Exploratory multinomial logit model–based driver injury severity analyses for teenage and adult drivers in intersection-related crashes

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ABSTRACT

Objective: Teenage drivers are more likely to be involved in severely incapacitating and fatal crashes compared to adult drivers. Moreover, because two thirds of urban vehicle miles traveled are on signal-controlled roadways, significant research efforts are needed to investigate intersection-related teenage driver injury severities and their contributing factors in terms of driver behavior, vehicle–infrastructure interactions, environmental characteristics, roadway geometric features, and traffic compositions. Therefore, this study aims to explore the characteristic differences between teenage and adult drivers in intersection-related crashes, identify the significant contributing attributes, and analyze their impacts on driver injury severities.

Methods: Using crash data collected in New Mexico from 2010 to 2011, 2 multinomial logit regression models were developed to analyze injury severities for teenage and adult drivers, respectively. Elasticity analyses and transferability tests were conducted to better understand the quantitative impacts of these factors and the teenage driver injury severity model’s generality.

Results: The results showed that although many of the same contributing factors were found to be significant in both teenage and adult driver models, certain different attributes must be distinguished to specifically develop effective safety solutions for the 2 driver groups.

Conclusions: The research findings are helpful to better understand teenage crash uniqueness and develop cost-effective solutions to reduce intersection-related teenage injury severities and facilitate driver injury mitigation research.

Introduction

Traffic statistics indicate that motor vehicle crashes are one of the leading causes of death among teenagers (Centers for Disease Control and Prevention 2010). More than 3,000 teenagers were killed due to fatal injuries caused in traffic crashes in 2010 (Centers for Disease Control and Prevention 2010). Previous studies show that 16-year-old drivers are more likely to be involved in fatal crashes than older drivers based on the results provided by the NHTSA’s General Estimates System and Fatal Accidents Reporting System (Ulmer et al. 2001). Similar conclusions were obtained by Geyer and Ragland (2002), indicating that young male drivers show higher severe crash risks than drivers from other age groups. In the state of New Mexico, the crash rate of teenage drivers is almost 3 times higher than the state average rate for all crashes (New Mexico Department of Transportation [NMDOT] 2010). Due to the efforts of transportation agencies, many countermeasures have been developed and implemented aiming to reduce the number of teenage driver–involved crashes during the past decade. The overall percentage of crashes is still disproportionately high given the fact that licensed drivers under 21 years old account for only approximately 7% of all licensed drivers (NMDOT 2010). These data indicate that though crashes associated with licensed drivers under the age of 21 have steadily reduced from 20.6 to 16.3% in New Mexico, teenage drivers are still overrepresented in terms of traffic crash frequency and severity. Significant research efforts are needed to better understand significant causal factors for teenage crash risks and driver injury severities in order to develop effective countermeasures and proper policies for traffic safety performance improvements system-wide.

Furthermore, two thirds of urban vehicle miles traveled are on signal-controlled roadways (Federal Highway Administration 2011). Significant injurious and fatal crashes, such as right-angle, rear-end, and left turn collisions, commonly occur around intersections due to control interruptions to traffic flow progression. In 2010, 42,802 crashes were reported and recorded in New Mexico, of which 15,937 crashes (about 40%) occurred at or were influenced by signalized intersections. Therefore, it is necessary to identify the impacts of certain roadway geometric characteristics, control interruptions, and human factors on intersection-related injury severities. This study aims to analyze the effect of adult and teenage drivers’ characteristics on
driver injury severities and identify the significant attributes for crashes occurring at and influenced by intersections in New Mexico. Based on the crash data collected in New Mexico during 2010 and 2011, 2 multinomial logit regression models were developed to analyze injury severities for teenage and adult drivers, respectively. Elasticity analyses and transferability tests were conducted in order to better understand the quantitative impacts of these contributing factors and teenage driver severity model’s generality. The distinction between significant attributes contributing to adult and teenage driver injury severities is potentially critical. The research findings are helpful to better understand the uniqueness of teenage crashes and develop cost-effective solutions to reduce intersection-related teenage driver injury severities.

**Literature review**

In the past decades, many studies have been conducted to explore teenage driver behaviors and characteristics as well as their relationship with driver injury severities. Due to insufficient experience and overestimation of their own driving skills, teenage drivers are more likely to be involved in severe crashes than adult drivers (Braitman et al. 2008). Teenage drivers tend to maintain shorter headways and higher speed when there are 2 or more passengers in their vehicle and the impact can be more significant with the presence of a male teenage passenger (Lambert-Bélanger et al. 2012; Simons-Morton et al. 2005). Williams (2014) calculated teenage driver fatal crash rates and compared them with those of 25- to 59-year-olds. They concluded that teenage drivers were more likely to be involved in a fatal or severe injury crashes than those in other age groups. Based on previous studies, many countermeasures have been implemented focusing on crash involvement reduction for teenage drivers. Graduated driver licensing has proved to be effective by imposing restrictions and delayed licensure on 15- to 17-year-old drivers (Karaca-Mandic and Ridgeway 2010). Ulmer et al. (2001) found that crash involvement resulting in fatalities or injuries among 16-year-old drivers decreased 22% due to delayed licensure in Connecticut. Cammisa et al. (1999) concluded that limiting vehicle ownership for newly licensed teenage drivers could also decrease crash involvement based on a survey among teenage drivers and their parents in 4 states in the United States. On the other hand, drivers tend to have more severe injuries and fatalities around intersections due to underestimating the traffic complexity of intersections. Therefore, crashes occurring around intersections have been studied in order to improve safety performance in intersections (Abdel-Aty and Keller 2005; H. Chen et al. 2012; Moore et al. 2011; Obeng 2008; Zhang et al. 2014). For example, Obeng (2008) investigated the contributing factors for crashes occurring at signalized intersections and concluded that seat belt use, especially 3-point seat belt use, is effective in reducing driver injury severities. Zhang et al. (2014) analyzed driver injury severities at intersections and found that a variety of factors, such as driver age and gender, types of vehicle, and driving conditions, have significant impacts on injury severity around intersections. Most previous studies have been conducted to analyze injury severities in either teenage driver-involved crashes or intersection-related crashes to identify their significant contributing factors. However, few studies were performed to simultaneously formulate driver injury severity considering both aspects. In order to address this gap, drivers involved in intersection-related crashes were classified into 2 driver groups for this study—teenage drivers and adult drivers—in order to identify and extract their causal attributes for intersection-related crashes.

