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# Factors associated with driver injury severity of lane changing crashes involving younger and older drivers

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ABSTRACT

Lane change maneuvers can be a difficult driving task for many drivers, particularly, younger and inexperienced drivers and older drivers. Frequent and improper lane changing has a substantial effect on both traffic operations and safety. This study investigates the factors that contribute to the injury severity of crashes resulting from improper lane change maneuvers involving younger and older drivers in Alabama. Crash data for the study was obtained from the Critical Analysis Reporting Environment (CARE) system developed by the Center for Advanced Public Safety at the University of Alabama. Preliminary data analysis showed that younger drivers were responsible for about 63.1 % of the crashes. Random logit with heterogeneity in means models were developed to identify significant crash factors that were associated with the crash outcomes. The results show that younger male drivers were more likely to be severely injured in lane changing crashes whereas older male drivers were less likely to be severely injured. The results further show that younger drivers were more likely to sustain a major injury on six-lane highways whereas older drivers sustained major injuries from overtaking maneuvers on two-lane highways. It was further found that while younger drivers got into major injury crashes under daylight conditions, older drivers were more likely to be involved in major injury crashes under dark/unlit lighting conditions. Improper lane changing constitutes some form of aggressive driving which needs to be addressed considering that many lives are lost annually from the practice. The findings from this study may be used by road safety advocates and practitioners to identify what and how to target crash countermeasures to the younger and older driver population groups in the state.

## 1. Introduction

Lane changing maneuvers can be a difficult driving task for many drivers. Frequent and improper lane changing has a substantial effect on both traffic operations and safety. Even though lane changing is a fundamental task during driving, decisions regarding whether (and when) to change lanes require operational and tactical processing (Blower and Kostyniuk, 2007). The decision to change lanes could either be mandatory (where a driver must change lane to follow a path to a specific destination) or discretionary (where a driver changes lane to improve his or her driving condition) (Gipps, 1986). Lane changing can pose a significant hazard for many drivers as the maneuver requires interrupting the flow of traffic, and also requires that drivers have the cognitive ability to quickly gather and process information about the safety and timeliness of the process (Antin et al., 2017). Lane changing behavior and style may be linked to many factors such as traffic condition, roadway geometry, roadway condition, and driver personality and demographic characteristics. For instance, while some drivers perform lane change with improper spacing and aggressively cut off a trailing vehicle in the destination lane, others perform lane changes much slower. Antin et al. (2017) observed that for both uninterrupted and interrupted lane changes, many drivers, regardless of age, fail to make over the shoulder and side mirror glances before initiating the lane change maneuver. From the 100-Car naturalistic driving study, Dingus et al. (2006) assessed driver behaviors that contribute to lane change crashes and near-crashes. They found that over 80 % of the drivers used their turn signals during planned left-lane change and only 24 % used their turn signals during unplanned left-lane changes.

Lane changing is a complex driving task that requires some level of experience. Further, the ability to safely change lanes may be affected by drivers' perception of risk. Different types of drivers have different perceptions and reactions to different factors such as road environment.

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As such, they have different lane changing behaviors. It has been observed that most at-fault drivers in lane change crashes do not attempt an avoidance maneuver, indicating that they are often unaware of the presence of any crash hazards (Chovan et al., 1994; Tijerina et al., 1999). Knipling (1993) specifically found that about three-quarters of lane change or merge crashes involve the failure of drivers to recognize potential crash hazards prior to the crash. Studies have shown that older drivers have more difficulty with lane change maneuvers compared to younger drivers and are consequently at greater risk of related crashes (McGwin and Brown, 1999; Chandraratna and Stamatiadis, 2003). Specifically, Eby et al. (1998) and Morgan and King (1995) observed that a decline in the cognitive ability among older driver populations affect their decision-making process during lane changes. They also found that drivers' ability to scan for visual hazards and the need for glances that require a large range of motion may be limited for older drivers. Di Stefano and Macdonald (2003) found older drivers to be 1.5 times more likely to be involved in a lane change crash compared with middle-aged drivers. Antin et al. (2017) observed that older drivers were more likely to activate their turn signals during lane change maneuvers but were also more likely to cut off another vehicle compared to younger and middle-aged drivers. Shawky (2020) investigated the factors that influence crashes involving lane change maneuvers where female drivers, young drivers, and drivers with low driving experience were found to record a high number of lane change crashes compared to other crashes. Previous studies have found that the driving characteristics of the younger driver population are in many ways similar to the older population. For instance, younger driver crashes have been linked to cognitive processes such as underestimation or overestimation of driving abilities and skills as well as the lower perception of risk (Tränkle et al., 1990; Deery, 1999; Teese and Bradley, 2008; Hatfield and Fernandes, 2009; White et al., 2011). Other studies have shown that young and inexperienced drivers are prone to errors that increase their likelihood of getting into road crashes (e.g. Clarke et al., 2005; Groeger, 2006; Shi et al., 2010).

