0031	**−0.0054**
Locality and roadway characteristics						
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise)	**0.0352**	−0.0117	−0.0235	**0.0356**	−0.0117	−0.0238
Two-way not divided (1 if the road configuration is two-way not divided; 0 otherwise)	**0.0624**	−0.0200	−0.0425	**0.0638**	−0.0200	−0.0438
NC route (1 if crash occurred on NC route; 0 otherwise)	**−0.0531**	0.0150	0.0380	**−0.0530**	0.0148	0.0381
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	0.0016	0.0018	**−0.0034**	0.0016	0.0018	**−0.0034**
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	0.0022	−0.0057	0.0034	−0.0002	−0.0059	0.0061
Time and environment characteristics						
Dark - roadway not lighted (1 if light condition is dark - roadway not lighted; 0 otherwise)	**0.0151**	−0.0050	−0.0101	**0.0147**	−0.0048	−0.0099
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	**0.0232**	−0.0088	−0.0144	**0.0230**	−0.0086	−0.0144
Traffic control characteristics and work zone						
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise)	0.0199	0.0338	**−0.0537**	0.0205	0.0344	**−0.0549**
Human control (1 if the type of traffic control is human control; 0 otherwise)	0.0090	0.0070	**−0.0160**	0.0090	0.0070	**−0.0160**

Noted: Values in bold indicate average direct marginal effects.

Table 5
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2007–2009 weekends).

Variable	RPL model			RPL model with heterogeneity in the mean		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics						
Pedestrian age: ≤ 24 (1 if pedestrian is younger than 25 years; 0 otherwise)	−0.0080	**0.0285**	−0.0204	−0.0089	**0.0307**	−0.0218
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	**0.0090**	−0.0033	−0.0057	**0.0112**	−0.0058	−0.0055
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	0.0171	0.0085	−0.0256	0.0177	0.0066	−0.0243
Male pedestrian (1 if pedestrian is male; 0 otherwise)	**0.0432**	−0.0191	−0.0240	**0.0445**	−0.0221	−0.0224
Driver characteristics						
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise)	0.0068	−**0.0230**	0.0163	0.0070	−**0.0230**	0.0159
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise)	0.0889	0.0793	−0.1681	0.0818	0.0893	−0.1712
Hit-and-run (1 if crash is hit-and-run; 0 otherwise)	**0.0090**	−0.0037	−0.0053	**0.0087**	−0.0038	−0.0049
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	**0.0337**	−0.0134	−0.0203	**0.0317**	−0.0147	−0.0171
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.0069	0.0139	−**0.0208**	0.0051	0.0130	−**0.0182**
Locality and roadway characteristics						
Curved roadway (1 if road geometry is curved roadway; 0 otherwise)	**0.0081**	−0.0040	−0.0041	**0.0080**	−0.0044	−0.0036
Commercial (1 if crash occurred in commercial area; 0 otherwise)	**0.0355**	−0.0141	−0.0215	**0.0350**	−0.0158	−0.0192
Farms, woods, pastures (1 if crash occurred in areas of farms, woods, or pastures; 0 otherwise)	0.0062	0.0052	−**0.0114**	0.0054	0.0054	−**0.0108**
Local street (1 if crash occurred on local street; 0 otherwise)	**0.0042**	−0.0023	−0.0019	**0.0042**	−0.0024	−0.0019
NC route (1 if crash occurred on NC route; 0 otherwise)	−**0.0593**	0.0231	0.0362	−**0.0587**	0.0271	0.0316
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	−0.0019	**0.0058**	−0.0040	−0.0018	**0.0055**	−0.0036
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	−**0.0177**	0.0051	0.0126	−**0.0198**	0.0058	0.0140
Time and environment characteristics						
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	**0.0357**	−0.0176	−0.0181	**0.0361**	−0.0195	−0.0166

Noted: Values in bold indicate average direct marginal effects.

0.0412 [RPL] vs. 0.0447 [RPL with heterogeneity in the mean]). This finding implies that without accounting for heterogeneity in the mean of random parameters, the effects of "alcohol-impaired pedestrian" on severe injury in the crash analysis for the corresponding periods would potentially be underestimated. In contrast, overestimations of this factor's effects on severe injury might happen for 2010–2012 weekends and 2013–2015 weekdays if no heterogeneity in means is considered. Furthermore, on 2010–2012 weekdays, the marginal effect of this factor on severe injury, further accounting for heterogeneity in the variances (0.0086), is much smaller than when using RPL only (0.0131) and RPL with heterogeneity in means (0.0137). This indicates that the effect of "alcohol-impaired pedestrian" in the analysis for 2013–2015 weekdays would be overestimated if such heterogeneity were not correctly taken into consideration.

6.1.2. Effects of older pedestrians (age ≥ 65)

Another critical factor that is statistically significant in most periods is the older pedestrian (age ≥ 65). Fig. 5 shows the marginal effects for all periods except 2010–2012 weekends and 2013–2015 weekends. According to the marginal effects, older pedestrians have a higher likelihood of sustaining severe injuries in all corresponding periods. The marginal effect of this factor on severe injury increased gradually from 2007 to 2012, whereas a downward trend was observed starting in 2013. Furthermore, in Tables 4-11 and Fig. 5, strong temporal instability is observed in its marginal effects on minor injury before and after 2013. Additionally, different marginal effects of this factor are also observed on all injury severity levels between weekdays and weekends in 2016–2018. For instance, the probability of an older pedestrian being severely injured is slightly higher on weekdays than on weekends. This again proves that pedestrian injury severity should be modeled by day of the week,

Regarding the model structure, on both 2007–2009 weekdays and 2016–2018 weekends, there are slight decreases in the marginal effect on severe injury (from 0.0085 to 0.0082 and from 0.0057 to 0.0053, respectively) considering heterogeneity in the means of the random parameters, while the effect increases in other periods. Moreover, by considering heterogeneity in the means and variances of the random parameters, the marginal effects of older pedestrians show a smaller value on

Table 6
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2010–2012 weekdays).

Variable	RPL model			RPL model with heterogeneity in the mean			RPL model with heterogeneity in the mean and variances		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics									
Pedestrian age: $\geq$ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	**0.0108**	−0.0048	−0.0060	**0.0115**	−0.0051	−0.0064	**0.0072**	−0.0029	−0.0043
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	**0.0131**	−0.0075	−0.0056	**0.0137**	−0.0078	−0.0059	**0.0086**	−0.0050	−0.0037
Driver characteristics									
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise)	**0.0026**	−0.0014	−0.0012	**0.0027**	−0.0015	−0.0013	**0.0023**	−0.0012	−0.0011
Crash characteristics									
Ambulance rescue (1 if service presents; 0 otherwise)	0.0803	0.1509	−0.2311	0.0784	0.1515	−0.2300	0.0764	0.1519	−0.2282
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	**0.0405**	−0.0201	−0.0204	**0.0506**	−0.0248	−0.0257	**0.0442**	−0.0219	−0.0223
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.0050	0.0061	−0.0111	0.0048	0.0059	−0.0107	0.0044	0.0065	−0.0109
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise)	**0.0157**	−0.0088	−0.0069	**0.0160**	−0.0089	−0.0071	**0.0157**	−0.0088	−0.0068
Locality and roadway characteristics									
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise)	**0.0101**	−0.0053	−0.0048	**0.0109**	−0.0059	−0.0051	**0.0092**	−0.0050	−0.0042
Grade-road (1 if crash occurred on grade-road; 0 otherwise)	−0.0003	**0.0018**	−0.0016	−0.0002	**0.0018**	−0.0016	−0.0002	**0.0017**	−0.0015
NC route (1 if crash occurred on NC route; 0 otherwise)	**−0.0071**	0.0041	0.0030	**−0.0176**	0.0095	0.0081	**−0.0026**	0.0019	0.0007
Private road, driveway (1 if crash occurred on driveway of private road; 0 otherwise)	**0.0046**	−0.0026	−0.0020	**0.0050**	−0.0028	−0.0022	**0.0049**	−0.0028	−0.0021
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	−0.0096	−0.0264	0.0361	−0.0099	−0.0250	0.0348	−0.0096	−0.0251	0.0347
Time and environment characteristics									
Dark - lighted roadway (1 if light condition is lighted roadway; 0 otherwise)	0.0007	−0.0154	0.0146	−0.0014	−0.0139	0.0153	0.0015	−0.0185	0.0169
Traffic control characteristics and work zone									
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise)	0.0592	0.0184	−0.0776	0.0835	0.0080	−0.0914	0.0764	0.0127	−0.0891
Human control (1 if the type of traffic control is human control; 0 otherwise)	0.0157	−0.0019	−0.0138	0.0200	−0.0038	−0.0162	0.0208	−0.0042	−0.0167

Noted: Values in bold indicate average direct marginal effects.

2010–2012 weekdays and a larger value on 2013–2015 weekdays than in models of RPL only and RPL with heterogeneity in means.

6.1.3. Effects of male pedestrians

The factor of "male pedestrian" is statistically significant in almost all weekend periods, excluding 2013–2015 weekends. In addition, based on Tables 4-11 and Fig. 6, there is strong temporal instability of this factor affecting the injury severity of male pedestrians in pedestrian-vehicle crashes. However, such instability shows a decrease in its marginal effect on severe injury to male pedestrians. This finding indicates that male pedestrians are less likely to sustain severe injuries than female pedestrians on weekends in the recent periods.

6.1.4. Effects of pedestrian age: 45–64

The factor "pedestrian age: 45–64" is significant only on weekdays, despite 2010–2012 weekdays. Fig. 7 shows the marginal effects of "pedestrian age: 45–64" in all models. Similar to "male pedestrian," the marginal effect of this factor on severe injury decreased after 2007, revealing temporal instability. In addition, although the marginal effect decreased over periods on weekdays, more attention should be paid to improving the safety of pedestrians aged 45 to 64 on weekdays. Moreover, this factor is insensitive to the presence of possible heterogeneity in means and variances.

Table 7
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2010–2012 weekends).

Variable	RPL model			RPL model with heterogeneity in the mean		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics						
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	**0.0118**	−0.0046	−0.0072	**0.0116**	−0.0050	−0.0066
Male pedestrian (1 if pedestrian is male; 0 otherwise)	**0.0218**	−0.0102	−0.0116	**0.0232**	−0.0122	−0.0110
Driver characteristics						
Driver age: ≤ 24 (1 if driver is younger than 25 years; 0 otherwise)	**0.0150**	−0.0068	−0.0082	**0.0146**	−0.0073	−0.0072
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise)	0.0046	**−0.0202**	0.0156	0.0049	**−0.0209**	0.0160
Driver age: ≥ 65 (1 if driver is older than 64 years old; 0 otherwise)	0.0030	**−0.0132**	0.0102	0.0032	**−0.0138**	0.0106
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise)	**0.0091**	−0.0042	−0.0049	**0.0092**	−0.0047	−0.0045
Male driver (1 if driver is male; 0 otherwise)	−0.0123	**0.0435**	−0.0312	−0.0126	**0.0434**	−0.0308
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise)	0.0884	0.0733	−0.1616	0.0845	0.0821	−0.1666
Hit-and-run (1 if crash is hit-and-run; 0 otherwise)	**0.0052**	−0.0023	−0.0029	**0.0055**	−0.0026	−0.0029
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	0.0457	0.0007	−0.0464	0.0452	0.0055	−0.0507
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.0129	0.0159	−0.0288	0.0123	0.0176	−0.0298
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise)	**0.0149**	−0.0054	−0.0096	**0.0154**	−0.0059	−0.0095
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise)	**0.0254**	−0.0109	−0.0145	**0.0298**	−0.0158	−0.0140
Locality and roadway characteristics						
Urban (1 if crash occurs in urban roadway; 0 otherwise)	−0.0250	−0.0694	**0.0944**	−0.0221	−0.0724	**0.0945**
Curved roadway (1 if road geometry is curved roadway; 0 otherwise)	**0.0102**	−0.0052	−0.0050	**0.0099**	−0.0055	−0.0044
Local street (1 if crash occurred on local street; 0 otherwise)	**0.0059**	−0.0031	−0.0029	**0.0058**	−0.0031	−0.0027
NC route (1 if crash occurred on NC route; 0 otherwise)	**−0.0382**	0.0151	0.0231	**−0.0392**	0.0176	0.0216
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	−0.0017	**0.0067**	−0.0050	−0.0019	**0.0074**	−0.0055
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	**−0.0136**	0.0038	0.0098	**−0.0139**	0.0043	0.0097
Time and environment characteristics						
Morning (1 if crash occurred during morning; 0 otherwise)	**0.0258**	−0.0105	−0.0153	**0.0264**	−0.0121	−0.0143
Dark - roadway not lighted (1 if light condition is dark - roadway not lighted; 0 otherwise)	**0.0398**	−0.0162	−0.0235	**0.0398**	−0.0182	−0.0215
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	**0.0596**	−0.0279	−0.0317	**0.0616**	−0.0322	−0.0293
Traffic control characteristics and work zone						
Work zone (1 if crash is on work-zone related road segment; 0 otherwise)	−0.0013	**0.0046**	−0.0034	−0.0013	**0.0046**	−0.0033

Noted: Values in bold indicate average direct marginal effects.

6.1.5. Effects of alcohol-impaired drivers

Commonly, the driver under the influence of alcohol is a critical risk factor in accident research. However, compared to alcohol-impaired pedestrians, alcohol-impaired drivers are not a statistically significant factor in all periods. Fig. 8 displays the marginal effects of this factor in the corresponding periods. Meanwhile, temporal instability is also observed, particularly for weekend periods. In addition, in 2016–2018, a larger marginal effect of this factor on severe injury is observable on weekends than on weekdays.

When considering heterogeneity in the means of the random parameters, the marginal effects of this factor on severe injury of pedestrians increases slightly. However, on 2010–2012 weekdays, the effect of this factor might be overestimated if potential heterogeneity in the variances of the random parameters is not considered.

6.1.6. Effects of male drivers

Male drivers are significant only on 2010–2012 weekends, 2013–2015 weekends, and 2016–2018 weekdays. According to Fig. 9, the marginal effect of this factor on severe injury increases over time. Furthermore, this is a typical factor showing temporal instability of its effects on pedestrian injury severity across the three-year periods and between weekdays and weekends.

6.1.7. Effects of other human characteristics

On 2016–2018 weekends, older drivers (age ≥ 65) were less likely to cause severe injuries to pedestrians (marginal effect of −0.0083 for both RPL and RPL with heterogeneity in the means models), as shown in Table 11. Some factors are also

Table 8
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2013–2015 weekdays).