Previous studies have investigated the effects of various factors on driver injury severity, including driver characteristics, vehicle characteristics, and geometric characteristics, which provided valuable insights to investigate teenage driver injury severity around intersections when choosing our research methodology. Considering that the injury severity outcomes were usually classified into several categories, such as no injury, injury, and fatality, various discrete probability models have been proposed and developed to analyze contributing factors in crash severity. For example, in H. Chen et al. (2012), a logistic regression model was employed to analyze the different crash severity levels at intersections and address the related factors for the different severity levels. Ulfarsson and Mannering (2004) estimated 2 separate multinomial logit models for male and female drivers in order to explore differences in injury severity outcomes between these 2 groups. These models can be categorized into 2 major groups: ordered models and unordered ones (see Mannering and Bhat [2014] for a thorough review). The ordered models, such as the ordered probit model (Zhang et al. 2014), ordered logit models (Kaplan and Prato 2012; Theofilatos et al. 2012), etc., consider the ordering of injury outcomes from no injury to fatality. In the ordered models, variables were considered to either increase injury severity outcomes or decrease injury outcomes, which may not be suitable for non-monotonically changing severity data. For instance, if an airbag is deployed, the probability of severe injury and fatality could decline but it may increase the likelihood of minor injury resulting from airbag activation (Obeng 2008). In order to overcome the ordinal limitation in ordered models, unordered models, including the multinomial logit model (Bham et al. 2011; Tay et al. 2011; Ulfarsson and Mannering 2004), nested logit model (Savolainen and Mannering 2007), mixed logit models (F. Chen and Chen 2011; Wu et al. 2014), etc., have been widely used during the past decades. Therefore, an unordered multinomial logit model was developed in this study to identify significant causal factors in intersection-related traffic crashes for teenage drivers and adult drivers. A nested logit model and mixed logit model were also conducted and the results are discussed in Section “Model estimation results and discussion,” showing that the multinomial logit model is more suitable for this study.

**Data description**

Intersection-related crashes, defined as crashes occurring around intersections or those caused by any action or behavior of traffic units through intersections (National Safety Council 2011), were investigated in this study based on the data obtained from the NMDOT Traffic Safety Division and Division of Government Research at the University of New Mexico from 2010 to 2011. The data consist of 3 major components, including crash, vehicle, and driver records that detail information such as crash occurrence time, location, severities, environmental conditions,
geometric characteristics, weather conditions, number of vehicles involved, vehicle characteristics, driver demographic information and behavior, etc.

A total of 65,107 vehicles were recorded as intersection-related crashes in New Mexico from 2010 to 2011. Due to incomplete or obviously incorrect information in some records, 49,073 vehicle records were selected to develop the models in this study. These data were fairly evenly distributed in 2010 and 2011. Driver injury severities are classified into 3 categories: No injury, injury, and fatality. Overall, 31,191 drivers were reported as no injury, which accounts for 63.6% of the total drivers; 17,789 drivers resulted in injury, which represents 36.3%; and 93 (0.2%) drivers were killed in intersection-related crashes. The significant attributes of teenage crashes and the comparisons between teenage and adult drivers are concentrated on in this study. The NHTSA (2012) classified drivers into 7 groups based on their ages: under the age of 16, 16–20, 21–34, 35–44, 45–54, 55–64, and 65 and older. In New Mexico, the minimum age for driving is 15 years old with supervision of an approved instructor, and this supervision should last at least 6 months. Because the behavior of drivers aged 15 can be affected by supervisors, which does not reflect real characteristics of the teenage drivers themselves, this study adopts the NHTSA standard that 16- to 20-year-old drivers are defined as teenage drivers and all other drivers are considered adult drivers. Therefore, 7,056 teenage drivers, which accounts for 14.4% of total drivers, and 42,017 adult drivers (85.6% of total drivers) who were involved in intersection-related crashes were selected for this study. Although the vehicles in teenage driver–involved crashes account for only 14.4% of all vehicles involved in crashes, this is much higher than the proportion of all licensed teenage drivers (7%) according to the NMDOT records. The specific variable definitions and summary statistics are illustrated in Table 1.

### Methodology

Considering that 3 discrete severity outcomes are specified, many statistical modeling approaches can be used, such as ordered discrete probability models, which can explicitly recognize the monotonic change pattern in crash severities and unordered models, which release the strong restriction on the linear relationship between explanatory variables and independent outcomes and are more suitable for nonmonotonically changing severity data. In this study, a more commonly used unordered discrete modeling approach, the multinomial logit model, was adopted to identify contributing factors for teenage and adult drivers involved in intersection-related crashes.