Generally, under low traffic density, as it is in many rural areas, drivers have little need for lane changes. However, under high traffic density conditions especially in urban areas, drivers have increased need but little opportunity to execute lane changes. Crashes that occur as a result of improper lane changing often involve multiple vehicles and may lead to severe injuries and major damage to vehicles. Sen et al. (2003) estimate that annually more than 250,000 crashes occur as a result of lane changing errors in the U.S. NHTSA's National Center for Statistics and Analysis (NCSA) conducted the National Motor Vehicle Crash Causation Survey (NMVCCS) of crashes with focus on the factors related to pre-crash events involving light passenger vehicles and found lane change to account for 2.1 % of the movement of a vehicle immediately before the occurrence of the critical event that made the crash imminent (NHTSA, 2008). Efforts to reduce human error in crash causation have led to the development of vehicles equipped with technologies to assist drivers in performing driving tasks such as lane changing. For instance, the proliferation of vehicles equipped with lane departure warning and blind-spot detection technologies has the potential to significantly reduce lane changing conflicts and crashes. Highway Loss Data Institute (HLDI) (2014) projects these technologies could reach 95 % of the registered vehicle fleet between 2032 and 2048. However, presently, these advanced vehicles constitute only a small fraction of the vehicle fleet on our roads. HLDI estimated that in 2013, only about 2% of new car models had crash avoidance technologies, with the predicted proportion of some of the technologies (e.g., blind-spot monitoring) reaching about 30 % by 2022 (HLDI, 2018). So, while efforts are being made to increase the market share of newer vehicles equipped with advanced safety features, there is still the need to study and implement crash countermeasures that would reduce the occurrence and severity of crashes involving the current fleet of vehicles on the road.

Considering the complexity of lane changing and the multiple factors that influence lane changing maneuvers, this study investigates the crash factors that are associated with driver injury severity outcomes of unsafe lane changing crashes. The study used police reported crash records from Alabama and included only those crashes in which the primary contributing factor was lane changing. Separate injury severity models were developed for younger and older drivers to understand how various crash factors are associated with crash outcomes. Random parameters logit with heterogeneity in means modeling approach was used to account for unobserved heterogeneity and to improve the statistical fit of the crash data, enhance the accuracy of findings and to ensure that countermeasure decisions that may be made based on the findings are accurate and reflect the actual factors that need to be targeted.

## 2. Data and empirical settings

The study was based on 2012–2016 crash data obtained from the Critical Analysis Reporting Environment (CARE) system developed by the Center for Advanced Public Safety at the University of Alabama. The database was queried to select crashes in which the primary contributing factor was unsafe lane change and involved younger drivers (defined as at-fault driver age less than 25 years based on the authors' experiential knowledge of crash patterns involving drivers in this age category in Alabama) or older drivers (defined as at-fault driver aged 65 years and older based on the National Highway Traffic Safety Administration (NHTSA) definition of older drivers) (NHTSA, 2019). Observations with missing or ambiguous values were omitted from the original dataset before performing the model estimation. This yielded a total of 18,488 crash observations. Younger drivers were involved in 11,657 (63.1 %) of these crashes and older drivers were involved in 6,831 (36.9 %) of the crashes. This study used three injury-severity categories: major injury (fatal or incapacitating injury), minor injury (non-incapacitating injury or possible injury), and no injury as done in other studies (e.g., Morgan and Mannering, 2011; Adanu et al., 2018). Table 1 shows the distribution of the injury severity categories between younger and older drivers and Table 2 presents the descriptive statistics of the explanatory variables used in estimating the models. Table 1 shows that more at-fault younger drivers were involved in injury-related lane changing crashes than older drivers. Specifically, 2.8 % of all the crashes involving younger drivers resulted in fatal or incapacitating injury compared to 1.8 % of the crashes involving older drivers.

The majority of crash observations occurred in urban areas and under clear/daylight conditions. About 21 % of the crashes involving younger drivers occurred on dark, unlit roads whereas only 10 % of such crashes involved older drivers. Over three-quarters of lane change crashes occurred within 40.2 km (25 miles) from the residence of the at-fault drivers. Interestingly, 10 % of at-fault younger drivers had no valid driving license, compared to only 2% of older drivers. Also, younger drivers were slightly more represented in crashes that occurred on two-lane roads, whereas older drivers made up a higher proportion of crashes that occurred on four-lane roads. About 52 % of at-fault younger drivers and 55 % of older drivers were males.