Variable	RPL model			RPL model with heterogeneity in the mean			RPL model with heterogeneity in the mean and variances		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics									
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise)	**0.0132**	−0.0061	−0.0071	**0.0132**	−0.0062	−0.0069	**0.0131**	−0.0062	−0.0069
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	0.0084	0.0110	−0.0193	0.0085	0.0109	−0.0194	0.0088	0.0061	−0.0151
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	0.0175	−0.0019	−0.0155	0.0167	−0.0013	−0.0154	0.0167	−0.0014	−0.0152
Driver characteristics									
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise)	−0.0041	−0.0125	**0.0166**	−0.0038	−0.0122	**0.0160**	−0.0038	−0.0120	**0.0158**
Crash characteristics									
Ambulance rescue (1 if service presents; 0 otherwise)	0.0954	0.1167	−0.2122	0.0952	0.1157	−0.2109	0.0949	0.1165	−0.2114
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.0078	0.0153	−0.0231	0.0074	0.0157	−0.0231	0.0075	0.0153	−0.0228
Locality and roadway characteristics									
Urban (1 if crash occurs in urban roadway; 0 otherwise)	−0.0114	−0.0413	**0.0527**	−0.0111	−0.0427	**0.0539**	−0.0110	−0.0407	**0.0517**
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise)	**0.0186**	−0.0095	−0.0091	**0.0193**	−0.0104	−0.0089	**0.0193**	−0.0103	−0.0090
Two-way not divided (1 if the road configuration is two-way not divided; 0 otherwise)	**0.0615**	−0.0289	−0.0326	**0.0623**	−0.0296	−0.0326	**0.0621**	−0.0291	−0.0330
Bottom road (1 if crash occurred at the bottom of the roadway; 0 otherwise)	**−0.0267**	0.0127	0.0139	**−0.0271**	0.0132	0.0138	**−0.0273**	0.0132	0.0141
Local street (1 if crash occurred on local street; 0 otherwise)	**0.0027**	−0.0014	−0.0013	**0.0027**	−0.0015	−0.0012	**0.0026**	−0.0015	−0.0012
NC route (1 if crash occurred on NC route; 0 otherwise)	−0.0344	−0.0193	0.0536	−0.0346	−0.0201	0.0548	−0.0346	−0.0204	0.0551
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	−0.0118	−0.0366	0.0484	−0.0121	−0.0339	0.0460	−0.0123	−0.0335	0.0456
Time and environment characteristics									
Morning (1 if crash occurred during morning; 0 otherwise)	0.0071	**−0.0246**	0.0175	0.0079	**−0.0361**	0.0282	0.0073	**−0.0337**	0.0264
Dark - lighted roadway (1 if light condition is lighted roadway; 0 otherwise)	−0.0089	**0.0606**	−0.0517	−0.0106	**0.0724**	−0.0619	−0.0103	**0.0713**	−0.0610
Dark - roadway not lighted (1 if light condition is dark - roadway not lighted; 0 otherwise)	0.0044	0.0161	**−0.0205**	0.0046	0.0169	**−0.0215**	0.0047	0.0169	**−0.0215**
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	**0.0142**	−0.0076	−0.0066	**0.0148**	−0.0081	−0.0067	**0.0148**	−0.0081	−0.0067
Traffic control characteristics and work zone									
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise)	0.0084	0.0273	**−0.0356**	0.0109	0.0361	**−0.0470**	0.0112	0.0356	**−0.0468**

Noted: Values in bold indicate direct average marginal effects.

statistically significant and show temporal instability, such as "driver age: 45–64." However, these factors have no significant effects in 2016–2018.

6.2. Crash characteristics

This group of factors contains ambulance rescue service, hit-and-run, and characteristics that are strongly associated with human behaviors.

6.2.1. Effects of ambulance rescue

"Ambulance rescue" is statistically significant in all periods. Fig. 10 shows the marginal effects of "ambulance rescue" across all periods. This factor is a post-crash characteristic, but its marginal effects increase the risk of pedestrians suffering

Table 9
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2013–2015 weekends).

Variable	RPL model			RPL model with heterogeneity in the mean		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics						
Pedestrian age: ≤ 24 (1 if pedestrian is younger than 25 years; 0 otherwise)	−0.0091	**0.0407**	−0.0315	−0.0097	**0.0413**	−0.0316
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	**0.0388**	−0.0156	−0.0232	**0.0392**	−0.0174	−0.0219
Driver characteristics						
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise)	0.0049	**−0.0204**	0.0156	0.0112	**−0.0437**	0.0325
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise)	**0.0131**	−0.0055	−0.0076	**0.0135**	−0.0061	−0.0074
Male driver (1 if driver is male; 0 otherwise)	0.0151	0.0254	**−0.0405**	0.0139	0.0273	**−0.0413**
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise)	0.0947	0.0752	−0.1700	0.0907	0.0908	−0.1815
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	**0.0339**	−0.0122	−0.0216	**0.0351**	−0.0143	−0.0208
Dash/dart out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	**0.0147**	−0.0054	−0.0093	**0.0147**	−0.0061	−0.0086
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise)	**0.0114**	−0.0048	−0.0067	**0.0119**	−0.0054	−0.0065
Locality and roadway characteristics						
Curved roadway (1 if road geometry is curved roadway; 0 otherwise)	**0.0096**	−0.0038	−0.0057	**0.0097**	−0.0043	−0.0055
NC route (1 if crash occurred on NC route; 0 otherwise)	−0.0312	−0.0211	0.0524	−0.0309	−0.0218	0.0528
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	0.0013	**−0.0047**	0.0034	0.0013	**−0.0048**	0.0034
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	−0.0092	−0.0380	0.0473	−0.0093	−0.0414	0.0506
Time and environment characteristics						
Dark - lighted roadway (1 if light condition is lighted roadway; 0 otherwise)	**−0.0225**	0.0069	0.0156	**−0.0227**	0.0080	0.0147
Dark - roadway not lighted (1 if light condition is dark - roadway not lighted; 0 otherwise)	**−0.0196**	0.0067	0.0129	**−0.0205**	0.0079	0.0126

Noted: Values in bold indicate average direct marginal effects.

severe injuries. One possible reason is that high medical costs may prevent those involved (drivers, occupants, or pedestrians) from calling ambulance rescue services unless the severity of the crash reaches a certain level. According to Fig. 10, the marginal effects of this factor on severe injury are comparatively stable over time, and no obvious difference is observed between weekdays and weekends.

If potential heterogeneity in means and variances is not properly accounted for, the effects of "ambulance rescue" would be overestimated for all periods, excluding 2007–2009 weekdays and 2016–2018 weekdays.

6.2.2. Effects of hit-and-run

The "hit-and-run" factor is statistically significant on 2010–2012 weekends, 2016–2018 weekdays, and 2016–2018 weekends. Based on Fig. 11, compared to 2010–2012 weekends, this factor has much smaller effects on all pedestrian injury severity levels in 2016–2018. No significant difference is observed between weekdays and weekends or in different model structures.

6.2.3. Effects of pedestrian crossing roadway

Fig. 12 illustrates the marginal effects of the "pedestrian crossing roadway" factor in periods except for 2013–2015 weekdays and 2016–2018 weekdays. For weekend periods, the marginal effects on severe injury first increase and then decrease, with the highest value in 2010–2012. However, when 2010–2012 weekends are excluded, the effect is relatively stable over time for weekend periods, which requires further exploration of 2010–2012 in future research.

6.2.4. Effects of pedestrian dash/dart-out

Within the group of crash characteristics, "pedestrian dash/dart-out" is the second-largest crash type following "pedestrian crossing roadway." This factor is a significant contributing factor in all periods. Fig. 13 shows strong instability in its marginal effects. Furthermore, its marginal effects on severe injury are generally greater on weekends than on weekdays. One report from NCDOT (Thomas et al., 2018) mentioned that children (aged ≤ 16) are overrepresented in the crash type of dash/dart-out. This could be a possible explanation of the larger marginal effects of this factor on weekends, since children might have a higher chance of playing in the road.

Table 10
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2016–2018 weekdays).

Variable	RPL model			RPL model with heterogeneity in the mean		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics						
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise)	**0.0083**	−0.0043	−0.0040	**0.0078**	−0.0040	−0.0037
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	0.0071	0.0066	−0.0138	0.0073	0.0066	−0.0139
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	0.0127	−0.0008	−0.0119	0.0130	−0.0010	−0.0120
Driver characteristics						
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise)	0.0031	−0.0002	−0.0029	0.0032	−0.0003	−0.0030
Male driver (1 if driver is male; 0 otherwise)	**0.0288**	−0.0154	−0.0134	**0.0298**	−0.0159	−0.0138
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise)	0.0918	0.0690	−0.1608	0.0925	0.0685	−0.1610
Hit-and-run (1 if crash is hit-and-run; 0 otherwise)	**0.0027**	−0.0014	−0.0013	**0.0027**	−0.0014	−0.0013
Backing vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise)	−0.0058	−0.0052	0.0110	−0.0055	−0.0053	0.0108
Dash/dart out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.0050	0.0103	−0.0152	0.0048	0.0104	−0.0153
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise)	**0.0022**	−0.0006	−0.0015	**0.0024**	−0.0007	−0.0017
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise)	**0.0071**	−0.0037	−0.0034	**0.0072**	−0.0038	−0.0034
Locality and roadway characteristics						
Curved roadway (1 if road geometry is curved roadway; 0 otherwise)	**0.0057**	−0.0026	−0.0031	**0.0054**	−0.0024	−0.0030
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise)	0.0115	0.0021	−0.0136	**0.0113**	0.0022	−0.0137
Commercial (1 if crash occurred in commercial area; 0 otherwise)	0.0040	−**0.0236**	0.0196	0.0041	−**0.0244**	0.0203
Farms, woods, pastures (1 if crash occurred in areas of farms, woods, or pastures; 0 otherwise)	**0.0112**	−0.0065	−0.0048	**0.0157**	−0.0091	−0.0067
Interstate (1 if crash occurred on interstate; 0 otherwise)	0.0012	0.0023	−**0.0036**	0.0013	0.0024	−**0.0036**
NC route (1 if crash occurred on NC route; 0 otherwise)	−**0.0299**	0.0158	0.0141	−**0.0268**	0.0142	0.0126
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	**0.0033**	−0.0014	−0.0019	**0.0032**	−0.0014	−0.0019
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	−0.0012	−0.0127	**0.0139**	−0.0012	−0.0126	**0.0138**
Time and environment characteristics						
Dark - lighted roadway (1 if light condition is lighted roadway; 0 otherwise)	−**0.0247**	0.0120	0.0127	−**0.0245**	0.0119	0.0126
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	−0.0032	**0.0081**	−0.0049	−0.0035	**0.0086**	−0.0050
Traffic control characteristics and work zone						
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise)	**0.0217**	−0.0118	−0.0099	**0.0209**	−0.0113	−0.0096
Human control (1 if the type of traffic control is human control; 0 otherwise)	**0.0112**	−0.0057	−0.0055	**0.0126**	−0.0066	−0.0059
Traffic sign (1 if the type of traffic control is traffic sign; 0 otherwise)	0.0008	−**0.0064**	0.0056	0.0008	−**0.0063**	0.0056

Noted: Values in bold indicate average direct marginal effects.

Considering possible heterogeneity in the means of the random parameters, smaller marginal effects on severe injury are obtained for most periods, while the marginal effects on 2007–2009 weekdays and 2016–2018 weekends have larger values. With possible heterogeneity in the variances of random parameters, the marginal effects further decrease on 2010–2012 weekdays (0.0044 compared to 0.0050 and 0.0048 in the RPL-only and RPL with heterogeneity in means models, respectively), again indicating the influence of unobserved heterogeneity in the crash data.

6.2.5. Effects of pedestrian in roadway

"Pedestrian in the roadway" consists of several circumstances, such as pedestrians playing, walking, and working in the roadway. Fig. 14 shows that the effect on severe injury decreases over time, which implies an improvement in pedestrian safety in the roadway.

6.2.6. Effects of other factors on crash characteristics

The factor "pedestrian off roadway" is significant in both 2016–2018 and 2010–2012. A more significant mitigatory effect on severe injury is found on 2016–2018 weekends than on 2016–2018 weekdays, as shown in Tables 10 and 11. Another

Table 11
Marginal effects of significant factors for pedestrian injury severity in pedestrian-vehicle crashes (2016–2018 weekdays).

Variable	RPL model			RPL model with heterogeneity in the mean		
	Severe injury	Minor injury	No or possible injury	Severe injury	Minor injury	No or possible injury
Pedestrian characteristics						
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	0.0057	0.0111	−**0.0168**	0.0053	0.0123	−**0.0176**
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	**0.0412**	−0.0167	−0.0246	**0.0447**	−0.0217	−0.0230
Male pedestrian (1 if pedestrian is male; 0 otherwise)	−0.0117	**0.0343**	−0.0226	−0.0152	**0.0378**	−0.0225
Driver characteristics						
Driver age: ≥ 65 (1 if driver is older than 64 years old; 0 otherwise)	−**0.0083**	0.0026	0.0057	−**0.0083**	0.0030	0.0053
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise)	**0.0070**	−0.0026	−0.0044	**0.0069**	−0.0029	−0.0041
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise)	0.0850	0.0498	−0.1349	0.0845	0.0489	−0.1333
Hit-and-run (1 if crash is hit-and-run; 0 otherwise)	**0.0047**	−0.0017	−0.0030	**0.0047**	−0.0019	−0.0028
Backing Vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise)	−**0.0073**	0.0021	0.0052	−**0.0080**	0.0021	0.0059
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	**0.0293**	−0.0109	−0.0184	**0.0306**	−0.0130	−0.0177
Dash/dart out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	**0.0117**	−0.0041	−0.0076	**0.0120**	−0.0048	−0.0072
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise)	−**0.0086**	0.0022	0.0064	−**0.0084**	0.0025	0.0059
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise)	0.0034	−**0.0100**	0.0066	0.0037	−**0.0107**	0.0070
Locality and roadway characteristics						
Urban (1 if crash occurs in urban roadway; 0 otherwise)	−**0.0495**	0.0160	0.0335	−**0.0503**	0.0187	0.0316
Interstate (1 if crash occurred on interstate; 0 otherwise)	0.0048	0.0029	−**0.0077**	0.0041	0.0031	−**0.0072**
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	**0.0065**	−0.0028	−0.0038	**0.0064**	−0.0025	−0.0039
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	0.0018	−**0.0374**	0.0356	0.0017	−**0.0343**	0.0326
Time and environment characteristics						
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	**0.0333**	−0.0138	−0.0194	**0.0344**	−0.0160	−0.0184

Noted: Values in bold indicate average direct marginal effects.

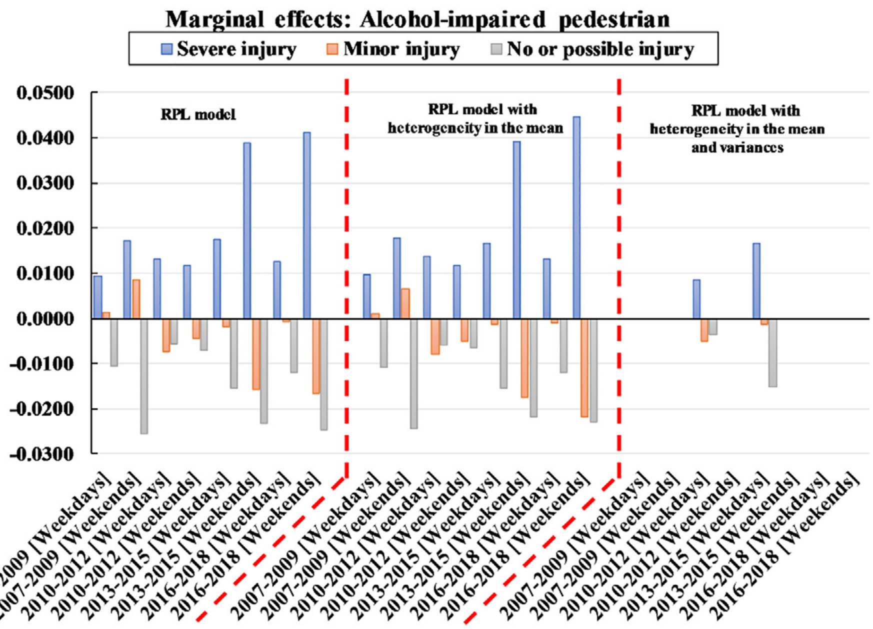

Fig. 4. Marginal effects for “alcohol-impaired pedestrian” (1 if pedestrian is alcohol-impaired; 0 otherwise).