#### Driver injury severity modeling

Multinomial logit models are used to analyze the relationship between significant contributing factors and driver injury severity in crashes. The probability of vehicle \( n \) with driver injury severity outcome \( i \) is defined as follows:

\[
P_{in} = P \left( U_{in} \geq U_{jn}, \forall i, j \in I, i \neq j \right),
\]

where \( U_{in} \) is the utility function determining the severity outcome, and \( I \) is the set of choice. It is assumed that a vehicle crash will result in a specific driver injury severity level with the largest \( U_{in} \). \( U_{in} \) is determined by a series of explanatory variables, \( V_{in} \), and a random component, \( \varepsilon_{in} \), which represents unobservable influences on severity outcomes:

\[
P \left( V_{in} + \varepsilon_{in} \geq V_{jn} + \varepsilon_{jn}, \forall i, j \in I, i \neq j \right).
\]

If the deterministic utility component, \( V_{in} \), has a linear-in-parameter form, the utility function can be expressed as follows:

\[
U_{in} = \beta_i \cdot X_{in} + \varepsilon_{in},
\]

where \( \beta_i \) is a set of estimable coefficients for severity outcome \( i \) and \( X_{in} \) is the exogenous explanatory variable (geometric characteristics, environmental conditions, driver demographic features and behaviors, etc.) that determines the injury severity \( i \) for vehicle \( n \). \( \varepsilon_{in} \) is normally assumed to be generalized extreme value distributed (McFadden 1981); thus, a standard multinomial logit model can be shown as

\[
P_{in} = \frac{\exp \left[ \beta_i \cdot X_{in} \right]}{\sum_{\forall I} \exp \left[ \beta_i \cdot X_{in} \right]}.
\]

#### Elasticity analysis

The developed multinomial logit model specifications and estimated model coefficients can qualitatively elaborate the impacts of significant contributing factors on driver injury severity, but they cannot interpret how changes in these explanatory variables affect severity probabilities in a quantitative manner. To address this issue, elasticity analysis is conducted to measure the magnitude of the explanatory variable changes on outcome probabilities for their marginal effect evaluation. For indicator variables (those variables coded as 0 and 1), a pseudo-elasticity can be computed by

\[
E_{P_{in}}^{\beta_k} = \frac{P_{in} \left[ \text{given} X_{nk} = 1 \right] - P_{in} \left[ \text{given} X_{nk} = 0 \right]}{P_{in} \left[ \text{given} X_{nk} = 0 \right]}.
\]

This value measures the percentage change in the severity outcome probability \( P_{in} \) when the \( k \)th indicator variable, \( X_{nk} \), switches from 0 to 1 (Washington et al. 2003).

Because the pseudo-elasticity of a specific variable in terms of a severity category is the percentage change in severity outcome probability for each observation \( n \), it is estimated by taking the average value for all observations.

#### Transferability test

The relationship between driver injury severities and their associated contributing factors may vary under different conditions. To assess the transferability and generality of the proposed model specifications, the data set used to calibrate and validate the models was divided into 2 groups in the temporal domain: 2010 and 2011 data sets. The transferability of model parameters was tested between these 2 time periods. Examination of temporal transferability ensures that the proposed model specifications are valid and applicable to forecast crash severities over
### Table 1. Variable definition and summary statistics.

| Variable                      | No injury | Injury | Fatality | Teenager | Adult | All |
|-------------------------------|----------|--------|----------|----------|-------|-----|
|                               | n        | %      | n        | %        | %     | %   |
| Severity                      |          |        |          |          |       |     |
| Crash-specific variables      |          |        |          |          |       |     |
| Day                           |          |        |          |          |       |     |
| Sunday                        | 2,284    | 60.5   | 1,481    | 39.2     | 12    | 0.3 |
| Monday                        | 4,805    | 64.0   | 2,683    | 35.8     | 15    | 0.2 |
| Tuesday                       | 5,001    | 63.6   | 2,853    | 36.4     | 15    | 0.2 |
| Wednesday                     | 4,968    | 63.4   | 2,853    | 36.4     | 15    | 0.2 |
| Thursday                      | 5,104    | 65.3   | 2,703    | 34.6     | 9     | 0.1 |
| Friday                        | 5,720    | 64.2   | 3,171    | 35.6     | 18    | 0.2 |
| Saturday                      | 3,309    | 61.7   | 2,045    | 38.1     | 11    | 0.2 |
| Crash analysis                |          |        |          |          |       |     |
| Motorcycle involved           | 12       | 23.1   | 394      | 73.9     | 16    | 3.0 |
| Truck involved                | 694      | 73.1   | 242      | 25.5     | 14    | 1.5 |
| Time period                   |          |        |          |          |       |     |
| Morning (5 a.m. to 12 a.m.)   | 11,543   | 64.1   | 6,436    | 35.7     | 37    | 0.2 |
| Afternoon (1 p.m. to 4 p.m.)  | 10,869   | 63.7   | 6,182    | 36.2     | 19    | 0.1 |
| Evening (5 p.m. to 8 p.m.)    | 7,179    | 63.3   | 4,146    | 36.5     | 24    | 0.2 |
| Night (9 p.m. to 4 a.m.)      | 1,600    | 60.7   | 1,025    | 38.9     | 13    | 0.5 |
| Weather                       |          |        |          |          |       |     |
| Clear                         | 29,126   | 63.3   | 16,826   | 36.5     | 88    | 0.2 |
| Rain                          | 1,100    | 65.1   | 589      | 34.9     | 0     | 0.0 |
| Snow                          | 651      | 77.0   | 195      | 23.0     | 0     | 0.0 |
| Fog                           | 36       | 60.0   | 20       | 33.3     | 4     | 6.7 |
| Dust                          | 27       | 61.4   | 17       | 38.6     | 0     | 0.0 |
| Wind                          | 251      | 63.7   | 142      | 36.0     | 1     | 0.3 |
| Light                         |          |        |          |          |       |     |
| Dark                          | 4,137    | 62.2   | 2,490    | 37.4     | 27    | 0.4 |
| Dawn                          | 984      | 64.3   | 543      | 35.5     | 3     | 0.2 |
| Daylight                      | 26,070   | 63.8   | 14,756   | 36.1     | 63    | 0.2 |
| Urban                         | 1,295    | 56.3   | 976      | 42.5     | 28    | 1.2 |
| Population group              |          |        |          |          |       |     |
| Population group 1 (< 25,000) | 7,676    | 64.5   | 4,178    | 35.1     | 46    | 0.4 |
| Population group 2 (25,000–50,000) | 10,191 | 64.7   | 5,536    | 35.2     | 18    | 0.1 |
| Population group 3 (> 50,000) | 13,324   | 62.2   | 8,075    | 37.7     | 29    | 0.1 |
| Curve                         | 1,710    | 70.6   | 708      | 29.2     | 4     | 0.2 |
| Grade                         |          |        |          |          |       |     |
| Level                         | 27,552   | 63.5   | 15,766   | 36.4     | 81    | 0.2 |
| Hillcrest                     | 766      | 69.8   | 331      | 30.2     | 0     | 0.0 |
| On grade                      | 2,793    | 62.6   | 1,656    | 37.1     | 12    | 0.3 |
| Dip                           | 80       | 69.0   | 36       | 31.0     | 0     | 0.0 |
| Road surface condition        |          |        |          |          |       |     |
| Dry                           | 28,741   | 63.2   | 16,638   | 36.6     | 88    | 0.2 |
| Wet                           | 1,680    | 64.4   | 924      | 35.6     | 4     | 0.2 |
| Snow                          | 363      | 77.2   | 107      | 22.8     | 0     | 0.0 |
| Ice                           | 350      | 83.3   | 69       | 16.4     | 1     | 0.2 |
| Loose material                | 33       | 62.3   | 20       | 37.7     | 0     | 0.0 |
| Slush                         | 24       | 68.6   | 11       | 31.4     | 0     | 0.0 |
| Paved road                    | 31,064   | 63.5   | 17,742   | 36.3     | 93    | 0.2 |
| Traffic controls              |          |        |          |          |       |     |
| No control                    | 5,410    | 63.0   | 3,153    | 36.7     | 24    | 0.3 |
| Stop/yield sign               | 6,808    | 67.7   | 3,214    | 32.0     | 32    | 0.3 |
| Signal control                | 18,926   | 62.3   | 11,414   | 37.6     | 37    | 0.1 |
| Railroad gate                 | 47       | 85.5   | 8        | 14.5     | 0     | 0.0 |
| Number of lanes per direction |          |        |          |          |       |     |
| One lane                      | 8,380    | 65.7   | 4,346    | 34.1     | 36    | 0.3 |
| Two lanes                     | 12,459   | 64.1   | 6,954    | 35.8     | 31    | 0.2 |
| Multiple lanes                | 10,332   | 61.4   | 6,489    | 38.5     | 26    | 0.2 |
| Vehicle-specific variables    |          |        |          |          |       |     |
| Number of vehicles            |          |        |          |          |       |     |
| Single vehicle                | 84       | 70.6   | 33       | 27.7     | 2     | 1.7 |
| Two vehicles                  | 28,776   | 66.6   | 14,375   | 33.3     | 77    | 0.2 |
| Multiple vehicles             | 2,331    | 40.7   | 3,381    | 59.0     | 14    | 0.2 |