## 3. Methodology

The need to account for unobserved heterogeneity in crash severity studies is important in improving statistical model inference and the use

**Table 1**
Distribution of lane changing crash outcomes by driver age group.

| Severity | Younger drivers<br>Number of observations (%) | Older drivers<br>Number of observations (%) |
|---|---|---|
| Major injury | 322 (2.8 %) | 121 (1.8 %) |
| Minor injury | 1,081 (9.3 %) | 476 (7.0 %) |
| No injury | 10,254 (87.9 %) | 6,234 (91.2 %) |
| Total | 11,657 (100 %) | 6,831 (100 %) |

**Table 2**
Descriptive statistics of variables used in model estimation.

| Variables | Description | Younger Freq | (%) | Older Freq | (%) |
|---|---|---|---|---|---|
| *Lighting condition* | | | | | |
| Dark | Lighting condition at time of crash: Dark/Unlit (1=Yes, 0=No) | 2,448 | (21 %) | 682 | (10 %) |
| Clear | Lighting condition at time of crash: Daylight (1=Yes, 0=No) | 8,859 | (76 %) | 5943 | (87 %) |
| *Location characteristics* | | | | | |
| Urban area | Crash location: Urban (1=Yes, 0=No) | 0. 82 | (82 %) | 5738 | (84 %) |
| Close to home | Driver residence from crash: Less than 40.2 km (1=Yes, 0=No) | 8,861 | (76 %) | 5055 | (74 %) |
| *Manner of crash* | | | | | |
| Sideswipe | Manner of crash: Sideswipe-same direction (1=Yes, 0=No) | 5,945 | (51 %) | 3,962 | (58 %) |
| Rear end | Manner of crash: Rear end (front to rear) (1=Yes, 0=No) | 816 | (7%) | 410 | (6%) |
| Side impact | Manner of crash: Side impact (same direction) (1=Yes, 0=No) | 1,399 | (12 %) | 751 | (11 %) |
| Angle collision | Manner of crash: Same direction angle collision (1=Yes, 0=No) | 1,166 | (10 %) | 615 | (9%) |
| Rollover | Most harmful event: rollover (1=Yes, 0=No) | 117 | (1%) | 68 | (1%) |
| *Roadway characteristics* | | | | | |
| Six lanes | Number of lanes: Six lane road (1=Yes, 0=No) | 2,098 | (18 %) | 1,230 | (18 %) |
| Four lanes | Number of lanes: Four lane road (1=Yes, 0=No) | 4,896 | (42 %) | 3,279 | (48 %) |
| Two lanes | Number of lanes: Two lane road (1=Yes, 0=No) | 3,147 | (27 %) | 1,435 | (21 %) |
| Solid painted line | Opposing lane separation: Solid painted line (1=Yes, 0=No) | 4,430 | (38 %) | 2,391 | (35 %) |
| Unpaved median | Opposing lane separation: Unpaved (1=Yes, 0=No) | 2,331 | (20 %) | 1,571 | (23 %) |
| Interstate | Highway classification: Interstate (1=Yes, 0=No) | 1,632 | (14 %) | 820 | (12 %) |
| County road | Highway classification: County road (1=Yes, 0=No) | 933 | (8%) | 342 | (5%) |
| *Driver characteristics and factors* | | | | | |
| Male | Driver gender: Male (1=Yes, 0=No) | 6,062 | (52 %) | 3,757 | (55 %) |
| Normal | At-fault driver condition: Not impaired (1=Yes, 0=No) | 11,307 | (97 %) | 6,626 | (97 %) |
| Unbelted | Seatbelt use: No seatbelt (1=Yes, 0=No) | 119 | (1%) | 69 | (1%) |
| Impaired | At-fault driver condition at time of crash: driving under influence of alcohol or drug (1=Yes, 0=No) | 117 | (1%) | 68 | (1%) |
| Invalid license | Driver license status: Invalid or no license (1=Yes, 0=No) | 1,168 | (10 %) | 137 | (2%) |
| *Vehicle characteristics* | | | | | |
| SUV at fault | Causal vehicle type: Sport Utility Vehicle (SUV) (1=Yes, 0=No) | 1,749 | (15 %) | 1,161 | (17 %) |
| Sedan at fault | Causal vehicle type: Sedan (1=Yes, 0=No) | 7,694 | (66 %) | 3,620 | (53 %) |
| Sedan not at fault | Vehicle 2 (not at fault) type: Sedan (1=Yes, 0=No) | 5,829 | (50 %) | 3,347 | (49 %) |
| Trailer at fault | At-fault vehicle: Trailer (1=Yes, 0=No) | 118 | (1%) | 205 | (3%) |
| SUV not at fault | Vehicle 2 (not at fault) type: SUV (1=Yes, 0=No) | 0.17 | (17 %) | 1,093 | (16 %) |
| | | 350 | (3%) | 343 | (5%) |
| Trailer not at fault | Vehicle 2 (not at fault) type: Trailer (1=Yes, 0=No) | | | | |
| Motorbike not at fault | Vehicle 2 (not at fault) type: Motorcycle (1=Yes, 0=No) | 117 | (1%) | 68 | (1%) |
| Pickup not at fault | Vehicle 2 (not at fault) type: Pickup (1=Yes, 0=No) | 2,098 | (18 %) | 1,230 | (18 %) |

of heterogeneity models has become standard in this area of study (Behnood and Mannering, 2016; Mannering and Bhat, 2014). Heterogeneity models allow analysts to obtain better model estimates by accounting for observation-specific variations in the effects of explanatory variables (Venkataraman et al., 2014; Behnood and Mannering, 2016, 2016; Sarwar and Anastasopoulos, 2017; Zeng et al., 2017). For this study, a random parameters (mixed) logit model with heterogeneity in means is adopted to account for possible observation-specific variations.