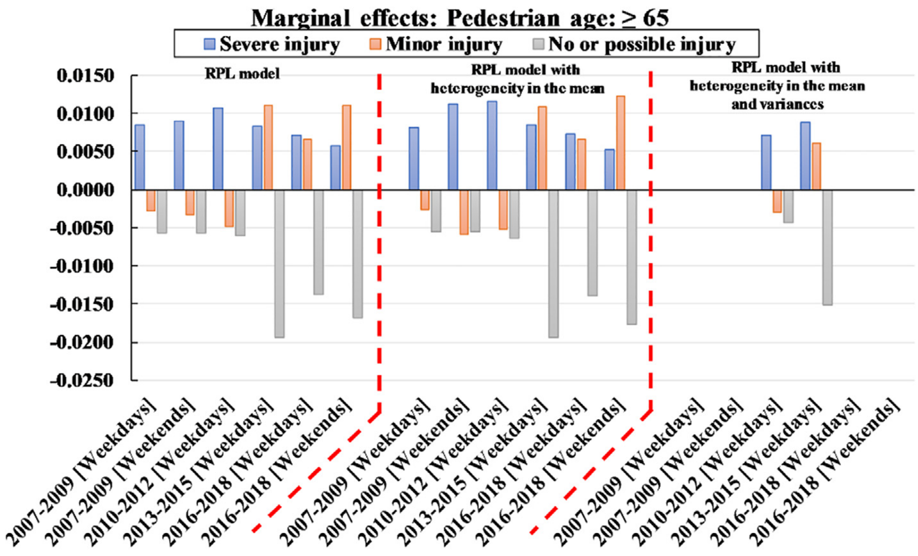

Fig. 5. Marginal effects for "pedestrians age: ≥ 65" (1 if pedestrian is older than 64 years old; 0 otherwise).

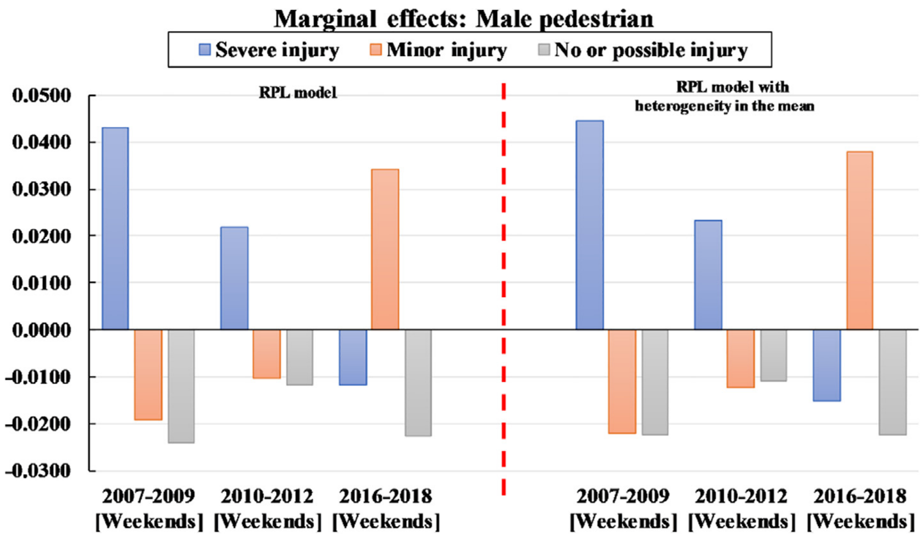

Fig. 6. Marginal effects for "male pedestrian" (1 if pedestrian is male; 0 otherwise).

factor, "backing vehicle," is statistically significant in 2016–2018, and its marginal effects generally decrease the likelihood of severe injuries to pedestrians. In addition, some other factors are significant in other periods, but not in 2016–2018.

6.3. Locality and roadway characteristics

6.3.1. Effects of state secondary route

The factor "state secondary route" is the only statistically significant factor in all periods, with the associated marginal effects demonstrated in Fig. 15. According to the marginal effects, this factor decreases the likelihood of severe injury for a pedestrian in all periods, excluding 2007–2009 weekdays and 2016–2018 weekends. The results indicate a strong instability of the effect over time. However, the opposite impacts are observed between weekdays and weekends in 2016–2018. This finding again supports the division of the dataset based on day of the week.

When potential heterogeneity in the means of the random parameters is considered, the marginal effect of "state secondary route" changes its sign from positive to negative towards severe injury on 2007–2009 weekdays. This implies that accounting for heterogeneity in means reduces the probability of a severe outcome, while in the RPL-only model, such an effect increases the likelihood of a pedestrian being severely injured.

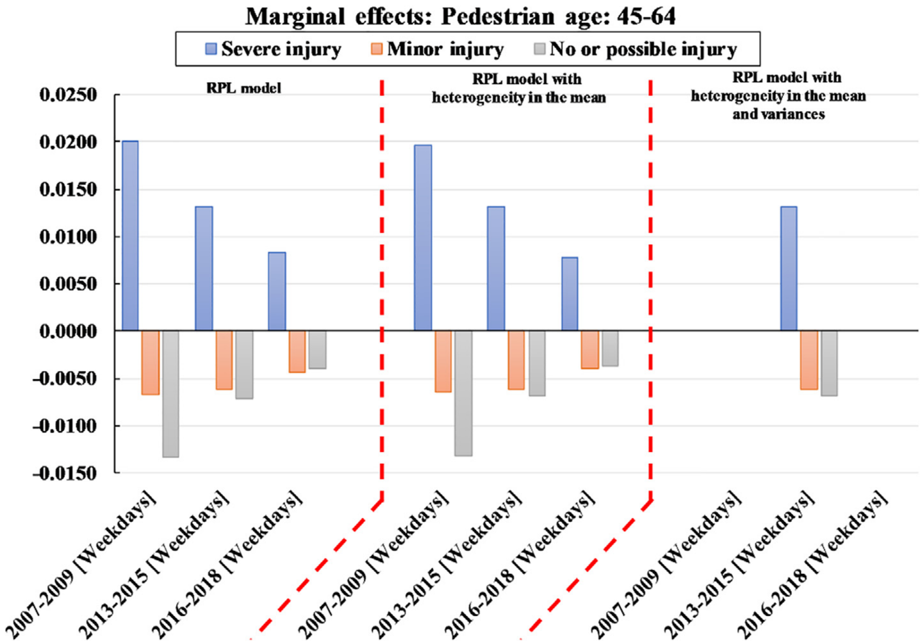

Fig. 7. Marginal effects of "pedestrian age: 45–64" (1 if pedestrian is aged 45–64; 0 otherwise).

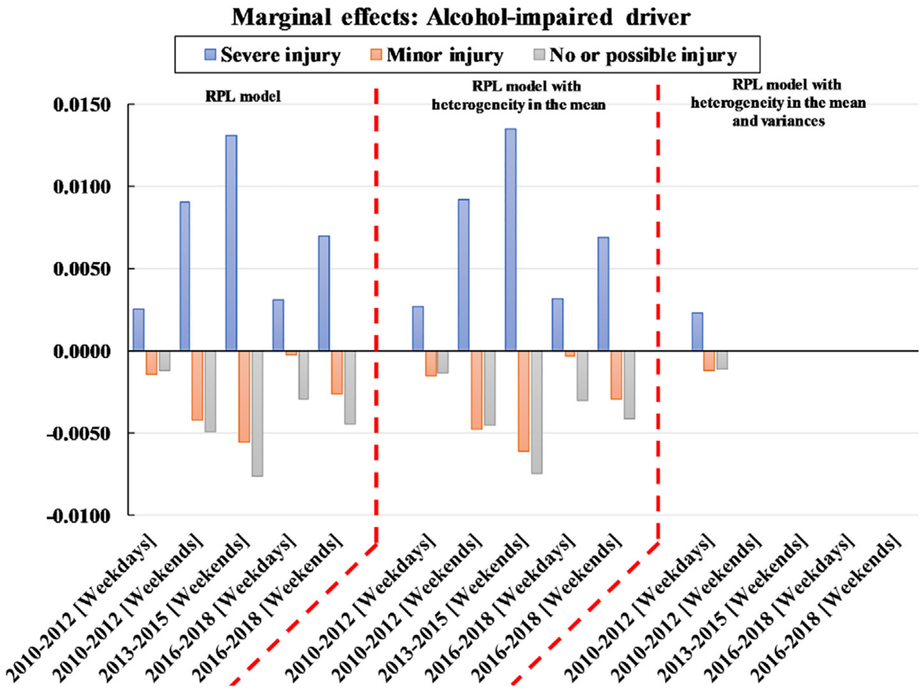

Fig. 8. Marginal effects for "alcohol-impaired driver" (1 if driver is alcohol-impaired; 0 otherwise).

6.3.2. Effects of NC route

Another significant factor is "NC route," though its effect is not apparent on 2016–2018 weekends. This factor generally mitigates severe injury to pedestrians. Based on Fig. 16, however, the mitigatory effect of the factor decreases over time with the increase in its marginal effect. Thus, corresponding maintenance and monitoring might be further planned to prevent such deterioration.

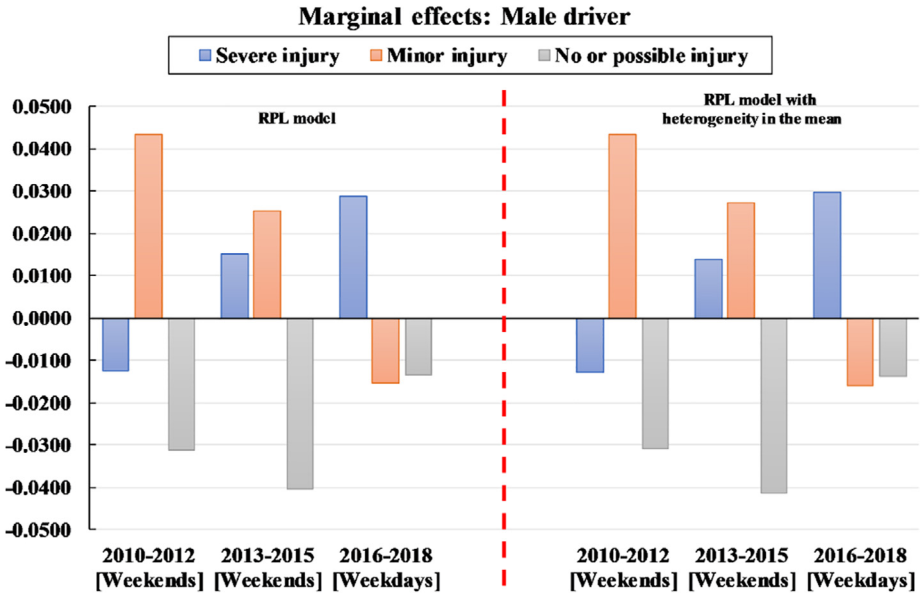

Fig. 9. Marginal effects for "male driver" (1 if driver is male; 0 otherwise).

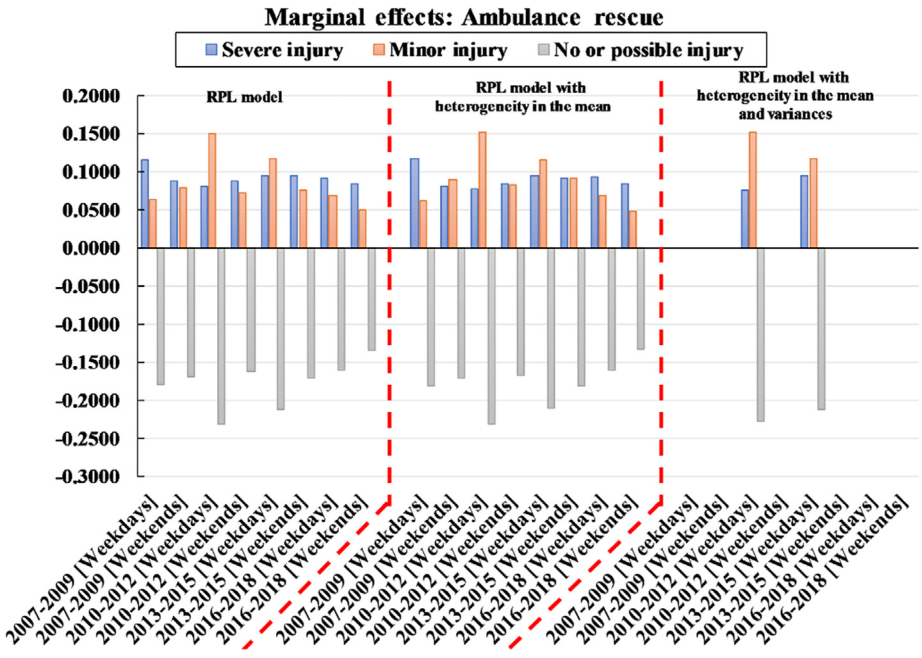

Fig. 10. Marginal effects for "ambulance rescue" (1 if service presents; 0 otherwise).

Regarding the model structures, the marginal effects of "NC route" on severe injury when heterogeneity in means is considered are smaller than in the RPL-only model for 2010–2012 weekdays, 2010–2012 weekends, and 2013–2015 weekdays and greater for other periods. Moreover, when further considering heterogeneity in the variances of the random parameters on 2013–2015 weekdays, a much smaller effect is obtained, as shown in to Table 8 (-0.0026 vs −0.0071 and −0.1076 in the RPL-only and the RPL with heterogeneity in means models, respectively).

6.3.3. Effects of public vehicular area

Based on the results of marginal effects, as shown in Fig. 17, the effects of "public vehicular area" on all injury severity levels show strong instability over time. In addition, this factor is nonsignificant on 2010–2012 weekdays and 2013–2015

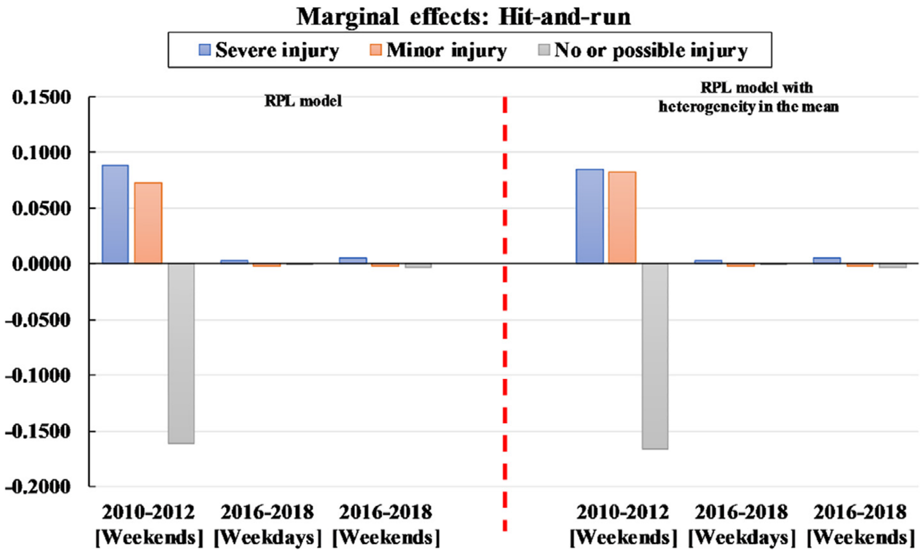

Fig. 11. Marginal effects of hit-and-run (1 if crash is hit-and-run; 0 otherwise).