(Continued)
time. Likelihood ratio tests are applied to determine whether the estimated parameters are stable as follows (Washington et al. 2003):

\[
\chi^2 = -2 [ LL(\beta_A) - LL(\beta_{2010}) - LL(\beta_{2011}) ] ,
\]

where \( LL(\beta_A) \) is the log likelihood at convergence of the model developed with the data from both time periods, \( LL(\beta_{2010}) \) is the log likelihood at convergence of the model using the 2010 data, and \( LL(\beta_{2011}) \) is the log likelihood at convergence of the model with the 2011 data. In this test, 2 additional models were estimated based on 2 separate data sets with the same variables used in the full-data model. This statistic is \( \chi^2 \) distributed with degrees of freedom equal to the summation of the number of estimated coefficients in the 2010 and 2011 models minus the number of coefficients in the overall model.

**Model estimation results and discussion**

In order to identify and analyze the significant contributing factors influencing driver injury severity, 2 multinomial logit models were developed and estimated for teenage and adult drivers. Elasticity analysis was conducted to quantitatively interpret the coefficients estimated in those models and their impacts on severity outcomes. Transferability tests were performed to examine the transferability of the teenage driver injury severity model. The statistical software package Python Biogem was used to estimate the model parameters and calculate the average pseudo-elasticity of each variable. The results are shown in Tables 2 to 5 including coefficient estimates, \( t \)-statistics, coefficient significance levels, and average pseudo-elasticity values with respect to a specific severity category. All coefficients were significantly different from zero at the significance level of \( P = .05 \) in Tables 2 and 4. The average pseudo-elasticities are presented in Tables 3 and 5.

**Adult driver model**

The estimation results of the multinomial logit model for adult drivers are presented in Table 2, and the corresponding pseudo-elasticities are shown in Table 3. As we can see in Table 2, the

| Variable description | Coefficient | SE | T-ratio | P-value |
|-----------------------|-------------|----|--------|---------|
| Constant (N)          | 2.39        | 0.56 | 4.28   | .00     |
| Constant (I)          | 2.11        | 0.56 | 3.77   | .00     |
| Motorcycle involved (I) | 1.82      | 0.11 | 16.12  | .00     |
| Motorcycle involved (F) | 4.09      | 0.31 | 13.08  | .00     |
| Truck involved (F)    | 1.84        | 0.33 | 5.67   | .00     |
| Dark (F)              | 0.87        | 0.25 | 3.47   | .00     |
| Urban (N)             | 1.87        | 0.26 | 7.21   | .00     |
| Urban (I)             | 1.44        | 0.26 | 5.57   | .00     |
| Population group 1 (N) | 0.08   | 0.03 | 2.52   | .01     |
| Population group 3 (N) | -0.13  | 0.02 | 5.29   | .00     |
| Hillcrest (N)         | 0.25        | 0.07 | 3.46   | .00     |
| Signal control (F)    | -0.99       | 0.25 | -3.96  | .00     |
| Two vehicles (F)      | -0.79       | 0.29 | -2.78  | .01     |
| Passenger car (N)     | -0.06       | 0.02 | -2.65  | .01     |
| Overtaking (N)        | 0.61        | 0.18 | 3.44   | .00     |
| Right turn (N)        | 0.75        | 0.05 | 16.01  | .00     |
| Seat belt (F)         | -1.29       | 0.48 | -2.72  | .01     |
| Alcohol impaired (I)  | 0.73        | 0.08 | 6.66   | .00     |
| Alcohol impaired (F)  | 1.78        | 0.41 | 4.35   | .00     |
| Female (N)            | -0.20       | 0.02 | -9.37  | .00     |
| Log likelihood with constant only | -46.16 |    |        |         |
| Log likelihood at convergence | -27.597 |    |        |         |
| Likelihood ratio index, \( \rho^2 \) | 0.40 |    |        |         |

Letters in parentheses indicate variable coefficients are significant specific to (N) no injury, (I) injury, and (F) fatality. For the constants, the fatality outcome has, without loss of generality, its coefficient normalized to 0.