To arrive at an estimable model, a severity function $S_{in}$ that determines the probability that driver-injury severity level $i$ will result in crash $n$ was defined as (Washington et al., 2011),

$$S_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{1}$$

Where $X_{in}$ is a vector of explanatory variable that affect driver-injury severity level k (major injury, minor injury, no injury) in crash $n$, and $\varepsilon_{in}$ is the error term which is assumed to follow an independent and identically distributed extreme value Type I distribution (McFadden, 1981).

Also, in Eq. (1), unobserved heterogeneity across crashes is accounted for by letting $\beta_n$ be a vector of estimable parameters that varies across crashes defined as (Behnood and Mannering, 2016),

$$\beta_n = b + \Theta Z_n + \varphi_n \tag{2}$$

Where $b$ is the mean parameter estimate across all crashes, $Z_n$ is a vector of explanatory variables from crash $n$ that influence the mean of $\beta_n$, $\Theta$ is a vector of estimable parameters, and $\varphi_n$ is a randomly distributed term that captures unobserved heterogeneity across crashes.

If crash-specific unobserved heterogeneity is allowed, $\beta_n$ vector is made to have a continuous density function $P(\beta_n = \beta) = f(\beta|\varphi)$, where $\varphi$ is a vector of parameters characterizing this function. Thus, the resulting random parameters multinomial logit injury-severity probabilities are (see McFadden and Train, 2000; Behnood and Mannering, 2016),

$$P_n(i) = \int \frac{exp(\beta_i X_{in})}{\Sigma\, exp(\beta_i X_{in})} f(\beta|\varphi) d\beta \tag{3}$$

Where $P_n(i)$ is the probability of injury severity $i$ in crash $n$ conditional on $f(\beta|\varphi)$. This model is estimated by simulated maximum likelihood estimation where the logit probabilities shown in Eq. (3) are approximated by drawing values of $\beta$ from $f(\beta|\varphi)$ for given values of $\varphi$. Maximum likelihood estimation of mixed logit models is computationally complex. This is because of the difficulty associated with the required numerical integration of the logit function over the distribution of random, unobserved parameters. Bhat (2003) has shown that an efficient method of drawing values to compute the logit probabilities is to use a Halton sequence approach (Halton, 1960). 500 Halton draws was used to estimate possible mixing distributions for this study and the normal probability density function was assumed for random parameters (Milton et al., 2008).

To investigate the effect of individual parameters on the injury-severity outcome probabilities, marginal effects were computed as:

$$ME_{X_{ijk}}^{P_{ij}} = P_{ij}(X_{ijk} = 1) - P_{ij}(X_{ijk} = 0) \quad (4)$$

The probabilities specific to each severity level $i$ for crash $j$, are calculated when the $k^{th}$ indicator variable, $X_{ijk}$ equals to 1 or 0, respectively. The explanatory variables included in the estimated models in this study are primarily indicator variables, hence, the marginal effects will indicate the effect of the explanatory variable increasing from a value of 0 (i.e., no effect) to 1 on the injury severity outcomes (Ulfarsson and Mannering, 2004; Chen and Chen, 2011; Washington et al., 2011).

## 4. Results

Recent studies (e.g., Behnood and Mannering, 2017; Seraneeprakarn et al., 2017; Waseem et al., 2019; Yu et al., 2020; Islam et al., 2020) have shown that mixed logit with heterogeneity in means and variances models perform better than the traditional mixed logit and mixed logit with heterogeneity in means models. In this study, none of the variables tested was found to produce a statistically significant heterogeneity in variance parameter and significant improvement in model fit statistics, hence the decision to use mixed logit with heterogeneity in means.

Upon the development of an initial injury severity model for all the lane change crashes, a likelihood ratio test (Washington et al., 2011) was used to determine whether the contributing factors of the crash injury severity have similar impacts in crashes involving both younger and older drivers. As such, the likelihood ratio test was performed to determine whether separate models should be developed for crashes involving younger drivers and older drivers. The test statistic is given by:

$$X^2 = -2[LL(\beta_T) - LL(\beta_k)], \quad (5)$$

Where $LL(\beta_T)$ is the log-likelihood value at convergence of the restricted model including all the data (younger and older drivers) with parameters constrained such that effects are homogeneous between groups, $LL(\beta_k)$ is the sum of the log-likelihood value at convergence for the unrestricted models (where parameters are free to vary among the separate younger driver and older driver models). The $X^2$ statistic is $\chi^2$ distributed with degrees of freedom ($d.o.f$) equal to the difference in parameters between the restricted and unrestricted models ($d.o.f = 19$). The resulting $X^2$ ($= 129.16$) statistic indicates whether or not the parameters for the subset data are significantly different from the model for the full-sample data. Based on the likelihood ratio test result, it was determined that the two separate severity models were justified at a 95 % confidence level.