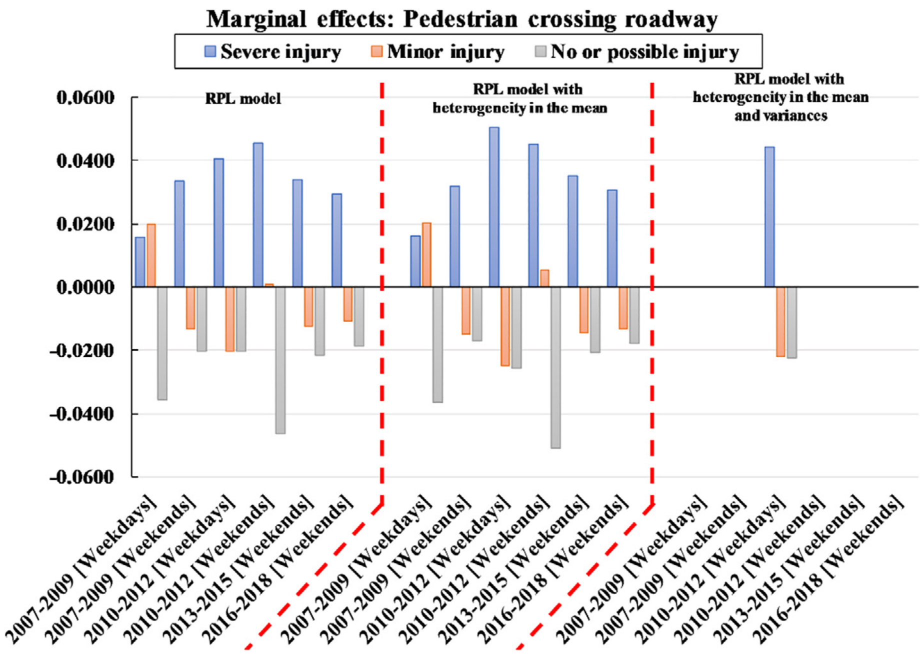

Fig. 12. Marginal effects of pedestrian crossing roadway (1 if crash happened when pedestrian was crossing a roadway; 0 otherwise).

weekends. Similar to the NC route factor, an upward trend of the marginal effects on severe injury appears over time but under a more deteriorative situation. Specifically, the mitigatory effect of "public vehicular area" turns out to increase the likelihood of being severe injury to pedestrians after 2010–2012. One possible reason for such degeneration might be more pedestrian activities in public vehicular areas. Thus, plans should be further developed to improve the safety of pedestrians in public vehicular areas.

With regard to the model structures, no significant changes were detected when considering possible heterogeneity in the means of the random parameters.

6.3.4. Effects of curved roadway

"Curved roadway" is a significant contributing factor to severe injury on 2016–2018 weekdays. Similar effects of this factor also appear on 2007–2009 weekends, 2010–2012 weekends, and 2013–2015 weekends, as shown in Fig. 18. Although

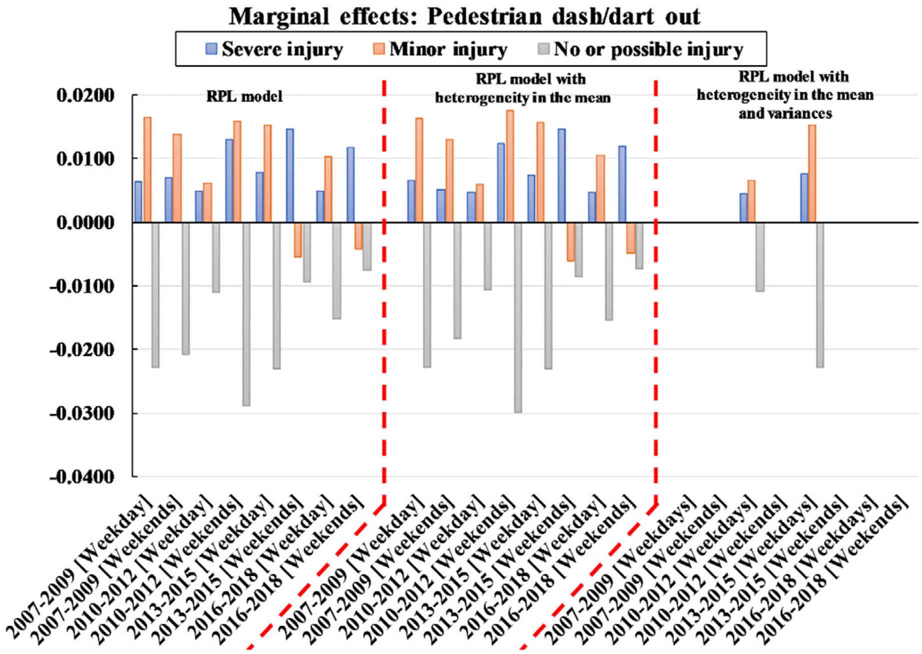

Fig. 13. Marginal effects of pedestrian dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise).

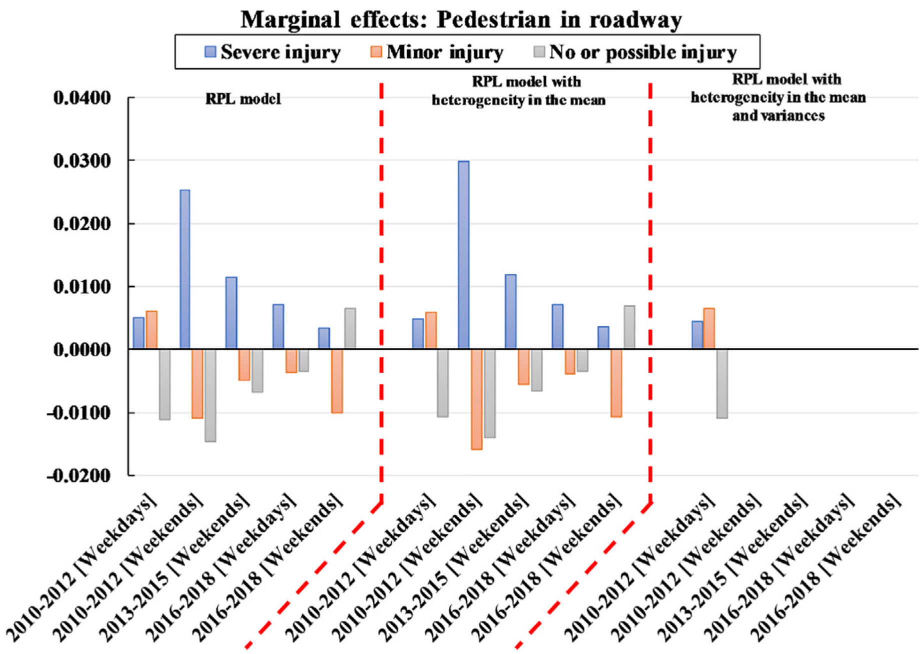

Fig. 14. Marginal effects of pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise).

small changes in marginal effects are observed, their effects on each severity injury level are relatively stable over time. In addition, the effects of this factor are insensitive to the consideration of heterogeneity in the means of the random parameters.

6.3.5. Effects of two-way divided roadway

The two-way divided road configuration is statistically significant on all weekdays. As illustrated in Fig. 19, its effects over time reveal an unstable trend in relation to all injury severity levels. On the other hand, no significant effects of this factor are

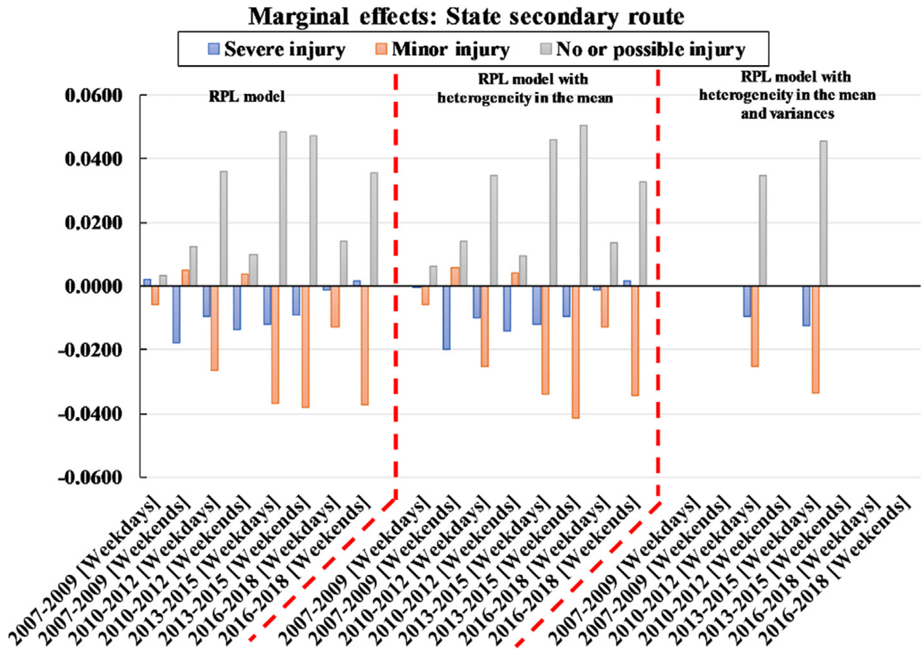

Fig. 15. Marginal effects of state secondary route (1 if crash occurred on a state secondary route; 0 otherwise).

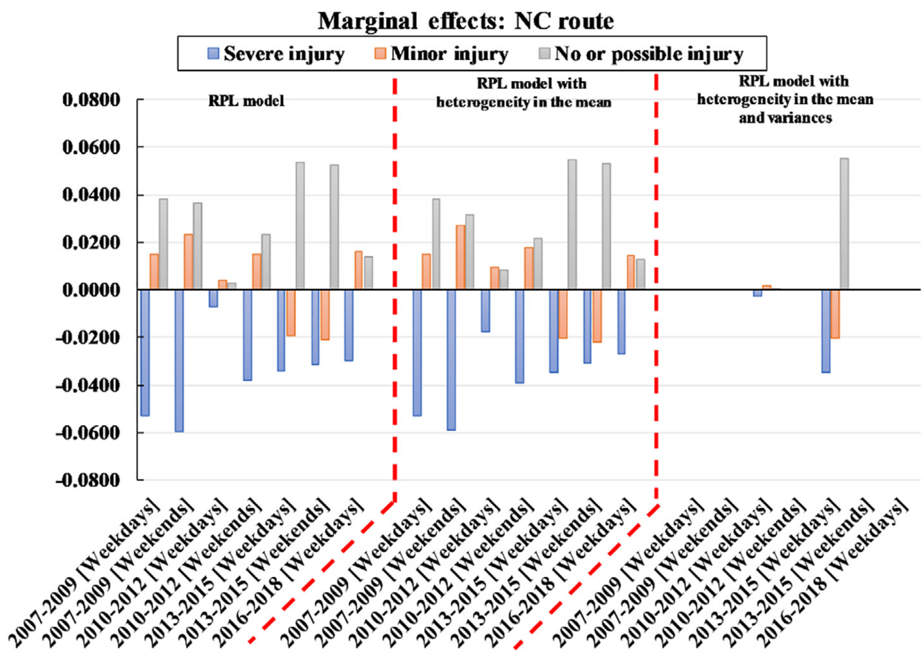

Fig. 16. Marginal effects of NC route (1 if crash occurred on an NC route; 0 otherwise).

observed on any weekends, which further supports segmenting the data by day of the week. Additionally, the marginal effect of this factor is not sensitive to heterogeneity in the means and variances of the random parameters.

6.3.6. Effects of interstate

Pedestrian-vehicle crashes occurring along interstates are extreme cases, and most of them are closely related to pedestrian-at-fault crashes. This factor is significant on both weekdays and weekends of 2016–2018. It is not surprising that this factor increases the risks of pedestrians sustaining both severe and minor injuries. As shown in Tables 10 and 11, while

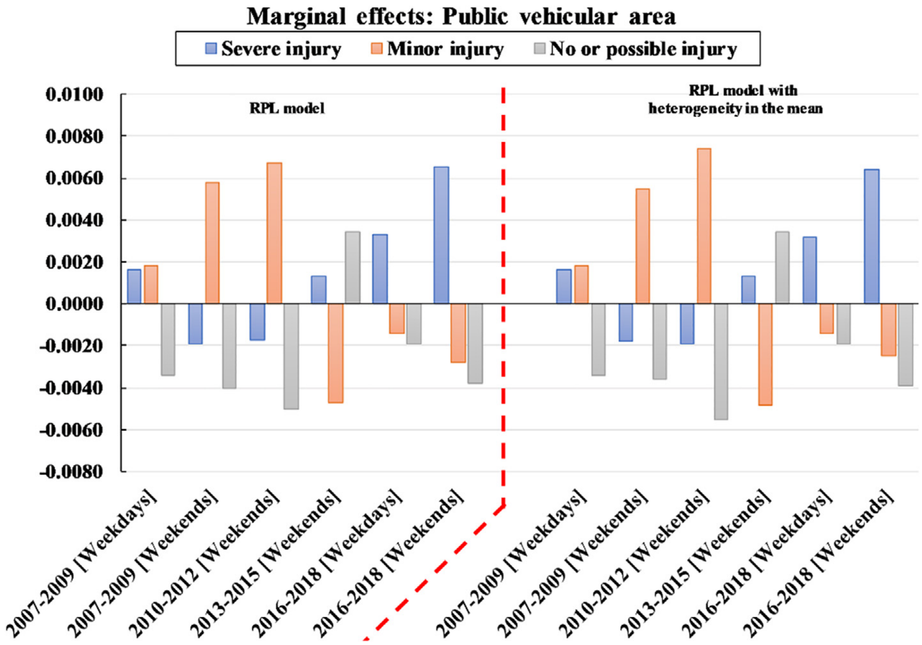

Fig. 17. Marginal effects of public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise).

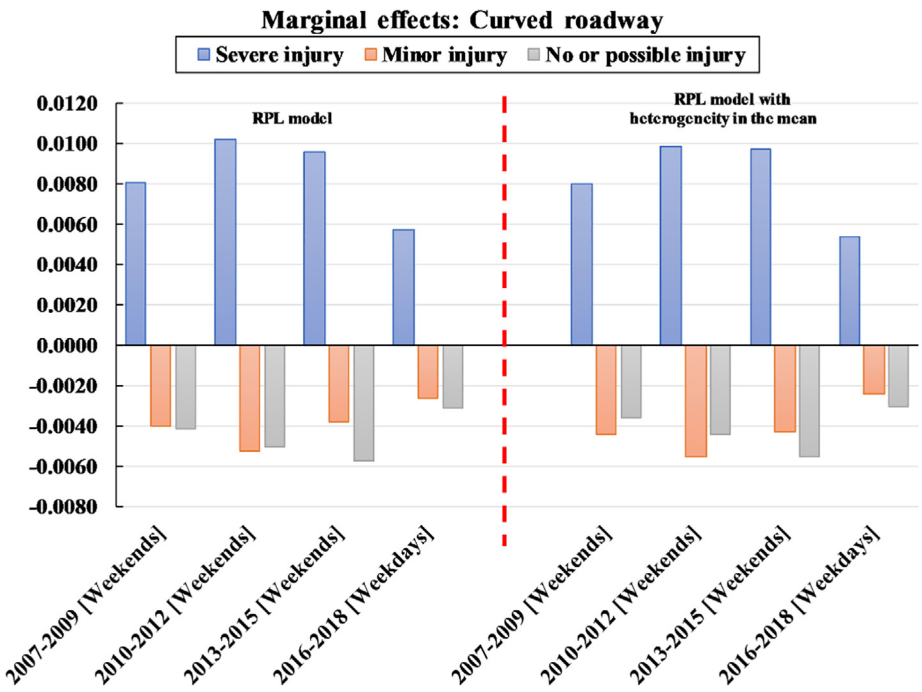

Fig. 18. Marginal effects of curved roadway (1 if road geometry is a curved roadway; 0 otherwise).

accounting for potential heterogeneity in the means of the random parameters, the effects on severe injury increase on 2016–2018 weekdays (marginal effects 0.0012 and 0.0013 for RPL only and RPL with heterogeneity in means, respectively) but decrease on 2016–2018 weekends (marginal effects 0.0048 and 0.0041 for RPL only and RPL with heterogeneity in means, respectively).