Table 1. Continued

| Variable                      | No injury | Injury | Fatality | Teenager | Adult | All |
|-------------------------------|-----------|--------|----------|----------|-------|-----|
|                               | \( n \)  | %  | \( n \) | %  | \( n \) | %  | \( n \) | %  | \( n \) | %  | \( n \) | %  |
| Vehicle type                  |           |      |          |          |       |     |          |      |          |      |       |     |
| Passenger car                 | 17,597    | 62.8 | 10,383   | 37.1     | 42    | 0.1 | 17.2     | 82.8 | 26,883   |      |       |     |
| Truck                         | 6,755     | 65.9 | 3,479    | 33.9     | 22    | 0.2 | 11.4     | 88.6 | 10,256   |      |       |     |
| Tractor                       | 351       | 73.4 | 121      | 25.3     | 6     | 1.3 | 0.8      | 99.2 | 478      |      |       |     |
| Van                           | 6,309     | 62.9 | 3,700    | 36.9     | 23    | 0.2 | 10.7     | 89.3 | 10,032   |      |       |     |
| Bus                           | 179       | 62.8 | 106      | 37.2     | 0     | 0   | 2.5      | 97.5 | 285      |      |       |     |
| Driver-specific variables     |           |      |          |          |       |     |          |      |          |      |       |     |
| Action                        |           |      |          |          |       |     |          |      |          |      |       |     |
| Straight                      | 22,399    | 62.1 | 13,628   | 37.8     | 65    | 0.2 | 13.7     | 86.3 | 36,092   |      |       |     |
| Overtaking                    | 152       | 75.2 | 50       | 24.8     | 0     | 0   | 16.8     | 83.2 | 202      |      |       |     |
| Right turn                    | 2,516     | 77.6 | 726      | 22.4     | 2     | 0.1 | 13.2     | 86.8 | 3,244    |      |       |     |
| Left turn                     | 4,918     | 62.6 | 2,908    | 37.1     | 26    | 0.3 | 8.2      | 91.8 | 7,847    |      |       |     |
| U-turn                        | 65        | 73.0 | 24       | 27.0     | 0     | 0   | 14.6     | 85.4 | 89       |      |       |     |
| Slowing                       | 798       | 64.6 | 437      | 35.4     | 0     | 0   | 14.8     | 85.2 | 1,235    |      |       |     |
| Backing                       | 348       | 95.6 | 16       | 4.4      | 0     | 0   | 12.4     | 87.6 | 364      |      |       |     |
| Seat belt                     | 31,092    | 63.7 | 17,634   | 36.1     | 85    | 0.2 | 14.4     | 85.6 | 48,811   |      |       |     |
| Alcohol impaired              | 298       | 46.7 | 331      | 51.9     | 9     | 1.4 | 6.9      | 93.1 | 638      |      |       |     |
| Drug impaired                 | 91        | 56.9 | 69       | 43.1     | 0     | 0   | 8.1      | 91.9 | 160      |      |       |     |
| Female                        | 14,764    | 61.4 | 9,232    | 38.4     | 31    | 0.1 | 15.0     | 85.0 | 24,027   |      |       |     |
| Driver residence              | 3,791     | 64.4 | 2,072    | 35.2     | 27    | 0.5 | 11.1     | 88.9 | 5,890    |      |       |     |
Table 3. Average pseudo-elasticity of each variable for adult driver model.

| Variable                     | Pseudo-elasticities (%) |
|------------------------------|-------------------------|
| Crash-specific variables     |                         |
| Motorcycle involved          | 65.8                    |
| Truck involved               | -0.8                    |
| Dark                         | -0.2                    |
| Urban                        | 20.3                    |
| Population group 1           | 2.8                     |
| Population group 3           | -4.5                    |
| Hillcrest                    | 8.9                     |
| Signal control               | 0.2                     |
| Vehicle-specific variables   |                         |
| Two vehicles                 | 0.2                     |
| Passenger car                | -2.0                    |
| Driver-specific variables    |                         |
| Overtaking                   | 20.6                    |
| Right turn                   | 25.2                    |
| Seat belt                    | 0.5                     |
| Alcohol impaired             | -28.4                   |
| Female                       | -6.9                    |

Table 4. Driver injury severity model estimation for teenage drivers.

| Variable description | Coefficient | SE | T-ratio | P-value |
|----------------------|-------------|----|---------|---------|
| Constant (N)         | 8.22        | 0.72 | 11.42   | .00     |
| Constant (I)         | 5.94        | 0.45 | 13.22   | .00     |
| Motorcycle involved  | -1.66       | 0.28 | -5.86   | .00     |
| Night (N)            | -0.25       | 0.09 | -2.82   | .00     |
| Urban (N)            | 0.32        | 0.12 | 2.62    | .01     |
| Hillcrest (N)        | 0.52        | 0.20 | 2.64    | .01     |
| Paved road (N)       | -1.28       | 0.56 | -2.29   | .02     |
| Multiple lanes (N)   | -0.20       | 0.06 | -3.02   | .00     |
| Vehicle-specific variable |          |     |         |         |
| Multiple vehicles (N) | -1.05      | 0.08 | -12.98  | .00     |
| Driver-specific variables |        |     |         |         |
| Straight (I)         | 0.51        | 0.07 | 7.81    | .00     |
| Left turn (N)        | -0.70       | 0.08 | -8.83   | .00     |
| Alcohol impaired (F) | 3.48        | 1.11 | 3.14    | .00     |
| Female (N)           | -0.17       | 0.05 | -3.39   | .00     |
| Log likelihood with constants only | -7.752  |    |         |         |
| Log likelihood at convergence | -4.622  |    |         |         |
| Likelihood ratio index, $\rho^2$ | 0.43 | | | |