During model estimations, variables were included in the specification if they had t-statistics corresponding to the 90 % confidence interval or above on a two-tailed t-test, and the random parameters were included if their standard deviations had t-statistics corresponding to 90 % confidence interval or above. These indicate that the means of the fixed variables and standard deviations of the random variables are significantly different from zero (with at least 90 % confidence). Model estimation results for younger and older drivers are presented in Tables 3 and 4 respectively.

In the younger driver model, the interstate crash indicator produced a random parameter that is normally distributed with a mean of -0.110 and a standard deviation of 1.622. This implies that for 47.3 % of the observations, this variable decreased the likelihood of minor injuries (increasing the likelihood of major injuries and no injuries) and for 52.7 % of the observations, this variable increased the likelihood of minor injuries. In the older driver model, two indicator variables (four-lane highway and male driver) were found to produce random parameters. The four-lane highway indicator, which was normally distributed, had a mean of -0.864 and a standard deviation of 1.975, meaning that for 33.1 % of the observed crashes, this variable decreased the likelihood of minor injuries and for 66.9 % of the crashes this variable increased the likelihood of minor injuries. For the male indicator variable (with mean of -0.557 and standard deviation of 1.991), minor injury was less likely for 39.0 % of the observed crashes and minor injury was more likely for 61.0 % of the crashes.

The models were checked for heterogeneity in means for all the variables with statistically significant random parameters. For the younger drivers model (Table 3), only one variable (an indicator variable for sideswipe collision) produced heterogeneity in the mean of the interstate random parameter variable. The negative value of 0.646 on this parameter estimate indicates a decrease in the mean of the interstate random variable. This means that lane changing activities on the

**Table 3**
Injury severity model estimation results and marginal effects for younger drivers.

| Variable | Parameter estimate | t-Statistic | Marginal effects | | |
|---|---|---|---|---|---|
| | | | Major injury | Minor injury | No injury |
| *Defined for major injury* | | | | | |
| Urban area | −1.290 | −11.18 | −0.0166 | 0.0017 | 0.0149 |
| Unbelted | 1.965 | 9.59 | 0.0045 | −0.0006 | −0.0039 |
| Sedan at fault | −0.399 | −3.55 | −0.0057 | 0.0006 | 0.0051 |
| SUV at fault | −0.684 | −3.44 | −0.0018 | 0.0002 | 0.0016 |
| Motorbike not at fault | 2.598 | 7.16 | 0.0018 | −0.0003 | −0.0015 |
| Male driver | 0.163 | 1.88 | 0.0025 | −0.0003 | −0.0015 |
| *Defined for minor injury* | | | | | |
| Rear-end collision | 0.891 | 8.38 | −0.0013 | 0.0088 | −0.0084 |
| Side impact collision | 0.389 | 3.92 | −0.0002 | 0.0044 | −0.0042 |
| Six-lane highway | −0.317 | −2.91 | 0.0001 | −0.0042 | 0.0041 |
| Pickup not at fault | −0.576 | −5.45 | 0.0003 | −0.0073 | 0.0069 |
| Impaired | 0.646 | 2.07 | −0.0001 | 0.0009 | −0.0008 |
| Clear weather condition | −0.157 | −2.13 | 0.0003 | −0.0092 | 0.0089 |
| <u>Random parameter</u> | | | | | |
| Interstate highway | −0.110 | −0.17 | −0.0004 | 0.0092 | −0.0089 |
| Standard deviation for Interstate highway (normally distributed) | 1.622 | 1.68 | | | |
| <u>Heterogeneity in means</u> | | | | | |
| Interstate highway: Sideswipe | −0.646 | −1.91 | | | |
| *Defined for no injury* | | | | | |
| Constant | 1.251 | 6.75 | | | |
| Normal | 0.604 | 3.73 | −0.0125 | −0.0441 | 0.0565 |
| Four-lane highway | 0.304 | 4.28 | −0.0020 | −0.0089 | 0.0109 |
| County road | −0.236 | −2.42 | 0.0011 | 0.0017 | −0.0028 |
| SUV not at fault | 0.543 | 5.40 | −0.0013 | −0.0067 | 0.0080 |
| Angle collision | −0.250 | −2.62 | 0.0009 | 0.0020 | −0.0029 |
| Invalid license | −0.168 | −1.76 | 0.0004 | 0.0014 | −0.0019 |
| Unpaved median | −0.210 | −2.63 | 0.0009 | 0.0034 | −0.0043 |
| Sedan not at fault | 0.474 | 6.05 | −0.0040 | −0.0180 | 0.0219 |
| *Model Statistics* | | | | | |
| Number of observations | | | | 11,657 | |
| Log-likelihood at zero | | | | −12806.52 | |
| Log-likelihood at convergence - fixed parameters | | | | −5041.3 | |
| Log-likelihood at convergence - random parameters with no heterogeneity in mean | | | | −4711.72 | |
| Log-likelihood at convergence - random parameters with heterogeneity in means | | | | −4707.94 | |
| McFadden pseudo-$\rho^2$ | | | | 0.632 | |