6.3.7. Effects of other locality and roadway characteristics factors

Some other factors within the group of locality and roadway characteristics are statistically significant on weekdays or weekends of 2016–2018. The factor "urban area" is significant on 2016–2018 weekends with an effect of reducing the chance of pedestrians suffering severe injuries. Fig. 20 displays the marginal effects of "urban area" on 2010–2012 weekends, 2013–2015 weekdays, and 2016–2018 weekends. Furthermore, by considering possible heterogeneity in the means of the random parameters (on 2016–2018 weekends), the effect of "urban area" on severe injury decreases (marginal effect from −0.0495 to −0.0503), but the effect on minor injury increases (marginal effect from 0.0160 to 0.0187).

The factors "commercial area" and "farms, woods, and pastures" are statistically significant on 2016–2018 weekdays. Additionally, both effects increase the likelihood of pedestrians being severely injured, as shown in Table 10.

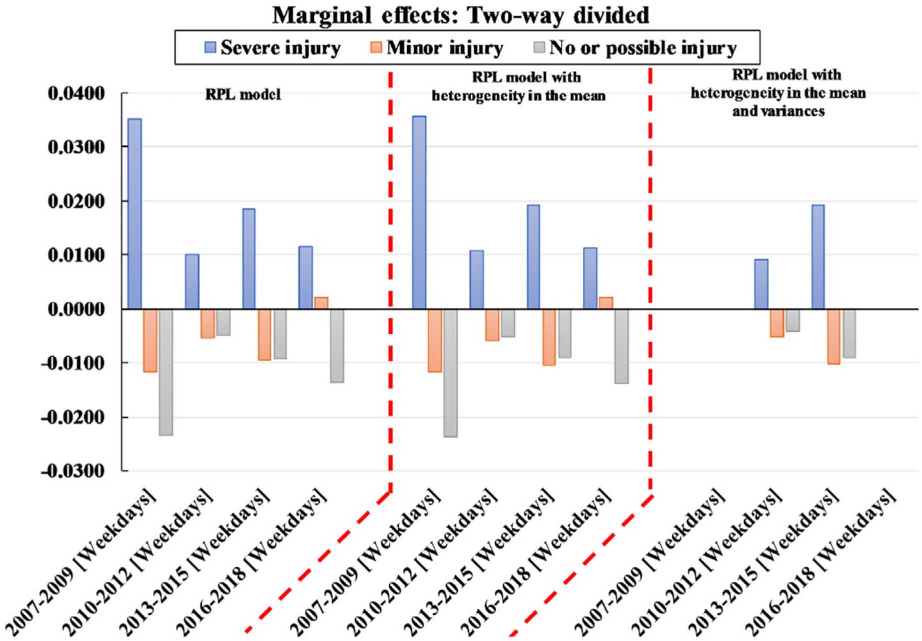

Fig. 19. Marginal effects of two-way divided roadway (1 if the road configuration is two-way divided; 0 otherwise).

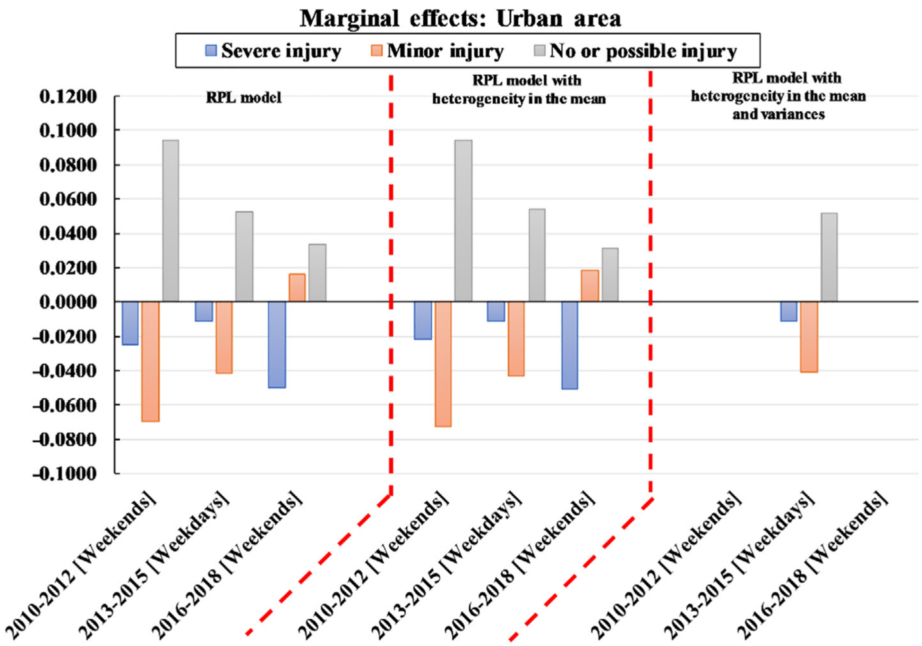

Fig. 20. Marginal effects of urban area (1 if crash occurs on an urban roadway; 0 otherwise).

6.4. Time and environment characteristics

The factors that are statistically significant in this group are mostly related to light conditions.

6.4.1. Effects of dawn/dusk light

The factor "dawn/dusk light" is statistically significant in most periods. As demonstrated in Fig. 21, its marginal effect shows strong temporal instability. When examining weekdays, a downward trend of the marginal effects on severe injuries to pedestrians can be observed over time. Moreover, the sign of its marginal effect even becomes negative on 2016–2018 weekdays. This phenomenon means that the "dawn/dusk light" condition decreases the probability of a severe outcome for a pedestrian on 2016–2018 weekdays. In contrast, a positive value of the marginal effect is found on 2016–2018 weekends, which once again suggests the necessity of segmentation of the data by day of the week.

When accounting for possible heterogeneity in the means of the random parameters, the marginal effects on severe injury become greater than those in the RPL-only model on both 2007–2009 weekdays and 2016–2018 weekdays, while the marginal effects decrease in other periods. Moreover, on 2013–2015 weekdays, this factor is insensitive to the presence of heterogeneity in variances of the random parameters.

6.4.2. Effects of dark – Lighted roadway

The factor "dark – lighted roadway" is statistically significant on 2016–2018 weekdays and the other three periods, as shown in Fig. 22. For weekdays, the marginal effect of "dark – lighted roadway" on severe injury decreases over time. This shows an enhancement of the effects on reducing the probability of severe outcomes for pedestrians. Compared to the "dawn/dusk light" factor, "dark – lighted roadway" has a mitigatory impact on severe injury. In other words, insufficient natural light could be more dangerous to pedestrians (or drivers) than sufficient artificial lighting.

When considering heterogeneity in means and variances, the marginal effect of "dark – lighted roadway" shows an ambiguous trend. Specifically, the marginal effect is negative (-0.0014) when accounting for heterogeneity in means, while positive values are observed in the other model structures (0.0007 for RPL only and 0.0015 for RPL with heterogeneity in means and variances).

6.5. Traffic control characteristics and work zones

In this group, no factors were statistically significant on 2016–2018 weekends.

6.5.1. Effects of double yellow line, no-passing

As illustrated in Fig. 23, this factor is significant only on weekdays. Meanwhile, the effect has strong temporal instability. For all periods except 2016–2018 weekdays, the marginal effects of "double yellow line, no passing" on severe injury are

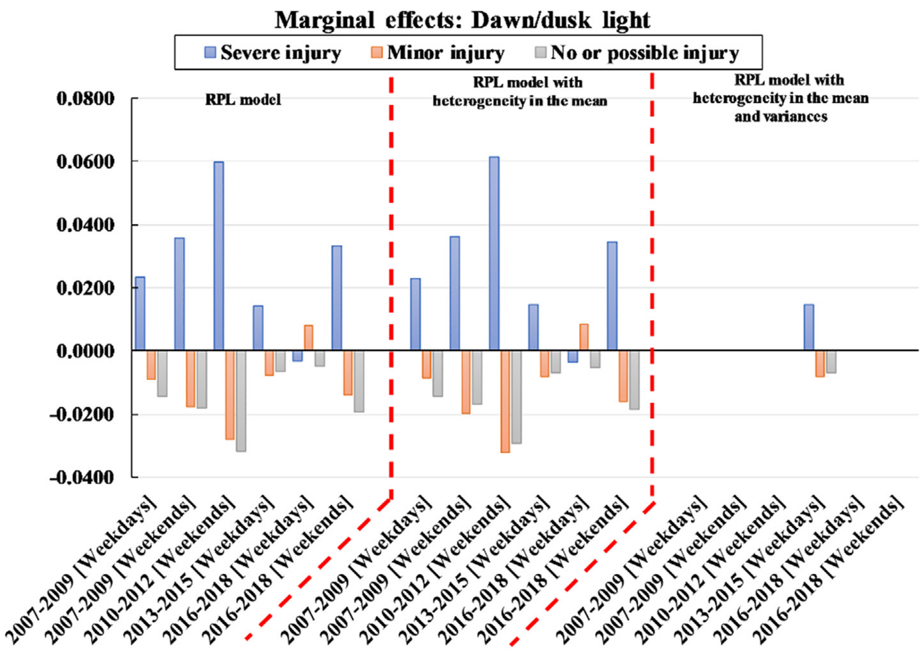

Fig. 21. Marginal effects of dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise).

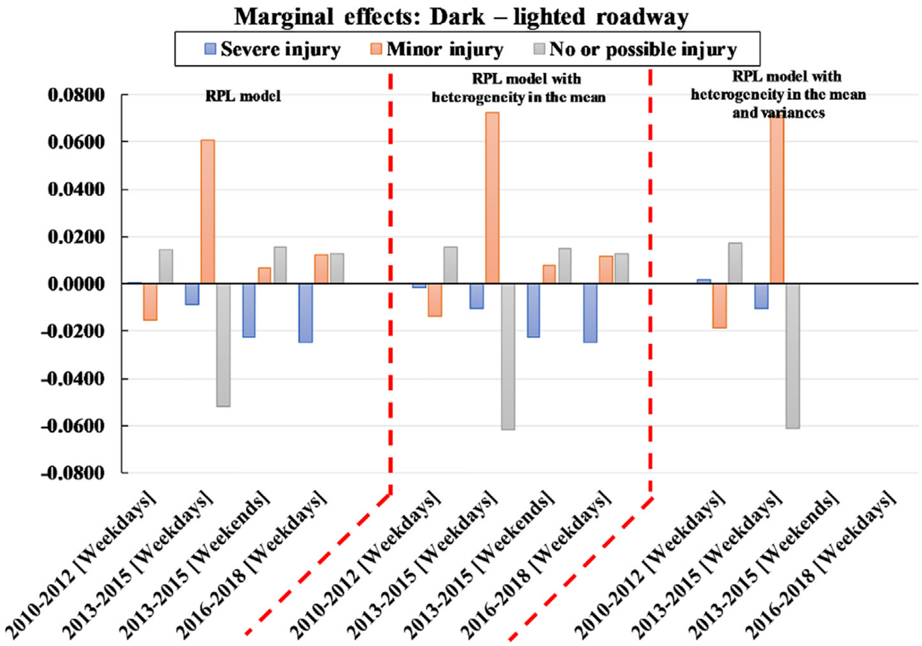

Fig. 22. Marginal effects of dark-lighted roadway (1 if light condition is lighted roadway; 0 otherwise).

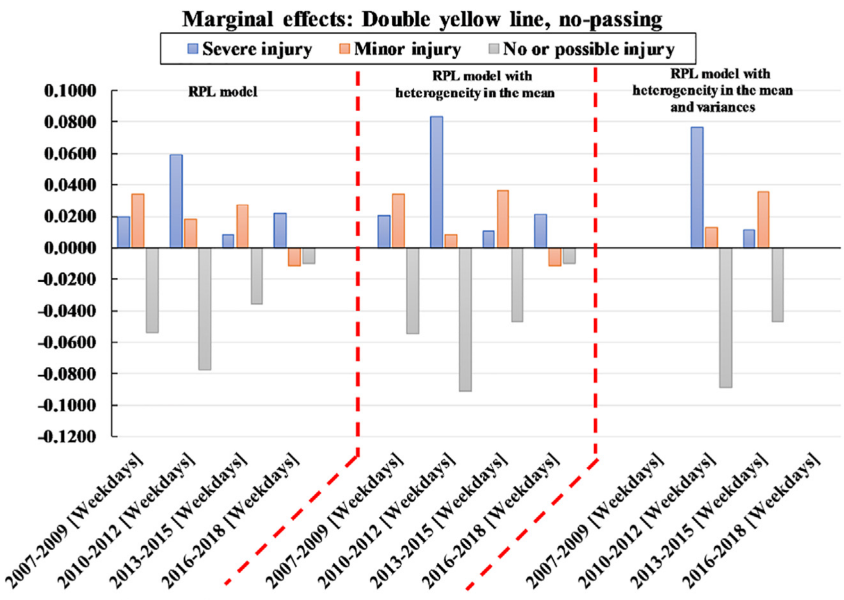

Fig. 23. Marginal effects of double yellow line, no-passing zone (1 if crash occurs within a no-passing zone with a double yellow line; 0 otherwise). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

greater when potential heterogeneity in means is accounted for than when using the RPL-only model, which implies the underestimation of this factor's effect on severe injury. On 2013–2015 weekdays, the marginal effect becomes even greater when possible heterogeneity in the variances of the random parameters is considered (marginal effect of 0.0112 for RPL with heterogeneity in means and variances model vs. 0.008 and 0.0109 for RPL only and RPL with heterogeneity in means only models, respectively). However, a smaller marginal effect is observed on 2010–2012 weekdays by accounting for potential heterogeneity in the variances of the random parameters, as shown in Table 6 and Fig. 23.

6.5.2. Effects of traffic control: human control

The factor "traffic control: human control" is statistically significant on 2007–2009 weekdays, 2010–2012 weekdays, and 2016–2018 weekdays, and the are shown in Fig. 24. On 2007–2009 weekdays, the marginal effects of this factor are insensitive to the presence of potential heterogeneity in means for all severity levels. However, in the other two periods, the effects on severe injury become larger when considering potential heterogeneity in means. An even larger marginal effect is observed when further considering potential heterogeneity in the variances of the random parameters on 2010–2012 weekdays. Furthermore, although the net effect change in the increase is small for 2010–2012 weekdays, the change is approximately 30% (marginal effect of 0.0208 in RPL with heterogeneity in means and variances vs. marginal effect of 0.0157 in RPL only).

7. Policy-Related recommendations

The purpose of this section is to provide immediate recommendations to improve the safety of pedestrians. Policy makers should focus particularly on factors that greatly increase the risk of pedestrians sustaining severe injuries and factors that deteriorate over time.

The effects of drunk pedestrians show a dramatically deteriorative trend on weekends over all three-year periods. Such deterioration becomes even worse in 2016–2018. The effect of this factor on severe injuries to pedestrians is much greater on weekends than on weekdays. Therefore, more frequent patrols and alcohol tests should be deployed on weekends. A similar phenomenon can be observed for drunk drivers when comparing the effects between weekends and weekdays. However, these effects were found to decrease the risk of pedestrians being killed in 2016–2018 (in comparison to 2010–2012 and 2013–2015). This proves the effects of continued enforcement efforts to identify drunk drivers. However, more attention should be paid to the pedestrian side, with campaigns focusing on drunk pedestrians on weekends. As discussed previously, there are downward trends of the marginal effects of pedestrians over 45 on severe injuries over time. These phenomena might have benefited from the efforts of safety research and campaigns in recent years that addressed the risk to older pedestrians in pedestrian-vehicle crashes. The same is true for male pedestrians. In other words, it is more necessary to develop campaigns to raise awareness of the risk of being severely injured for female pedestrians. In addition, male drivers increase the likelihood of pedestrians being severely injured on 2016–2018 weekdays. Hence, campaigns should also be developed to raise male drivers' awareness of pedestrians on weekdays.