*Letters in parentheses indicate variable coefficients are significant specific to (N) no injury, (I) injury, and (F) fatality. For the constants, the fatality outcome has, without loss of generality, its coefficient normalized to 0.*

Table 5. Average pseudo-elasticity of each variable for teenage driver model.

| Variable                     | Pseudo-elasticities (%) |
|------------------------------|-------------------------|
| Crash-specific variables     |                         |
| Motorcycle involved          | -58.8                   |
| Night                        | -8.8                    |
| Urban                        | 13.4                    |
| Hillcrest                    | 17.0                    |
| Paved road                   | -25.6                   |
| Multiple lanes               | -6.9                    |
| Vehicle-specific variable    |                         |
| Multiple vehicles            | -37.4                   |
| Driver-specific variables    |                         |
| Straight                     | -16.1                   |
| Left turn                    | -24.2                   |
| Alcohol impaired             | -2.2                    |
| Female                       | -5.9                    |

likelihood ratio index, $\rho^2$, is equal to 0.40, which shows a reasonable goodness-of-fit of the proposed model to the data. The constant specific to fatality is assumed to be equal to 0. The constants in the utility function reflect the potential severity probability without taking into consideration any factors affecting severity outcomes captured in the model. As shown in Table 2, the values of constants specific to no injury and injury are estimated as 2.39 and 2.11, respectively, which verify that drivers are more likely to experience no injury and less likely to have fatal injuries given a crash occurrence without considering any other factor.

In terms of contributing factor identification, a wide variety of variables is found to significantly influence driver injury severity levels with a total of 18 coefficients estimated. For example, the coefficients of the variable motorcycle involved specific to fatality and injury are 4.09 and 1.82, respectively, and they are shown in Table 2, illustrating that adult drivers in crashes involving motorcycles are more likely to suffer more severe injury outcomes around intersections. This finding can be further verified by their pseudo-elasticities in Table 3. Relative to driver injuries in non-motorcycle-involved crashes, on average, there are 111.2 and 1944.6% increases in the likelihood of driver injury and fatality, respectively, for crashes involving motorcycles. This reflects the higher severity levels of driver injuries in motorcycle-involved crashes, which is consistent with conclusions from the previous studies (Chang and Yeh 2006; Pai 2009). The variable truck involved, indicating whether trucks are involved in a crash or not, has shown a result similar to that for drivers in motorcycle-involved crashes. Relative to non-truck-involved crashes, the probability of drivers being fatally injured in truck-involved crashes is 483.1% higher, indicating that truck involvement dramatically increases the probability of fatality for adult drivers in intersection-related crashes. This result is consistent with the statistical data that large trucks account for 8% of all vehicles involved in fatal crashes, though they made up only 4% of total registered vehicles in the United States in 2010 (NHTSA 2012). Due to inferior braking capability, slow acceleration, the large turning radii associated with trucks, and control interruption to traffic flow progression at intersections, special research efforts should be undertaken to address truck-involved severe crashes around intersections.

Similar analyses can be conducted for the other variables. The variable dark has a positive coefficient specific to fatality and its pseudo-elasticity is 133.7% specific to the severity outcome of fatality. This shows, relative to crashes occurring under other lighting conditions including dawn, dusk, and daylight, that unfavorable dark lighting conditions during nighttime may cause crashes to increase the probability of fatality for adult drivers by 137.9%. These findings show that, as might be expected, under dark lighting conditions, inferior visual environments and drivers’ insobriety may result in lengthened perception/reaction time that induce more severe crashes. Additionally, crashes occurring around signalized intersections have a 65.4% decrease in the probability of fatality for adult drivers relative to crashes taking place around intersections under no control, stop/yield sign control, and railroad gate control. These findings show that signal control can significantly reduce driver injury severity around intersections, though the total number...
of crashes may not noticeably decrease under these control modes.

The number of vehicles involved can also affect the severity outcomes for adult drivers in crashes occurring around intersections. The negative coefficient (−0.79) of the variable two vehicles specific to fatality indicates that the driver injury severity outcome of a 2-vehicle crash is more likely to be no injury or injury rather than fatality. Relative to single-vehicle and multiple-vehicle crashes, 2-vehicle crashes have a 54.6% decrease in driver injury severity or fatality. Because single-vehicle crashes only account for 1% of total crashes, it is safe to conclude that the probability of severely injured adult drivers would increase significantly when the number of vehicles involved in crashes increases to 3 or more. In terms of vehicle type, adult drivers of passenger cars have a 3.6% increase in the probabilities of injury and fatality relative to drivers of trucks, tractors, buses, etc.

As might be expected, using a seat belt can significantly decrease the probability of severe injuries for adult drivers. The pseudo-elasticity of the variable seat belt indicates that adult drivers using seat belts have a 74.2% decrease in the probability of fatality. When adult drivers involved in crashes are identified as under the influence of alcohol, their effects on different crash severity categories are significant. As shown in Table 2, the coefficients of the variable alcohol impaired specific to fatality and injury are 1.78 and 0.73, respectively. Its pseudo-elasticities specific to fatality and injury are 324.4 and 48.8% as shown in Table 3, showing that relative to non-alcohol-impaired drivers involved in crashes, the probabilities of fatality and injury for alcohol-impaired drivers increased by 324.4 and 48.8%, respectively. These findings are consistent with previous studies that showed the devastating impacts of alcohol on traffic crashes (Hu and Donnell 2010; Traynor 2005; Zador 1991). The variable female has a negative coefficient specific to no injury and its pseudo-elasticity is equal to 13.1% specific to the severity outcomes of injury and fatality. This shows that there is a 13.1% increase in the likelihood of injury and fatality for female adult drivers when they are involved in crashes around intersections relative to males.

