What factors result in having a severe crash? A closer look on distraction-related factors

Hesamoddin Razi-Ardakani¹, Ahmadreza Mahmoudzadeh²*, and Mohammad Kermanshah¹

Abstract: This study provides a comprehensive literature review to summarize all contributing factors and the logit-based models that were used to predict the severity of crashes. Using the General Estimates Systems (GES) dataset, as a subset and a branch of the National Automotive Sampling System in the US, a Generalized Ordered Logit (GLM) model is developed to predict the crash severity. The developed severity model detects the most important parameters based on characteristics of the driver, the environment, the vehicle, the road, and the type of crash. This study aims to take a more in-depth look into the distraction-related factors as one of the most important groups of contributing factors to traffic crashes. Distraction-related factors are categorized into five groups based on the generating source, including cellular phone, cognitive, passenger, outside events, and in-vehicle activities. Moreover, the effect of distraction on crashes in the presence of other factors is studied. Analyzing the severity of crashes revealed that cell phone usage and distraction caused by in-vehicle activities increase the severity of crashes, whereas other factors of distraction decrease the severity.

ABOUT THE AUTHORS

Hesamoddin Razi-Ardakani is a Ph.D. candidate of Civil Engineering at the Sharif University of Technology, where he received his master's degree. His research interests are traffic safety & human factor, transportation modeling & travel demand behavior, data mining and statistical analysis in transportation.

Ahmadreza Mahmoudzadeh is a Ph.D. student at the Zachry Department of Civil and Environmental Engineering at Texas A&M University and a research assistant at Texas A&M Transportation Institute (TTI). He earned his master's and bachelor's degrees from Amirkabir University of Technology, Iran. His area of experience includes numerical and statistical analysis in transportation, modeling and optimization of transport systems, and sensor fusion in health monitoring.

Mohammad Kermanshah is a professor of Civil Engineering at Sharif University of Technology, and head of the Institute for Transportation Studies & Research (ITSR). He received his Ph.D. at the University of California at Davis, California, United States. His research interests are accident analysis, transportation planning, and transportation demand analysis.

PUBLIC INTEREST STATEMENT

One of the most important features of a transportation network is safety. Road crashes are one of the three most frequent causes of death in the world among people aged 5 to 44. According to the National Highway Traffic Safety Administration (NHTSA) report in 2019, 9% of traffic fatalities in 2017 contained at least one distracted driver. This study provides a comprehensive literature review to summarize all contributing factors in crash occurrence and the statistical methods that were used to detect/predict the crash occurrences. An American-based crash dataset was used for this purpose. Moreover, factors that caused a distraction are categorized into five groups “usage of cellular phones, cognitive, passengers distracting the driver, outside events attracting the driver’s attention and in-vehicle activities.” The study developed a model to measure how these parameters affect the crash occurrences as well. Analyzing the severity of crashes revealed that cell phone usage and distraction caused by in-vehicle activities increase the severity of crashes.
1. Introduction

One of the most important features of a transportation network is safety. Each year nearly 1.3 million people around the world lose their lives and 20 to 50 million suffer injuries (NHTSA, 2008). Road crashes are one of the three most frequent causes of death in the world among people aged 5 to 44 (NHTSA, 2008). According to the National Highway Traffic Safety Administration (NHTSA) report in 2019, 9% of traffic fatalities in 2017 contained at least one distracted driver (National Highway Traffic Safety Administration [NHTSA], 2017). Also, there is an 8.8% increase in the number of fatal crashes that occurred because of distraction from 2014 to 2015 (NHTSA, 2015). National Highway Traffic Safety Administration stated that in 2006, at any given moment, 0.04% of drivers were busy using electronic devices (for example texting) while this proportion increases to 2.2% In 2014 which remained constant in 2015 (NHTSA's National Center for Statistics and Analysis, 2015). It is important to mention that distraction is more than just using electronic devices and new technologies while a person is driving; it includes all the activities that affect the driver’s sight, hearing, reflex and decision making.

In general, the distraction of drivers has attracted many scholars. They have used various methods to study the relationship between crashes and distraction. Some of these methods are including simulation of driving and observing the driver’s behavior, directly observing the driver’s behavior in real-time driving, analysis of crashes' statistics and in-person interviews. However, few studies have been performed to account for the impacts of distraction on the features of a crash. The most important feature of a collision is its severity. Severity shows the level of casualties and damages exerted on drivers and society.