**Table 4**
Injury severity model estimation results and marginal effects for older drivers.

| Variable | Parameter estimate | t-Statistic | Marginal effects | | |
|---|---|---|---|---|---|
| | | | Major injury | Minor injury | No injury |
| *Defined for major injury* | | | | | |
| Urban area | −0.945 | −5.12 | −0.0087 | 0.0007 | 0.0080 |
| Unbelted | 2.069 | 4.35 | 0.0015 | −0.0002 | −0.0013 |
| Sedan at fault | −0.419 | −2.15 | −0.0028 | 0.0003 | 0.0025 |
| Motorbike not at fault | 3.628 | 8.24 | 0.0031 | −0.0002 | −0.0029 |
| Interstate highway | 0.664 | 2.60 | 0.0021 | −0.0002 | −0.0018 |
| Two-lane highway | 0.689 | 3.45 | 0.0039 | −0.0004 | −0.0036 |
| Trailer at fault | −1.110 | −2.50 | −0.0003 | 0.0001 | 0.0002 |
| *Defined for minor injury* | | | | | |
| Rear-end collision | 1.186 | 4.97 | −0.0003 | 0.0067 | −0.0064 |
| Side impact collision | 0.184 | 1.90 | −0.0001 | 0.0012 | −0.0012 |
| Close to home | 0.244 | 1.74 | −0.0002 | 0.0090 | −0.0087 |
| Solid painted line median | −0.242 | −1.71 | 0.0001 | −0.0037 | 0.0036 |
| Random parameters | | | | | |
| Four-lane highway | −0.864 | −1.42 | −0.0001 | 0.0121 | −0.0120 |
| Standard deviation for four lanes (normally distributed) | 1.975 | 2.93 | | | |
| Male driver | −0.557 | −0.84 | −0.0006 | 0.0281 | −0.0275 |
| Standard deviation for male driver (normally distributed) | 1.991 | 2.68 | | | |
| Heterogeneity in means | | | | | |
| Four-lane highway: Sideswipe | −0.960 | −2.95 | | | |
| Male driver: Sideswipe | −0.577 | −2.14 | | | |
| *Defined for no injury* | | | | | |
| Constant | 1.928 | 6.91 | | | |
| Normal | 1.195 | 4.67 | −0.0153 | −0.0529 | 0.0682 |
| Angle collision | −0.260 | −1.86 | 0.0006 | 0.0013 | −0.0020 |
| Dark lighting condition | −0.292 | −1.97 | 0.0006 | 0.0016 | −0.0022 |
| Trailer not at fault | −0.593 | −2.57 | 0.0007 | 0.0017 | −0.0023 |
| Rollover | −3.958 | −7.09 | 0.0014 | 0.0008 | −0.0023 |
| *Model Statistics* | | | | | |
| Number of observations | | | | 6,831 | |
| Log-likelihood at zero | | | | −7504.62 | |
| Log-likelihood at convergence - fixed parameters | | | | −2326.14 | |
| Log-likelihood at convergence - random parameters with no heterogeneity in mean | | | | −2134.68 | |
| Log-likelihood at convergence - random parameters with heterogeneity in means | | | | −2120.39 | |
| McFadden pseudo-$\rho^2$ | | | | 0.718 | |

interstates that resulted in sideswipe crashes had a lower likelihood of recording minor injury outcome (relative to other collision types). For the older drivers model (Table 4), the sideswipe crash indicator variable was also found to produce heterogeneity in means of the two random parameters. With respect to the four-lane random variable, the results found that the sideswipe indicator variable with a negative value of 0.960 decreased the mean, indicating that minor injury was less likely for lane changing sideswipe crashes that occurred on four-lane highways (relative to other collision types). Similarly, for the male random variable, the sideswipe variable with a negative value of 0.577 indicates a decrease in the mean, hence making minor injury outcome less likely for males involved in sideswipe lane change crashes (relative to other collision types).

For easy comparison of crash factors between younger and older drivers, the variables with similar attributes are grouped together and the marginal effects provided in Tables 3 and 4 are discussed for each group in the following subsections.

### 4.1. Driver characteristics and crash factors

The ability to successfully execute lane change depends on many factors related to the driver. The model estimation results from this study show that the male indicator variable in the younger driver model increases the likelihood of major injury by 0.025 and decreases the likelihood of minor injury and no injury by 0.0003 and 0.022, respectively. For the older driver model, male drivers had a decreased likelihood of major injury by 0.0006 and an increased likelihood of minor injury by 0.0281. Failure to use a seatbelt increases the probability of major injury by 0.0045 for younger drivers and 0.0015 for older drivers. With respect to driver condition at the time of the crash, the findings show that drivers who were not impaired i.e., not driving under the influence of alcohol or drugs decrease the likelihood of any form of injury and increase the likelihood of no injury, for both younger and older drivers. However, younger drivers who were driving under the influence of alcohol or drugs were found to have increased chances of a minor injury. Also, the likelihood of major injury and minor injury are increased by 0.0004 and 0.0014 respectively for younger drivers who did not have a valid driving license at the time of the crash.