Teenage driver model

The crash severity model specifications for teenage drivers are presented in Table 4, and the corresponding average pseudo-elasticities with respect to 3 severity categories are illustrated in Table 5 to better interpret the quantitative impacts of each factor on severity outcomes. As shown in Table 4, the likelihood ratio index, $\hat{\rho}^2$, is equal to 0.43, indicating an acceptable overall model fit. Because the constant specific to fatality is normalized to zero, comparisons between the constants specific to injury (5.94 in Table 4) and no injury (8.22) show that given a crash occurrence for teenage drivers, they tend to suffer no injury rather than injury or fatality without considering any other contributing factors. Compared to the adult driver model, there are certain differences in significant variables and their pseudo-elasticities for the teenage driver model shown in Tables 4 and 5. Some variables become insignificant, such as truck involved, seat belt, dark, overtaking, passenger car, population group 1, population group 3, right turn, and signal control. Some additional variables are found to significantly influence teenage driver injury severities, including left turn, night, multiple vehicles, multiple lanes, paved road, and straight.

The variable night is found to significantly influence teenage driver injury severity in crashes. Relative to crashes occurring during the morning, afternoon, and evening, nighttime intersection-related crashes have a 16.7% increase in the probabilities of injurious and fatal severity outcomes for teenage drivers. This finding is consistent with the statistical data that only 14% of the miles driven by 16- to 17-year-old drivers occurred between 9 p.m. and 6 a.m., but this time period accounted for 32% of fatal crashes in this age group (Williams 2007). Special care must be taken to address nighttime teenage driving issues, such as nighttime driving restriction programs.

Similar analyses can be conducted for the variables paved road, multiple lanes, and multiple vehicles. Relative to unpaved roadways, the probability of having teenage driver injuries and fatalities in crashes increases by 167.7% on paved roadways. These results imply that under favorable driving conditions, such as paved roadways with multiple lanes, teenage drivers tend to speed up and are involved in more severe crashes around intersections on average. When the number of lanes increases, roadway segments are capable of carrying more traffic under prevailing conditions. The model estimation results indicate that relative to one-lane and 2-lane (per direction) roadways, the probability of having injurious and fatal crashes is 13.2% higher for teenage drivers on roadways with 3 lanes or more. Additionally, relative to single-vehicle and 2-vehicle crashes, there is a 78.9% increase in the likelihood of injuries and fatalities for teenage drivers in crashes in which more than 2 vehicles are involved.

The coefficient of the variable left turn specific to no injury is −0.70 and its pseudo-elasticities specific to no injury is −24.2% and specific to injury and fatality are 52.3%. Therefore, vehicle left turn movements potentially increase the probability of having injurious and fatal crashes by 52.3% for teenage drivers around intersections relative to other vehicle actions, including overtaking/passing, right-turning, U-turning, slowing, and backing. These results underscore the important fact that teenage drivers have insufficient experience to handle complex left turn movements, and their inexperience may result in more severe driver injury and fatality in crashes. More training is desirable for teenage drivers to enhance their cognitive skills for safe left turn movements. However, mixed impacts are identified for the vehicle action variable straight on driver injury severities. Its pseudo-elasticities specific to injury is 39.6% and specific to fatality is −16.1%, showing that relative to the other vehicle actions, there is a 39.6% increase in the probability of injury and a 16.1% decrease in the probability of fatality for teenage drivers going straight through intersections. This could be explained by teenage drivers using less caution when going straight due to comfortable driving conditions. As a result, they are more likely to be involved in injurious crashes, but they can promptly respond to abnormal situations to avoid fatal collisions.

Table 6 shows the similarities and differences between adult and teenage driver models in the effects of several representative, significant variables on crash severity probabilities, including
motorcycle involved, urban, alcohol impaired, and female. As can be expected, when drivers are identified under the influence of alcohol in crashes, the differential effects on driver injury severity outcomes are significant for adult and teenage drivers. Relative to non-alcohol-impaired adult drivers, alcohol-impaired adult drivers have a 324.4% higher probability of fatality. However, when the alcohol-impaired drivers are 20 years old or younger, they have a 3,075.2% increase in the probability of fatality relative to non-alcohol-impaired teenage drivers. These differences show that the adverse effect of alcohol involvement on injury severity is more significant for teenagers than for adult drivers. These results also underscore the significant and complex impacts that driver age group (adult vs. teenage in this study) have on injury outcomes, especially for fatal injuries.

Table A1 (see online supplement) explicitly highlights the differences between the adult and teenage driver models. A number of variables are found to be significant in the adult driver model but not in the teenage driver model. Additionally, some variables are found to be significant in the teenage driver model but not in the adult driver model. Their effects on overall injury severities are summarized, which also show the noticeable differences between adult and teenage driver crash severities.

### Teenage driver model specification and transferability test

In this study, multinomial logit models were developed based on a major restrictive assumption that the unobserved effects associated with some severity categories are independent of the effects in other categories. If this independent and irrelevant alternatives property of multinomial logit models cannot be met, potentially serious model specification errors may result. In this study, some injury categories (for example, injury and fatality) may share certain unobserved effects to violate the logit model independent and irrelevant alternatives assumption. Under such a condition, a multinomial logit model structure cannot effectively handle correlation among unobserved effects across various severity categories. Therefore, a nested logit model structure should be used. Previous injury severity studies have reported conflicting findings: some found significant correlation among unobserved effects crossing discrete outcome categories (Peek-Asa et al. 2010; Schneider et al. 2009), and another verifies their independence (Ulfarsson and Mannering 2004). Moreover, the mixed logit model, which is developed based on the multinomial logit model, is widely used due to its capability of explaining heterogeneous impacts of variables on injury outcomes. In the mixed logit model, the coefficients of variables are allowed to vary randomly across all observations (F. Chen and Chen 2011; Milton et al. 2008). This motivates us further to explore and examine the appropriateness of multinomial logit model structures to fit the crash data in this study.