With respect to significant factors within the group of crash characteristics, most of the factors could increase the risk of pedestrians sustaining severe injuries, although they show downward trends over time, denoting improvements to the safety of pedestrians from related policies. This finding supports efforts to address dangerous pedestrian behaviors and raise safety awareness among pedestrians. However, as pointed out previously, pedestrians dashing/darting out on weekends is closely related to children under 16 (Thomas et al., 2018), indicating that more educational activities are required for this population and that parents should be urged to pay more attention to children on weekends.

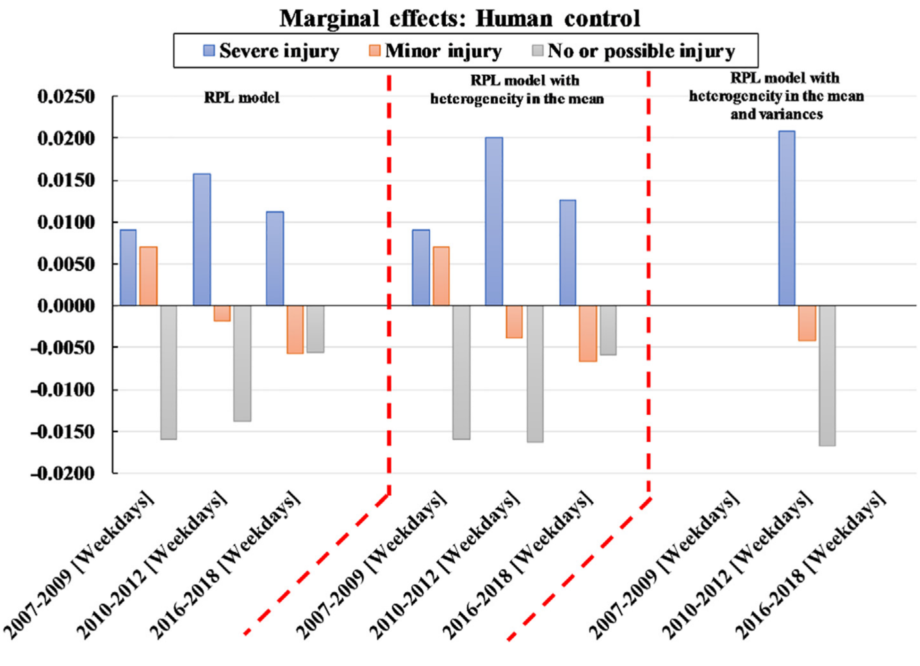

Fig. 24. Marginal effects of human control (1 if the type of traffic control is human control; 0 otherwise).

Three roadway class factors (state secondary route, NC route, and public vehicular area) had deteriorative trends in their mitigatory effects on severe injuries to pedestrians. In contrast to the continuous mitigatory effects of NC routes, state secondary routes and public vehicular areas turn out to increase the risks of pedestrians being severely injured over time. These phenomena indicate that local roadway infrastructures might require more maintenance. Moreover, further specific investigations on accident-prone roadway segments (especially for state secondary routes, NC routes, and public vehicular areas in this study) should be conducted. Then, corresponding improvement and maintenance plans need to be implemented. In addition, the curved roadway factor shows temporal stability in its effect on increasing the risk of pedestrians being severely injured. Therefore, special attention should be paid to improving the current design (horizontal alignment) of curved roadways.

It should be noted that factors whose effects vary dramatically over time might not be able to provide direct guidance to long-term reliable plans, and more in-depth investigations need to be performed. With respect to the period segmentation criteria, three years was selected as the appropriate time period for this study due to the examination of the current dataset, as applying a longer period might have ignored the inherent temporal instabilities within the data, and applying a shorter period would inevitably lead to the issue of insufficient sample size. However, the selection depends highly on the nature of the utilized dataset. Therefore, as such analysis is data driven, especially for datasets with inherent temporal instability, it is important to carefully set an appropriate period.

8. Conclusions

This study explores potential variation in the influence of factors impacting pedestrian injury severity in different periods (day-of-the-week and three-year periods) by utilizing pedestrian crash data for North Carolina from 2007 to 2018. A variety of possible contributing factors affecting pedestrian injury severity are examined within several different categories, including *pedestrian characteristics*, *driver characteristics*, *crash characteristics*, *locality and roadway characteristics*, *time and environment characteristics*, and *traffic control characteristics and work zones*.

Additionally, transferability tests between different periods are also conducted, and the results demonstrate significant temporal instability of the effects for most contributing factors. Only a few factors, such as "ambulance rescue" and "curved roadway," show temporally stable trends in their effects on pedestrian injury severity. Different changing trends of contributing factor effects over time are also detected. For instance, the marginal effects of "male pedestrian," "pedestrian age: 45–64," and "hit-and-run" on severe injury of pedestrians decrease over time, while the opposite trends were detected for "male driver," "state secondary route," "NC route," and "public vehicular area."

Despite temporal instability across different three-year periods, evidence of day-of-the-week variations was also identified in this study. "Pedestrian age: 45–64," "two-way divided roadway," "double yellow line, no passing," and "traffic control – human control" were statistically significant only on weekdays, and "male pedestrian" was significant solely on weekends. Other than the abovementioned phenomena, crashes with alcohol involvement (both alcohol-impaired drivers and pedestrians) were more likely to result in severe injuries to pedestrians on weekends than on weekdays in 2016–2018.

Moreover, in terms of model structures, the results indicate that without properly accounting for possible heterogeneities in the means and variances of the random parameters, the effects of some contributing factors might be overestimated or underestimated. For instance, the factor "dark-lighted roadway" in 2010–2012 produced a totally opposite effect in the RPL model with heterogeneity in the means and variances of the random parameters compared to the RPL-only and RPL with heterogeneity in the means of the random parameters models.

Regarding the long-term stability of policy making, factors with dramatically distinctive effects over time require updates to existing plans, and more in-depth investigations need to be done. Although some factors do show temporal instability (e.g., "pedestrian age: 45–64," "state secondary route," "public vehicular area," and "pedestrian in roadway"), the trends of their associated effects on injury severity indicate either "stable" upward (deteriorative) or downward (mitigating) trends over time. This indeed denotes the effectiveness of existing policies in either worsening or improving the related safety issues for pedestrians within the transportation system.

The findings of this work address the necessity of considering potential temporal instability and possible heterogeneity in the means and variances of the effects of variables affecting pedestrian injury severity in pedestrian-vehicle crashes. Therefore, the findings should be considered a solid reference for policy makers in future planning of safety improvements for pedestrians within the transportation system. Future works should focus on the analyses of specific characteristics of the built environment and more in-depth spatial–temporal modeling of pedestrian injury severity.

Acknowledgments

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Appendix A. Data Description

Table A1
Mean of variables used in the estimations for weekday models.

Description	2007–2009 [Weekends]	2010–2012 [Weekends]	2013–2015 [Weekends]	2016–2018 [Weekends]
Pedestrian characteristics				
Pedestrian age: 25–44 (1 if pedestrian is younger than 45 years old and older than 24 years old; 0 otherwise)	0.282	0.296	0.282	0.300
Pedestrian age: $\leq$ 24 (1 if pedestrian is younger than 25 years; 0 otherwise)	0.340	0.329	0.311	0.278
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise)	0.284	0.279	0.300	0.293
Pedestrian age: $\geq$ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	0.094	0.097	0.107	0.129
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	0.118	0.121	0.112	0.099
Male pedestrian (1 if pedestrian is male; 0 otherwise)	0.572	0.560	0.581	0.580
Driver characteristics				
Driver age: 25–44 (1 if driver is younger than 45 years old and older than 24 years old; 0 otherwise)	0.367	0.364	0.360	0.358
Driver age: $\leq$ 24 (1 if driver is younger than 25 years; 0 otherwise)	0.197	0.199	0.169	0.171
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise)	0.309	0.299	0.321	0.321
Driver age: $\geq$ 65 (1 if driver is older than 64 years old; 0 otherwise)	0.126	0.138	0.150	0.150
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise)	0.019	0.018	0.015	0.017
Male driver (1 if driver is male; 0 otherwise)	0.545	0.535	0.540	0.562
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise)	0.747	0.766	0.773	0.767
Hit-and-run (1 if crash is hit-and-run; 0 otherwise)	0.022	0.010	0.015	0.022
Backing vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise)	0.117	0.113	0.117	0.111
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	0.391	0.420	0.403	0.390
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.132	0.098	0.122	0.106
Midblock (1 if crash happened when pedestrian is crossing at midblock location; 0 otherwise)	0.009	0.007	0.007	0.008
Multiple-threat (1 if crash is a multiple-threat crash; 0 otherwise)	0.027	0.015	0.014	0.013
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise)	0.154	0.155	0.148	0.165
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise)	0.084	0.099	0.075	0.069
Waiting to cross (1 if crash occurred when pedestrian is waiting to cross the roadway; 0 otherwise)	0.001	0.002	0.000	0.001
Walking along roadway (1 if crash occurred when pedestrian is walking along roadway; 0 otherwise)	0.086	0.092	0.114	0.137
Locality and roadway characteristics				
Mixed (1 if crash occurs in mixed roadway; 0 otherwise)	0.141	0.131	0.143	0.139
Rural (1 if crash occurs in rural roadway; 0 otherwise)	0.123	0.126	0.112	0.112
Urban (1 if crash occurs in urban roadway; 0 otherwise)	0.736	0.742	0.744	0.749
Curved roadway (1 if road geometry is curved roadway; 0 otherwise)	0.048	0.042	0.042	0.044
One-way not divided (1 if the road configuration is one-way not divided; 0 otherwise)	0.080	0.081	0.090	0.092
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise)	0.180	0.176	0.188	0.204
Two-way not divided (1 if the road configuration is two-way not divided; 0 otherwise)	0.740	0.743	0.721	0.705
Commercial (1 if crash occurred in commercial area; 0 otherwise)	0.533	0.517	0.556	0.570
Farms, woods, pastures (1 if crash occurred in areas of farms, woods, or pastures; 0 otherwise)	0.092	0.091	0.081	0.084
Industrial (1 if crash occurred in industrial area; 0 otherwise)	0.005	0.007	0.008	0.004
Institutional (1 if crash occurred in Institutional area; 0 otherwise)	0.048	0.044	0.039	0.050
Residential (1 if crash occurred in Residential area; 0 otherwise)	0.322	0.342	0.316	0.292
Bottom-road (1 if crash occurred at the bottom of the roadway; 0 otherwise)	0.009	0.006	0.006	0.007
Grade-road (1 if crash occurred on grade-road; 0 otherwise)	0.150	0.143	0.131	0.111
Hillcrest (1 if crash occurred at the hillcrest of the roadway; 0 otherwise)	0.042	0.034	0.037	0.031
Level (1 if crash occurred at level roadway; 0 otherwise)	0.799	0.817	0.826	0.851
Interstate (1 if crash occurred on interstate; 0 otherwise)	0.012	0.007	0.008	0.009
Local street (1 if crash occurred on local street; 0 otherwise)	0.513	0.530	0.528	0.540
NC route (1 if crash occurred on NC route; 0 otherwise)	0.049	0.053	0.052	0.050
Private road, driveway (1 if crash occurred on driveway of private road; 0 otherwise)	0.019	0.025	0.018	0.015

Table A1 (*continued*)

Description	**2007–2009 [Weekends]**	**2010–2012 [Weekends]**	**2013–2015 [Weekends]**	**2016–2018 [Weekends]**
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	0.241	0.229	0.231	0.235
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	0.108	0.097	0.106	0.095
US route (1 if crash occurred on US route; 0 otherwise)	0.059	0.059	0.057	0.055
Time and environment characteristics				
Morning (1 if crash occurred during morning; 0 otherwise)	0.619	0.633	0.630	0.641
Dark – lighted roadway (1 if light condition is lighted roadway; 0 otherwise)	0.181	0.174	0.194	0.194
Dark – roadway not lighted (1 if light condition is dark – roadway not lighted; 0 otherwise)	0.171	0.155	0.150	0.164
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	0.042	0.053	0.042	0.043
Daylight (1 if light condition is daylight; 0 otherwise)	0.606	0.618	0.613	0.598
Clear (1 if the weather is clear; 0 otherwise)	0.754	0.788	0.730	0.779
Cloudy (1 if the weather is cloudy; 0 otherwise)	0.158	0.132	0.157	0.129
Fog, smog, smoke (1 if the weather is fog, smog, or smoke; 0 otherwise)	0.005	0.005	0.004	0.005
Rain (1 if the weather is raining; 0 otherwise)	0.080	0.071	0.105	0.083
Snow, sleet, hail, freezing rain/drizzle (1 if the weather is snow, sleet, hail, freezing rain, or drizzle; 0 otherwise)	0.002	0.004	0.005	0.003
Traffic control characteristics and work zones				
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise)	0.105	0.096	0.099	0.103
Human control (1 if the type of traffic control is human control; 0 otherwise)	0.013	0.012	0.012	0.014
No control present (1 if there is no control present; 0 otherwise)	0.645	0.644	0.626	0.615
Traffic sign (1 if the type of traffic control is traffic sign; 0 otherwise)	0.076	0.090	0.070	0.084
Traffic signal (1 if the type of traffic control is traffic sign; 0 otherwise)	0.161	0.158	0.193	0.185
Work zone (1 if crash on work-zone related road segment; 0 otherwise)	0.011	0.006	0.010	0.011

Table A2
Mean of the variables used in the estimations for weekend models.

Description	2007–2009 [Weekends]	2010–2012 [Weekends]	2013–2015 [Weekends]	2016–2018 [Weekends]
Pedestrian characteristics				
Pedestrian age: 25–44 (1 if pedestrian is younger than 45 years old and older than 24 years old; 0 otherwise)	0.317	0.318	0.304	0.334
Pedestrian age: $\leq$ 24 (1 if pedestrian is younger than 25 years; 0 otherwise)	0.381	0.354	0.344	0.292
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise)	0.231	0.247	0.261	0.281
Pedestrian age: $\geq$ 65 (1 if pedestrian is older than 64 years old; 0 otherwise)	0.071	0.082	0.091	0.093
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise)	0.223	0.216	0.232	0.192
Male pedestrian (1 if pedestrian is male; 0 otherwise)	0.616	0.632	0.581	0.591
Driver characteristics				
Driver age: 25–44 (1 if driver is younger than 45 years old and older than 24 years old; 0 otherwise)	0.403	0.375	0.382	0.379
Driver age: $\leq$ 24 (1 if driver is younger than 25 years; 0 otherwise)	0.220	0.218	0.203	0.175
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise)	0.273	0.281	0.261	0.296
Driver age: $\geq$ 65 (1 if driver is older than 64 years old; 0 otherwise)	0.104	0.126	0.154	0.149
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise)	0.060	0.063	0.064	0.043
Male driver (1 if driver is male; 0 otherwise)	0.572	0.563	0.578	0.589
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise)	0.744	0.768	0.785	0.771
Hit-and-run (1 if crash is hit-and-run; 0 otherwise)	0.026	0.024	0.029	0.031
Backing vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise)	0.126	0.130	0.137	0.117
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise)	0.322	0.307	0.323	0.342
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise)	0.136	0.121	0.153	0.109
Midblock (1 if crash happened when pedestrian is crossing at midblock location; 0 otherwise)	0.010	0.007	0.003	0.008

(*continued on next page*)

Table A2 (*continued*)