### 4.2. Roadway characteristics

Lane changing crash outcomes on interstate highways were more likely to be severe for older drivers than younger drivers. The results show that the likelihood of interstate crash being major injury increases by 0.0021 for older drivers but decreases by 0.0004 for younger drivers. Crashes that occurred on county highways were more likely to record some form of injury when younger drivers are involved. Multi-lane highways make weaving or lane changing activities easier for drivers. In this study, it was found that lane changing crashes that occurred on four-lane highways were less likely to result in any form of injury among younger drivers but the chances of minor injury increase by 0.0121. Overtaking maneuver crashes involving older drivers on two-lane highways had 0.0039 increased likelihood of being major injury, whereas the likelihood of crashes involving younger drivers on six-lane highways being major injury increases by 0.0001. Perception of risk from opposing-traffic influence drivers' decisions during lane changing activities. As such, this study assessed the effects of opposing lane separation types on crash outcomes. The estimation results show that for crashes that occurred on roadways with unpaved medians, the likelihood of major injury increase by 0.0009, and the likelihood of minor injury increase by 0.0034 for younger drivers. For older drivers, the findings show that the likelihood of major injury increases by 0.0001 for crashes that occurred on roads with opposing traffic lane separation being solid painted lines.

### 4.3. Vehicle characteristics and manner of collision

From Table 3, it can be observed that sedans make up more than half of the vehicles involved in lane changing crashes. The model estimation results show that where the at-fault vehicle is sedan, the likelihood of major injury decreases by 0.0057 while the likelihood of minor injury increases by 0.0006 for younger drivers. For at-fault sedans with older drivers, the likelihood of major injury decreases by 0.0028, and the likelihood of minor injury increases by 0.0003. Where the vehicle that is not at fault is a sedan, the likelihood of major injury and minor injury decrease by 0.004 and 0.018 for younger drivers. Crashes involving SUVs being at fault were less likely to result in major injury but more likely to lead to some minor injuries when the driver involved is younger. On the other hand, where the vehicle that is not at fault is SUV, the chances for any form of injury decrease when the crash involves an at-fault younger driver. However, where the vehicle that is not at fault is a pick-up truck, the likelihood of major injury increases by 0.0003 when the crash involves an at-fault younger driver. For older drivers, the likelihood of major injury in crashes involving at-fault semi-trailers decreases by 0.0003 but the likelihood of major injury and minor injury increase by 0.0007 and 0.0017, respectively when the vehicle that is not at fault is a semi-trailer. The chances of major injury increases when the lane changing activity is around a motorcycle (i.e., motorbike not at fault). For younger drivers at fault, the likelihood of the crash resulting in major injury increases by 0.0018, and the likelihood increases by 0.0031 for older drivers at-fault.

The manner of collision has been found to contribute to the severity of injury sustained in the crash. For both younger and older drivers, rear-end and side impact collisions were found to more likely be a minor injury but not a major injury. However, angle collisions were more likely to result in some form of injury for both driver groups. For crashes in which one of the vehicles rollovers due to the impact of the collision, the chances of major injury increased by 0.0014, and the chances of minor injury increased by 0.0008 among older drivers.

### *4.4. Location and roadway environment*

Crashes that occurred in urban areas had lower chances of resulting in major injury but a 0.0017 increase in the likelihood of being minor injury among younger drivers and 0.0007 increase in the likelihood of minor injury among older drivers. Further, for older drivers, the likelihood of minor injury increases by 0.009 for crashes that occurred less than 40.2 km from the driver's residence. Crashes that occurred on dark and unlit roadways increase the likelihood of major injury by 0.0006 and increase minor injury likelihood by 0.0016 when the driver involved is older. For younger drivers, crashes that occurred under clear weather conditions were more likely to result in major injury or no injury.