To examine the other model structures, 2 nested logit models and one mixed logit model were estimated for the teenage driver model. For the nested logit models, the first alternative specifies no injury as a category and has injury and fatality outcomes included in a single nest by assuming that injury and fatality outcomes share unobserved effects that are associated with serious crashes. The second specifies fatality as an outcome alone and has no injury and injury in a nest by assuming that these 2 outcomes share unobserved effects possibly associated with minor crashes. These 2 nested logit models were estimated and their logsum or inclusive value parameters reflecting correlation among unobserved effects within each nest were not statistically different from 1, showing the standard logit model is a reasonable specification and no nesting is needed (Chang and Yeh 2006; Pai 2009). For the mixed logit model, no random coefficients were found, indicating that all coefficients for significant variables are fixed across all teenage drivers. Then the mixed logit model was reduced to the standard multinomial logit model. Therefore, the multinomial logit model was more suitable for identifying contributing factors for teenage driver injury severities in this study.

Another model specification issue was examined to ensure its transferability across 2 sub-data sets temporally. The data used to estimate the teenage driver injury severity model were divided into 2 subsamples—2010 and 2011 data sets—to test the stability of the estimated model coefficients. Based on the same variables used in the full-data model as shown in Tables 4 and 5, 2 more models were developed and estimated for each sub-data set. The likelihood ratio test was performed to statistically verify whether the estimated model coefficient parameters were stable based on Eq. (6). As shown in Table A2 (see online supplement), the loglikelihood at convergence of each model was calculated and \( \chi^2 \) was equal to 12 with 11 degrees of freedom. This is less than the critical value of 19.68 at a 95% confidence level, indicating that the null hypothesis that the coefficients are the same across the sub-data sets cannot be rejected at a 95% confidence level. Therefore, based on the model transferability test results, we can conclude that the teenage driver injury severity model is stable temporally across the data and its coefficients are transferable across years.

Although teenage drivers account for only 7% of all licensed drivers in New Mexico, they are involved in 14.4% of all crashes (NMDOT 2010). Moreover, teenage drivers are more likely to be involved in more severe incapacitating and fatal crashes. Many countermeasures, such as the graduated driver licensing program, have been developed to address this problem. However,
little attention was paid to various contributing factors increasing the severity of teenage driver–involved crashes around intersections. This article developed 2 multinomial logit models for teenage drivers and adult drivers to explore the impacts of their different characteristics on intersection-related driver injury severity. Statewide intersection-related traffic crash data in New Mexico from 2010 to 2011 were used for model estimation in this study. Driver injury severities were classified into 3 categories: no injury, injury, and fatality. The pseudo-elasticity of each variable in those models was estimated to measure the magnitude of the influence of variables on the severity probabilities. The likelihood ratio test was performed to examine the temporal transferability of the teenage driver model.

Model specifications and estimation results indicate that a combination of vehicle dynamics, roadway geometric features, weather conditions, and driver characteristics significantly affected injury severity outcomes of crashes around intersections for both adult and teenage drivers. The differences between the factors determining teenage driver injury severity and adult driver injury severity are significant even for the variables found to be significant in both models. For instance, when drivers are identified as under the influence of alcohol in crashes, the differential effects on driver injury severity outcomes are significant for adult and teenage drivers. Relative to non-alcohol-impaired adult drivers, alcohol-impaired adult drivers have a 324.4% higher probability of fatality. However, when the alcohol-impaired drivers are 20 years old or younger, they have a 3,075.2% increase in the probability of fatality relative to non-alcohol-impaired teenage drivers. These differences show that the adverse effect of alcohol involvement on injury severity is more significant for teenage drivers than for adult drivers. Similar analyses can be conducted for the other variables found to be significant in both models to distinguish the magnitude of their impacts on driver severity outcomes.

Furthermore, a number of variables were found to be significant in either the adult driver model or the teenage driver model but not both. For instance, the variable left turn is significant in the teenage driver model but not in the adult driver model, and its estimation results indicate that vehicle left turn movements potentially increase the probability of having injurious and fatal crashes by 52.3% for teenage drivers around intersections relative to other vehicle actions, including overtaking/passing, right-turning, U-turning, slowing, and backing. These results underscore the important fact that teenage drivers have insufficient experience to handle complex left turn movements and may cause more severe crashes. More training is desirable for teenage drivers to enhance their cognitive skills for safe left turn movements. On the other hand, the variable seat belt is significant in the adult driver model, and using seat belts decreases their probability of fatality by 74.2%. However, seat belts are not significant in the teenage driver model. This could be attributable to the fact that it is only a short time period for teenage drivers passing the educational and practical driving examination so that seat belt wearing regulations are well complied with. Therefore, this variable will not play a critical role in determining driver injury severity in crashes.

The significant differences between adult and teenage driver injury severities in intersection-related crashes underscore the complex impacts that driver age group (adult vs. teenage in this study) has on driver injury outcomes. Although some fundamental analyses were conducted in this study, additional research is desirable to further qualify the intersection between teenage driver behaviors and crash-contributing factors such as geometrics, vehicle dynamics, environmental conditions, etc., for better teenage driver crash formulation and analyses. Moreover, additional data collection with more specific variables regarding signal control may enable in-depth research for a better understanding of teenage driver responses in intersection-related crashes to develop more effective countermeasures to substantially reduce teenage driver injury severities.

### Disclaimer

The results of this article reflect the views of the authors and do not necessarily reflect the official views of the NMDOT or UNM.

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