Description	2007–2009 [Weekends]	2010–2012 [Weekends]	2013–2015 [Weekends]	2016–2018 [Weekends]
Multiple-threat (1 if crash is a multiple-threat crash; 0 otherwise)	0.013	0.015	0.005	0.013
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise)	0.182	0.163	0.158	0.171
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise)	0.106	0.134	0.086	0.076
Waiting to cross (1 if crash occurred when pedestrian is waiting to cross the roadway; 0 otherwise)	0.000	0.000	0.001	0.001
Walking along roadway (1 if crash occurred when pedestrian is walking along roadway; 0 otherwise)	0.105	0.123	0.134	0.161
Locality and roadway characteristics				
Mixed (1 if crash occurs in mixed roadway; 0 otherwise)	0.148	0.163	0.122	0.168
Rural (1 if crash occurs in rural roadway; 0 otherwise)	0.158	0.167	0.156	0.137
Urban (1 if crash occurs in urban roadway; 0 otherwise)	0.694	0.671	0.721	0.695
Curved roadway (1 if road geometry is curved roadway; 0 otherwise)	0.056	0.069	0.062	0.047
One-way not divided (1 if the road configuration is one-way not divided; 0 otherwise)	0.066	0.070	0.070	0.081
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise)	0.209	0.201	0.170	0.210
Two-way not divided (1 if the road configuration is two-way not divided; 0 otherwise)	0.725	0.728	0.760	0.708
Commercial (1 if crash occurred in commercial area; 0 otherwise)	0.521	0.499	0.523	0.573
Farms, woods, pastures (1 if crash occurred in areas of farms, woods, or pastures; 0 otherwise)	0.115	0.128	0.117	0.115
Industrial (1 if crash occurred in industrial area; 0 otherwise)	0.007	0.001	0.009	0.001
Institutional (1 if crash occurred in Institutional area; 0 otherwise)	0.019	0.010	0.017	0.012
Residential (1 if crash occurred in Residential area; 0 otherwise)	0.338	0.361	0.335	0.299
Bottom-road (1 if crash occurred at the bottom of the roadway; 0 otherwise)	0.010	0.008	0.010	0.003
Grade-road (1 if crash occurred on grade-road; 0 otherwise)	0.127	0.143	0.113	0.099
Hillcrest (1 if crash occurred at the hillcrest of the roadway; 0 otherwise)	0.023	0.050	0.038	0.027
Level (1 if crash occurred at level roadway; 0 otherwise)	0.840	0.799	0.840	0.871
Interstate (1 if crash occurred on interstate; 0 otherwise)	0.018	0.021	0.016	0.017
Local street (1 if crash occurred on local street; 0 otherwise)	0.463	0.446	0.474	0.490
NC route (1 if crash occurred on NC route; 0 otherwise)	0.066	0.063	0.071	0.068
Private road, driveway (1 if crash occurred on driveway of private road; 0 otherwise)	0.024	0.030	0.028	0.012
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise)	0.253	0.228	0.241	0.231
State secondary route (1 if crash occurred on state secondary route; 0 otherwise)	0.103	0.139	0.097	0.103
US route (1 if crash occurred on US route; 0 otherwise)	0.073	0.073	0.071	0.079
Time and environment characteristics				
Morning (1 if crash occurred during morning; 0 otherwise)	0.448	0.456	0.484	0.472
Dark – lighted roadway (1 if light condition is lighted roadway; 0 otherwise)	0.273	0.235	0.273	0.267
Dark – roadway not lighted (1 if light condition is dark – roadway not lighted; 0 otherwise)	0.228	0.263	0.203	0.208
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise)	0.034	0.042	0.039	0.030
Daylight (1 if light condition is daylight; 0 otherwise)	0.465	0.460	0.486	0.495
Clear (1 if the weather is clear; 0 otherwise)	0.791	0.793	0.789	0.779
Cloudy (1 if the weather is cloudy; 0 otherwise)	0.129	0.136	0.119	0.125
Fog, smog, smoke (1 if the weather is fog, smog, or smoke; 0 otherwise)	0.003	0.005	0.004	0.006
Rain (1 if the weather is raining; 0 otherwise)	0.076	0.060	0.087	0.084
Snow, sleet, hail, freezing rain/drizzle (1 if the weather is snow, sleet, hail, freezing rain, or drizzle; 0 otherwise)	0.001	0.005	0.002	0.007
Traffic control characteristics and work zones				
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise)	0.096	0.137	0.105	0.113
Human control (1 if the type of traffic control is human control; 0 otherwise)	0.015	0.009	0.009	0.016
No control present (1 if there is no control present; 0 otherwise)	0.713	0.693	0.692	0.665
Traffic sign (1 if the type of traffic control is traffic sign; 0 otherwise)	0.062	0.052	0.053	0.060
Traffic signal (1 if the type of traffic control is traffic sign; 0 otherwise)	0.113	0.108	0.141	0.145
Work zone (1 if crash on work-zone related road segment; 0 otherwise)	0.007	0.016	0.007	0.012

Appendix B. Results of Model Estimations

Table B1
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2007–2009 weekdays).

Variable	RPL model		RPL model with heterogeneity in the mean	
	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−4.932	−9.59	−4.949	−9.52
Constant [MI]	−2.191	−11.05	−2.191	−10.96
Pedestrian characteristics				
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise) [SI]	0.776	4.73	0.755	4.58
Pedestrian age: $\geq$ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [SI]	1.112	4.31	1.060	4.12
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	0.725	2.93	0.760	2.92
Standard deviation of "Alcohol-impaired pedestrian"	1.764	2.88	1.877	2.64
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [MI]	0.733	2.93	0.754	2.95
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	2.144	8.86	2.153	8.65
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	1.028	5.35	0.997	4.78
Standard deviation of "Ambulance rescue"	3.410	3.60	3.476	3.28
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [PNI]	−0.615	−4.00	−0.629	−4.08
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [SI]	0.969	4.26	0.973	4.27
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [MI]	1.267	5.13	1.268	5.08
Midblock (1 if crash happened when pedestrian is crossing at midblock location; 0 otherwise) [SI]	2.047	2.77	2.041	2.76
Midblock (1 if crash happened when pedestrian is crossing at midblock location; 0 otherwise) [MI]	2.740	3.62	2.773	3.61
Multiple-threat (1 if crash is a multiple-threat crash; 0 otherwise) [PNI]	−1.204	−3.70	−1.213	−3.72
Locality and roadway characteristics				
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise) [SI]	1.717	4.00	1.733	4.03
Two-way not divided (1 if the road configuration is two-way not divided; 0 otherwise) [SI]	1.093	2.67	1.104	2.68
NC route (1 if crash occurred on NC route; 0 otherwise) [SI]	−1.274	−7.29	−1.274	−7.27
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise) [PNI]	−1.103	−2.83	−1.117	−2.85
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [SI]	−7.466	−2.32	−5.145	−2.23
Standard deviation of "State secondary route"	5.328	2.39	3.575	2.22
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [MI]	−0.851	−2.24	−0.526	−1.40
Standard deviation of "State secondary route"	1.739	2.77	1.408	2.02
Time and environment characteristics				
Dark – roadway not lighted (1 if light condition is dark – roadway not lighted; 0 otherwise) [SI]	0.835	4.45	0.814	4.32
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise) [SI]	0.982	5.11	0.980	5.09
Traffic control characteristics and work zone				
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise) [PNI]	−0.622	−4.33	−0.625	−4.33
Human control (1 if the type of traffic control is human control; 0 otherwise) [PNI]	−1.044	−4.87	−1.045	−4.84
Heterogeneity in the mean of the random parameters				
State secondary route: Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise) [SI]	–	–	−0.654	−1.70
Model statistics				
Number of observations	3021		3021	
Log-likelihood at zero	−3318.908		−3318.9077	
Log-likelihood at convergence	−2639.468		−2638.9842	
McFadden ρ2	0.2047		0.2049	
Akaike information criterion (AIC)	5334.9351		5335.9684	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury

Table B2
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2007–2009 weekends).

Variable	RPL model		RPL model with heterogeneity in the mean	
	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−3.015	−7.18	−2.927	−7.02
Constant [MI]	−2.191	−11.05	−1.328	−6.80
Pedestrian characteristics				
Pedestrian age: ≤ 24 (1 if pedestrian is younger than 25 years; 0 otherwise) [MI]	0.454	2.11	0.436	2.17
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [SI]	0.998	2.48	1.227	2.86
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	0.828	3.21	0.807	3.16
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [MI]	0.679	2.55	0.601	2.39
Male pedestrian (1 if pedestrian is male; 0 otherwise) [SI]	0.555	2.32	0.552	2.36
Driver characteristics				
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise) [MI]	−0.595	−2.54	−0.524	−2.45
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	1.576	5.17	1.587	5.23
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	1.059	4.69	1.229	5.55
Standard deviation of "Ambulance rescue"	1.823	2.59	1.285	1.78
Hit-and-run (1 if crash is hit-and-run; 0 otherwise) [MI]	1.986	3.58	1.876	3.44
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [MI]	0.723	2.93	0.664	2.74
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [PNI]	−0.891	−3.31	−0.758	−2.79
Locality and roadway characteristics				
Curved roadway (1 if road geometry is curved roadway; 0 otherwise) [SI]	0.892	2.23	0.844	2.19
Commercial (1 if crash occurred in commercial area; 0 otherwise) [MI]	0.654	2.73	0.628	2.67
Farms, woods, pastures (1 if crash occurred in areas of farms, woods, or pastures; 0 otherwise) [PNI]	−0.771	−2.44	−0.719	−2.34
Local street (1 if crash occurred on local street; 0 otherwise) [SI]	1.861	2.37	1.813	2.43
NC route (1 if crash occurred on NC route; 0 otherwise) [SI]	−1.101	−4.18	−1.073	−4.16
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise) [MI]	1.592	2.35	1.339	2.16
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [SI]	−2.250	−4.85	−2.426	−5.22
Time and environment characteristics				
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise) [SI]	0.910	3.49	0.875	3.42
Heterogeneity in the mean of the random parameters	–	–		
Ambulance rescue: Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [MI]	–	–	0.725	1.70
Ambulance rescue: State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [MI]	–	–	−0.710	−2.43
Model statistics				
Number of observations	913		913	
Log-likelihood at zero	−1003.0330		−1003.0330	
Log-likelihood at convergence	−804.9822		−801.1102	
McFadden ρ2	0.1975		0.2013	
Akaike information criterion (AIC)	1653.9644		1650.2204	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury

Table B3
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2010–2012 weekdays).

Variable	RPL model		RPL model with heterogeneity in the mean			
	Parameters estimate	t-stat	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−4.847	−7.38	−5.00829	−7.40	−5.411	−9.05
Constant [MI]	−1.442	−7.88	−1.46969	−8.02	−1.464	−7.93
Pedestrian characteristics						
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [SI]	1.473	4.76	1.374	4.66	1.236	3.29
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	0.801	4.15	0.752	4.13	0.586	2.54
Driver characteristics						
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise) [SI]	1.140	2.68	1.054	2.67	1.105	2.49
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	2.168	6.65	2.001	6.53	2.199	6.70
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	1.465	9.03	1.472	9.12	1.461	9.10
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [SI]	1.343	4.72	1.508	5.06	1.646	5.81
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [SI]	1.121	3.27	0.968	3.02	1.062	2.91
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [MI]	0.577	3.45	0.560	3.34	0.565	3.41
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise) [SI]	1.309	4.64	1.218	4.39	1.341	4.77
Locality and roadway characteristics						
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise) [SI]	0.654	3.19	0.630	3.34	0.662	2.91
Grade-road (1 if crash occurred on grade-road; 0 otherwise) [MI]	2.154	3.01	2.198	3.05	2.025	2.45
NC route (1 if crash occurred on NC route; 0 otherwise) [SI]	−1.862	−3.16	−0.148	−0.25	−1.069	−1.00
Standard deviation of "NC route"	1.322	2.75	1.252	1.66	2.114	2.23
Private road, driveway (1 if crash occurred on driveway of private road; 0 otherwise) [SI]	0.560	2.33	0.604	2.54	0.615	2.43
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [SI]	−1.874	−4.77	−1.819	−5.02	−1.897	−4.58
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [MI]	−0.812	−5.56	−0.780	−5.35	−0.804	−5.57
Time and environment characteristics						
Dark **–** lighted roadway (1 if light condition is lighted roadway; 0 otherwise) [SI]	−1.939	−2.58	−1.709	−2.33	−2.029	−3.24
Standard deviation of "Dark – lighted roadway"	2.149	2.60	1.834	2.16	2.272	3.49
Dark **–** lighted roadway (1 if light condition is lighted roadway; 0 otherwise) [MI]	−0.408	−3.24	−0.480	−3.47	−0.471	−3.56
Standard deviation of "Dark – lighted roadway"	2.080	2.87	1.372	2.86	1.113	2.27
Traffic control characteristics and work zone						
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise) [SI]	1.647	4.90	2.046	5.13	2.228	5.62
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise) [MI]	0.467	3.86	0.490	4.00	0.500	4.12
Human control (1 if the type of traffic control is human control; 0 otherwise) [SI]	1.617	4.24	1.902	4.60	2.093	5.01
Human control (1 if the type of traffic control is human control; 0 otherwise) [MI]	0.472	2.63	0.504	2.79	0.516	2.87
Heterogeneity in the mean of the random parameters						
Dark **–** lighted roadway: Two-way, divided (1 if the road configuration is two-way divided; 0 otherwise) [MI]	–	–	0.373	1.94	0.336	1.83
NC route: Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [SI]	–	–	−0.735	−2.21	−0.784	−1.97
NC route: Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise) [SI]	–	–	−0.987	−2.48	−0.902	−1.83
Heterogeneity in variances of the random parameters						
Dark - lighted roadway: Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [MI]	–	–	–	–	1.172	2.43
NC route: Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [SI]	–	–	–	–	0.661	2.14
NC route: Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	–	–	–	–	0.238	0.05
Model statistics						
Number of observations	3156		3156		3156	
Log-likelihood at zero	−3467.220		−3467.220		−3467.220	
Log-likelihood at convergence	−2692.163		−2685.789		−2679.366	
McFadden ρ2	0.2235		0.2254		0.2272	
Akaike information criterion (AIC)	5436.3265		5429.5783		5422.7327	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury

Table B4
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2010–2012 weekends).

Variable	RPL model		RPL model with heterogeneity in the mean	
	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−4.049	−6.33	−4.072	−6.43
Constant [MI]	−0.627	−1.95	−0.673	−2.19
Pedestrian characteristics				
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [SI]	1.346	3.20	1.294	3.14
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	0.632	2.37	0.643	2.49
Driver characteristics				
Driver age: ≤ 24 (1 if driver is younger than 25 years; 0 otherwise) [SI]	0.636	2.36	0.601	2.28
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise) [MI]	−0.474	−2.10	−0.435	−2.12
Driver age: ≥ 65 (1 if driver is older than 64 years old; 0 otherwise) [MI]	−0.722	−2.22	−0.668	−2.27
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise) [SI]	0.900	2.21	0.877	2.22
Male driver (1 if driver is male; 0 otherwise) [MI]	0.481	2.39	0.427	2.31
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	1.589	4.15	1.584	4.17
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	0.957	4.34	0.915	4.31
Standard deviation of "Ambulance rescue"	1.835	2.44	1.331	1.73
Hit-and-run (1 if crash is hit-and-run; 0 otherwise) [SI]	1.360	2.26	1.362	2.34
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [SI]	1.428	4.03	1.437	4.14
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [MI]	0.470	2.05	0.558	2.60
Dash/dart out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [SI]	1.890	4.12	1.882	4.17
Dash/dart out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [MI]	1.495	4.06	1.479	4.24
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise) [SI]	2.056	3.22	2.055	3.26
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise) [SI]	1.272	3.41	1.451	3.79
Locality and roadway characteristics				
Mixed (1 if crash occurs in mixed roadway; 0 otherwise) [PNI]	0.707	2.31	0.661	2.22
Urban (1 if crash occurs in urban roadway; 0 otherwise) [PNI]	0.809	3.05	0.761	3.01
Curved roadway (1 if road geometry is curved roadway; 0 otherwise) [SI]	1.008	2.60	0.936	2.48
Local street (1 if crash occurred on local street; 0 otherwise) [SI]	1.597	2.50	1.485	2.43
NC route (1 if crash occurred on NC route; 0 otherwise) [SI]	−0.949	−3.27	−0.954	−3.39
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise) [MI]	1.186	2.33	1.220	2.53
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [SI]	−2.978	−4.04	−2.971	−4.07
Time and environment characteristics				
Morning (1 if crash occurred during morning; 0 otherwise) [SI]	0.828	2.18	0.828	2.22
Dark – lighted roadway (1 if light condition is lighted roadway; 0 otherwise)				
Dark – roadway not lighted (1 if light condition is dark – roadway not lighted; 0 otherwise) [SI]	1.574	3.57	1.537	3.54
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise) [SI]	1.504	3.48	1.486	3.51
Traffic control characteristics and work zone				
Work zone (1 if crash on work-zone related road segment; 0 otherwise) [MI]	2.092	2.42	1.869	2.36
Heterogeneity in the mean of the random parameters				
Ambulance rescue: Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise) [MI]	–	–	0.635	1.79
Model statistics				
Number of observations	953		953	
Log-likelihood at zero	−1046.9775		−1046.9775	
Log-likelihood at convergence	−814.9091		−813.5301	
McFadden ρ2	0.2217		0.2230	
Akaike information criterion (AIC)	1689.8182		1689.0603	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury.