## 5. Discussion

Acceleration and lane changing decisions constitute some of drivers' main operational and tactical decisions. In particular, lane changing is a challenging driving maneuver to understand and to predict, and the corresponding driving decisions are often a major source of road crashes. Primarily, a discretionary lane changing is often done to gain a speed advantage or a better driving environment, whereas a mandatory lane change is performed to reach a planned destination (Zheng, 2014). Lane changing decision process can be viewed as a sequence of three steps: decision to consider a lane change, choice of a target lane, and gap acceptance. Drivers generally consider the necessity, desirability, and safety before performing lane changing maneuvers (Ahmed, 1999). Keyvan-Ekbatani et al. (2016) observed that different drivers have completely different strategies to choose lanes, and the choices to change lane are often related to their speed at which they are traveling. For instance, studies have found that older drivers are prone to lane changing crashes as they often have difficulties in making over the shoulder glances (Morgan and King, 1995; Eby et al., 1998) and have longer perception-reaction times due to cognitive-motor declines (Stelmach and Nahom, 1992; Morgan and King, 1995; Eby et al., 1998). Younger and novice drivers, on the other hand, often lack the skills to perform lane changing maneuvers, especially under peak traffic volume conditions although they are more likely to engage in risky driving behaviors such as speeding, drunk-driving, and aggressive driving (White et al., 2011). This makes understanding the lane changing decision-making process of different driver groups difficult, though this presents an opportunity for improvement through technology. Vehicle active safety technologies, for instance, improve traffic safety by extending the perception ability of drivers and in some cases taking appropriate actions before a potential crash. In-vehicle crash avoidance systems have the ability to provide warnings and/or limited automated control safety functions while vehicle-to-vehicle (V2V) communications support various crash avoidance applications. Cicchino (2018) observed that blind spot monitoring systems in vehicles, particularly, have a significant effect on lane changing crashes. While these technologies have significant benefits for all drivers, there may be additional benefits for younger and older drivers in performing some driving tasks and reducing their crash risk and/or reduce crash impacts that may especially be harmful to older drivers due to their increased frailty.

This comparative study of injury-severity determinants of lane changing crashes involving younger and older drivers has revealed some differences and similarities in the crash factors that are associated with the crash outcomes. The distribution of crash outcomes presented in Table 1 indicates that older drivers were at fault in fewer lane change crashes and injuries compared to younger drivers. Indeed, previous studies have generally found younger drivers to be at fault in a higher proportion of crashes compared to drivers in other age categories (Bates et al., 2014). The model estimation results show that younger male drivers were more likely to be severely injured in lane changing crashes whereas older male drivers were less likely to be severely injured. This finding may perhaps be due to the many years of driving experience of older drivers compared to younger drivers. Further, it was observed that younger drivers were more likely to sustain major injury on six-lane highways whereas older drivers sustained major injuries from overtaking crashes on two-lane highways. Also, it was revealed that while younger drivers got into major injury crashes under daylight conditions, older drivers were more likely to be involved in major injury crashes under dark/unlit lighting conditions.

Findings from this study, such as road types and temporal factors associated with lane changing crashes, provide data-driven evidence to increase education and driver awareness on hazardous lane changing maneuvers. One such strategy is to promulgate the popular "Share the Road" message through print and electronic media in a way to target different age groups of drivers. This calls for the involvement of media practitioners in crafting and regularly reporting on the dangers of hazardous lane changing maneuvers. Enforcement strategies on roads that are more likely to record many lane changing activities may also result in a reduction of discretionary lane changing maneuvers. Ultimately, risky driving behaviors among population groups require sustained law enforcement coupled with public awareness/education strategies which may be targeted to improve perceptions of risk and change the safety culture. Federal programs such as Ticketing Aggressive Cars and Trucks (TACT), for instance, maybe intensified and sustained on lane changing crash prone roads to change aggressive driving and other risky road user behaviors through public campaigns, education, and enforcement.

## 6. Conclusions

Lane changing can be a difficult task for many drivers as the process requires some level of skill, vigilance, and confidence. While lane changing is a basic task during driving, frequent and improper lane changing has a substantial effect on both traffic operations and safety. This study was conducted to identify the crash contributing factors that are associated with injury severity outcomes of lane changing crashes involving younger and older drivers in Alabama. Preliminary data analysis revealed that younger drivers got into more lane changing crashes and were more likely to be injured than older drivers. To account for unobserved heterogeneity and to enhance the quality of the findings, random parameters logit with heterogeneity in means models were developed.

Two injury severity models, for younger drivers and older drivers, were developed. The model estimation results showed that younger male drivers were more likely to sustain a major injury in lane changing crashes than older male drivers. It was also found that older drivers were more likely to be severely injured on interstate highways than younger drivers. Driving violations such as failure to use a seatbelt, impaired driving, driving with an invalid license have been found to be associated with major injury outcomes. Executing lane change maneuvers has been found to be less dangerous on multi-lane highways compared to two-lane highways.

Findings from this study can help state safety actors to focus specific countermeasure strategies towards the appropriate driving population. For instance, driving training programs may be designed to be rigorous for younger and novice drivers to build enough confidence and skills before getting on the highway. Safety campaigns and awareness creation on the dangers of improper lane changing should be directed at older drivers, while traffic law enforcement strategies may be employed to reduce unnecessary and risky lane changing maneuvers.

## CRediT authorship contribution statement

**Emmanuel Kofi Adanu:** Conceptualization, Methodology, Writing - original draft. **Abhay Lidbe:** Data curation, Writing - original draft, Writing - review & editing. **Elsa Tedla:** Writing - original draft, Writing - review & editing. **Steven Jones:** Writing - review & editing.

## Declaration of Competing Interest

The authors report no declarations of interest.

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