Table B5
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2013–2015 weekdays).

Variable	RPL model		RPL model with heterogeneity in the mean		RPL model with heterogeneity in the mean and variances	
	Parameters estimate	t-stat	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−3.510	−8.30	−3.572	−8.45	−3.575	−8.70
Constant [MI]	−1.196	−6.64	−1.259	−7.05	−1.267	−7.07
Pedestrian characteristics						
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise) [SI]	0.455	3.44	0.455	3.44	0.452	3.40
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [SI]	1.307	6.21	1.316	6.26	1.265	5.84
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [MI]	0.908	5.33	0.885	5.31	0.744	3.28
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	1.170	6.92	1.141	6.74	1.135	6.70
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [MI]	0.540	3.59	0.548	3.68	0.537	3.65
Driver characteristics						
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise) [PNI]	0.292	3.12	0.275	2.98	0.276	3.01
Crash characteristics						
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	1.849	8.01	1.840	7.97	1.844	7.77
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	1.287	9.38	1.248	9.17	1.268	9.11
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [SI]	1.216	6.68	1.198	6.58	1.191	6.27
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [MI]	1.129	7.02	1.111	6.93	1.089	6.80
Locality and roadway characteristics						
Urban (1 if crash occurs in urban roadway; 0 otherwise) [PNI]	0.396	3.46	0.395	3.50	0.385	3.37
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise) [SI]	0.983	2.83	1.033	2.98	1.036	3.13
Two-way not divided (1 if the road configuration is two-way not divided; 0 otherwise) [SI]	0.983	2.95	0.990	2.98	0.992	3.21
Bottom-road (1 if crash occurred at the bottom of the roadway; 0 otherwise) [SI]	−0.407	−2.88	−0.413	−2.93	−0.419	−2.85
Local street (1 if crash occurred on local street; 0 otherwise) [SI]	1.575	3.52	1.571	3.51	1.566	3.26
NC route (1 if crash occurred on NC route; 0 otherwise) [SI]	−1.037	−6.52	−1.048	−6.61	−1.052	−6.48
NC route (1 if crash occurred on NC route; 0 otherwise) [MI]	−0.395	−3.03	−0.398	−3.11	−0.402	−3.12
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [SI]	−2.173	−8.34	−2.203	−8.44	−2.195	−8.24
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [MI]	−1.247	−6.94	−1.118	−6.31	−1.174	−6.50
Time and environment characteristics						
Morning (1 if crash occurred during morning; 0 otherwise)	−0.697	−3.92	−0.644	−3.04	−0.623	−2.95
Standard deviation of "Morning"	1.556	3.79	1.341	3.08	1.263	2.92
Dark – lighted roadway (1 if light condition is lighted roadway; 0 otherwise) [MI]	0.631	4.37	0.717	4.83	0.729	4.87
Dark – roadway not lighted (1 if light condition is dark – roadway not lighted; 0 otherwise) [PNI]	−0.527	−4.20	−0.549	−4.39	−0.549	−4.42
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise) [SI]	0.559	3.67	0.588	3.85	0.589	3.87
Traffic control characteristics and work zone						
Double yellow line, no passing zone (1 if crash occurs within no passing zone with double yellow line; 0 otherwise) [PNI]	−0.326	−3.44	−0.421	−3.93	−0.426	−3.92
Heterogeneity in the mean of the random parameters						
Morning: Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise) [MI]	–	–	0.762	2.34	0.766	2.35
Morning: Two-way, divided (1 if the road configuration is two-way divided; 0 otherwise) [MI]	–	–	0.384	2.25	0.375	2.16
Morning: Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise) [MI]	–	–	−0.278	−1.77	−0.305	−1.91
Heterogeneity in variances of the random parameters						
Morning: Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [MI]	–	–	–	–	0.813	1.71
Model statistics						
Number of observations	3549		3549		3549	
Log-likelihood at zero	−3898.9750		−3898.9750		−3898.9750	
Log-likelihood at convergence	−2950.2885		−2942.9859		−2941.6552	
McFadden ρ2	0.2433		0.2452		0.2455	
Akaike information criterion (AIC)	5954.5770		5945.9718		5945.3103	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury.

Table B6
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2013–2015 weekends).

Variable	RPL model		RPL model with heterogeneity in the mean	
	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−2.618	−5.90	−2.583	−5.86
Constant [MI]	−0.775	−2.72	−0.649	−2.32
Pedestrian characteristics				
Pedestrian age: ≤ 24 (1 if pedestrian is younger than 25 years; 0 otherwise) [MI]	0.806	3.05	0.736	2.95
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	1.026	4.22	1.000	4.16
Driver characteristics				
Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise) [MI]	−0.623	−2.02	−1.229	−2.73
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise) [SI]	1.327	3.70	1.302	3.72
Male driver (1 if driver is male; 0 otherwise) [PNI]	−0.432	−2.41	−0.420	−2.42
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	1.627	4.65	1.612	4.64
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	0.909	3.57	0.767	3.10
Standard deviation of "Ambulance rescue"	2.483	2.22	1.926	2.06
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [SI]	0.900	3.01	0.904	3.07
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [SI]	0.963	2.59	0.947	2.58
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise) [SI]	0.930	2.47	0.925	2.51
Locality and roadway characteristics				
Curved roadway (1 if road geometry is curved roadway; 0 otherwise) [SI]	1.087	2.81	1.071	2.83
NC route (1 if crash occurred on NC route; 0 otherwise) [SI]	−0.858	−3.22	−0.854	−3.23
NC route (1 if crash occurred on NC route; 0 otherwise) [MI]	−0.502	−1.92	−0.483	−2.01
Public vehicular area (1 if crash occurred on public vehicular area; 0 otherwise) [MI]	−1.479	−1.85	−1.295	−1.86
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [SI]	−1.831	−3.79	−1.832	−3.81
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [MI]	−1.382	−4.29	−1.336	−4.47
Time and environment characteristics				
Dark – lighted roadway (1 if light condition is lighted roadway; 0 otherwise) [SI]	−0.806	−2.71	−0.805	−2.74
Dark – roadway not lighted (1 if light condition is dark – roadway not lighted; 0 otherwise) [SI]	−0.715	−2.41	−0.732	−2.53
Heterogeneity in the mean of the random parameters				
Ambulance rescue: Driver age: 45–64 (1 if driver is younger than 65 years old and older than 44 years old; 0 otherwise) [MI]	–	–	0.982	1.87
Model statistics				
Number of observations	1037		1037	
Log-likelihood at zero	−1139.2609		−1139.2609	
Log-likelihood at convergence	−905.2719		−903.5029	
McFadden ρ2	0.2054		0.2069	
Akaike information criterion (AIC)	1852.5437		1851.0057	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury

Table B7
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2016–2018 weekdays).

Variable	RPL model		RPL model with heterogeneity in the mean	
	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−3.306	−10.77	−3.344	−11.10
Constant [MI]	−0.871	−8.75	−0.870	−8.75
Pedestrian characteristics				
Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise) [SI]	0.320	2.34	0.291	2.15
Pedestrian age: $\geq$ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [SI]	0.929	4.51	0.914	4.52
Pedestrian age: $\geq$ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [MI]	0.402	3.60	0.404	3.62
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	1.086	5.98	1.077	6.01
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [MI]	0.507	3.55	0.505	3.54
Driver characteristics				
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise) [SI]	1.793	4.25	1.777	4.25
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise) [MI]	0.924	2.64	0.924	2.64
Male driver (1 if driver is male; 0 otherwise) [SI]	0.532	4.16	0.532	4.26
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	1.673	7.73	1.645	7.75
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	0.776	8.74	0.777	8.75
Hit and run (1 if crash is hit-and-run; 0 otherwise) [SI]	1.107	3.04	1.076	3.00
Backing vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise) [SI]	−1.258	−4.06	−1.168	−3.83
Backing vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise) [MI]	−0.352	−2.74	−0.352	−2.73
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [SI]	0.875	4.52	0.857	4.48
Dash/dart-out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [MI]	0.690	5.53	0.691	5.53
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise) [SI]	−5.595	−1.85	−6.052	−1.78
Standard deviation of "Off roadway"	4.116	2.12	4.437	2.06
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise) [SI]	0.761	3.93	0.745	3.94
Locality and roadway characteristics				
Curved roadway (1 if road geometry is curved roadway; 0 otherwise) [SI]	0.743	1.64	0.210	0.38
Standard deviation of "Curved roadway"	1.994	2.19	2.094	2.36
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise) [SI]	0.599	4.11	0.595	4.09
Two-way divided (1 if the road configuration is two-way divided; 0 otherwise) [MI]	0.230	2.38	0.230	2.38
Commercial (1 if crash occurred in commercial area; 0 otherwise) [MI]	−0.188	−2.46	−0.194	−2.55
Farms, woods, pastures (1 if crash occurred in areas of farms, woods, or pastures; 0 otherwise) [SI]	0.890	4.14	1.149	5.10
Interstate (1 if crash occurred on interstate; 0 otherwise) [PNI]	−0.383	−2.13	−0.388	−2.17
NC route (1 if crash occurred on NC route; 0 otherwise) [SI]	−0.694	−4.50	−0.617	−3.95
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise) [SI]	1.818	3.92	1.783	3.85
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [PNI]	0.281	2.83	0.279	2.80
Time and environment characteristics				
Dark – lighted roadway (1 if light condition is lighted roadway; 0 otherwise) [SI]	−0.759	−5.45	−0.734	−5.33
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise) [MI]	0.229	2.14	0.238	2.23
Traffic control characteristics and work zone				
Double yellow line, no-passing zone (1 if crash occurs within no-passing zone with double yellow line; 0 otherwise) [SI]	0.424	2.79	0.412	2.71
Human control (1 if the type of traffic control is human control; 0 otherwise) [SI]	0.148	0.34	0.910	2.45
Standard deviation of "Human control"	2.384	2.84	1.466	1.89
Traffic sign (1 if the type of traffic control is traffic sign; 0 otherwise) [MI]	−0.358	−2.75	−0.356	−2.73
Heterogeneity in the mean of the random parameters				
Curved roadway: Pedestrian age: 45–64 (1 if pedestrian is younger than 65 years old and older than 44 years old; 0 otherwise) [SI]	–	–	1.321	1.65
Human control: Farms, woods, pastures (1 if crash occurred in areas of farms, woods, or pastures; 0 otherwise) [SI]	–	–	−1.156	−2.95
Model statistics				
Number of observations	3791		3791	
Log-likelihood at zero	−4164.8392		−4164.8392	
Log-likelihood at convergence	−3321.1552		−3315.9618	
McFadden ρ2	0.2026		0.2038	
Akaike information criterion (AIC)	6714.3104		6707.9236	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury

Table B8
Random parameter logit models for pedestrian injury severity in pedestrian-vehicle crashes (2016–2018 weekends).

Variable	RPL model		RPL model with heterogeneity in the mean	
	Parameters estimate	t-stat	Parameters estimate	t-stat
Constant [SI]	−2.251	−6.04	−2.256	−6.10
Constant [MI]	−0.751	−3.14	−0.760	−3.30
Pedestrian characteristics				
Pedestrian age: ≥ 65 (1 if pedestrian is older than 64 years old; 0 otherwise) [PNI]	−1.217	−3.66	−1.209	−3.70
Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [SI]	1.298	5.43	1.384	5.69
Male pedestrian (1 if pedestrian is male; 0 otherwise) [MI]	−0.002	−0.01	−0.009	−0.03
Standard deviation of "Male pedestrian"	2.611	2.36	1.886	1.85
Driver characteristics				
Driver age: ≥ 65 (1 if driver is older than 64 years old; 0 otherwise) [SI]	−0.920	−2.56	−0.922	−2.59
Alcohol-impaired driver (1 if driver is alcohol-impaired; 0 otherwise) [SI]	1.095	2.52	1.044	2.43
Crash characteristics				
Ambulance rescue (1 if service presents; 0 otherwise) [SI]	1.309	4.41	1.321	4.47
Ambulance rescue (1 if service presents; 0 otherwise) [MI]	0.669	2.24	0.734	2.68
Standard deviation of "Ambulance rescue"	1.745	1.92	1.531	1.78
Hit-and-run (1 if crash is hit-and-run; 0 otherwise) [SI]	1.176	2.24	1.156	2.23
Backing vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise) [SI]	−1.676	−2.97	−1.748	−3.11
Crossing roadway (1 if crash happened when pedestrian is crossing roadway; 0 otherwise) [SI]	0.668	2.58	0.682	2.67
Dash/dart out (1 if pedestrian movement preceding crash is dashing/darting out; 0 otherwise) [SI]	0.792	2.30	0.798	2.34
Off roadway (1 if pedestrian moves off the roadway when vehicle approaches; 0 otherwise) [SI]	−1.576	−3.17	−1.556	−3.14
Pedestrian in roadway (1 if pedestrian is in the roadway; 0 otherwise) [MI]	−1.361	−2.33	−1.244	−2.38
Locality and roadway characteristics				
Urban (1 if crash occurs in urban roadway; 0 otherwise) [SI]	−0.824	−3.48	−0.828	−3.54
Interstate (1 if crash occurred on interstate; 0 otherwise) [PNI]	−0.813	−2.31	−0.751	−2.15
Public vehicular area (1 if crash occurred in public vehicular area; 0 otherwise) [SI]	3.308	3.84	3.102	3.61
State secondary route (1 if crash occurred on state secondary route; 0 otherwise) [MI]	−1.348	−4.39	−1.111	−3.84
Time and environment characteristics				
Dawn/dusk light (1 if light condition is dawn/dusk light; 0 otherwise) [SI]	0.969	3.77	0.964	3.80
Heterogeneity in the mean of the random parameters				
Ambulance rescue: Backing vehicle (1 if crash occurred when driver is backing vehicle; 0 otherwise) [MI]	–	–	−0.798	−1.76
Ambulance rescue: Alcohol-impaired pedestrian (1 if pedestrian is alcohol-impaired; 0 otherwise) [MI]	–	–	0.634	1.70
Model statistics				
Number of observations	1060		1060	
Log-likelihood at zero	−1164.5290		−1164.5290	
Log-likelihood at convergence	−947.8599		−944.7872	
McFadden ρ2	0.1861		0.1887	
Akaike information criterion (AIC)	1939.7198		1937.5743	

*Note: parameters defined for: [PNI] No/Possible injury; [MI] Minor injury; [SI] Severe injury.

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