Unlike many researchers that only study the relationship between distraction factors on the occurrence of crashes (McEvoy, Stevenson, & Woodward, 2006; Regan, 2006), this research finds out how distraction affects the severity of crashes, which is an important feature of a crash. Considering the fact that few studies have focused on distraction, this article pursues this goal in a general manner (although in a limited scope). Additionally, the impacts of distraction on crashes have been studied in the presence of other various factors. Factors that refer to the driver's personal characteristics such as age, gender, physical readiness or health, and also factors like time of occurrence, lighting and weather conditions. Other parameters are road and vehicle attributes, for instance, number of lanes, superelevation, slope, curves, type of vehicle and their life span.

2. Literature review

There have been many efforts to analyze the severity of crashes so far and the effects of their various contributing factors have been studied. Table A1 is a comprehensive review of effective variables identified by researchers and their impact on the severity of crashes that is available in the Appendices. It mentions the studies focused on variables related to characteristics of the driver, conditional and environmental properties, and characteristics of the vehicle, road, and crash in terms of increasing or decreasing the crash severity. The table shows that scholars might have similar or different views of the effect of some factors on the severity of crashes (for more information refer to the appendix).

Table A1 demonstrates that, based on different scholars, some factors are changing the crash severity level in different directions which might be due to the difference of the societies under consideration or a difference in the drivers’ driving habit. However, they are not the only factors. For example, in a society, temporal stability of the factor (Behnood & Mannering, 2015)
(e.g., due to economic recession (Behnood & Mannering, 2016)) could be a potential factor affecting the direction of the injury severities. Based on these studies, the most prevalent variables affecting crashes are the driver’s age and gender, consumption of alcohol or drugs by the driver, not using seatbelts, speeding, dimness, pavement status and curves.

Along with various researches regarding analyzing crashes (Abhari, Tabibi, Nejad, Khansari, & Amini, 1888–1896; Mansourkhaki, Karimpour, & Sadoghi Yazdi, 2016; Mansourkhaki, Karimpour, & Yazdi, 1912–1918; Parsa, Chauhan, Taghipour, Derrible, & Mohammadian, 2019; Parsa, Movahedi, Taghipour, Derrible, & Mohammadian, 2020; Shirani, Doustmohammadi, Haleem, & Anderson, 2018), severity analysis needs special look due to it’s ordered nature; therefore, discrete choice models are a more common method in analyzing severity (Savolainen, Mannering, Lord, & Quddus, 2011). Since there are various levels of severity, various discrete choice models have been used in this context. Table A2 presents a comprehensive review on prevalent models used to analyze crashes by providing the advantages and disadvantages of each one. As can be seen in Table A2, the most popular and frequently used models are Logit and Ordered Probit. Table 1 summarizes the pros and cons of using each of the models in crash analysis. One of the advantages of Generalized Ordered models over the Ordered model is that Generalized models offer different coefficients for various severity levels while considering the ordered nature of the data. Other mentioned models do not account for the ordered nature of the data. Out of all the existing models, according to the literature, one of the best models is the mixed logit model, but it has a very lengthy estimation process so it makes achieving the final model difficult. In this article, we choose to use the generalized ordered logit model to analyze crash severity. According to Curry et.

| Model             | Advantages                                                                 | Disadvantage                                                                                     |
|-------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Binary Probit or Logit | Provides one coefficient for each variable which makes it easier to interpret. does not have independence from irrelevant alternatives | Limits levels of severity to only two, assumes similar and independent distributions for errors, assumes that errors follow Gumbel distribution |
| Multinomial Logit | Provides different coefficients for the effects of each variable on different levels of severity | Assumes independent and similar distribution of errors. Assumes that errors follow gamble distribution, has independence from irrelevant alternatives. Is difficult to interpret due to estimation of many variables. |
| Nested logit      | Does not have independence from irrelevant alternatives.                  | Assumes that errors follow gamble distribution. Does not consider the ordered nature of severity of crashes. |
| Ordered Probit or logit | Considers the ordered nature of severity of crashes                       | Parallel line assumption, similar effect of each variable on different levels of severity, assumes independent and similar distribution of errors. Assumes gamble distribution for errors |
| Generalized ordered logit or Probit | Considers of the ordered nature of severity of crashes, provides different coefficients for the effects of each variable on different levels of severity | Assumes independent and similar distribution of errors. Assumes that errors follow gamble distribution |
| Mixed Logit or Probit | Provides different coefficients for the effects of each variable on different levels of severity, does not have independence from irrelevant alternatives | Does not consider the ordered nature of severity of crashes. Lengthy and time-consuming calibration with the software |
al, driving with high speed, recognition errors and distraction factors are the most common factors among all crashes (Curry, Hafetz, Kallan, Winston, & Durbin, 2011). Distraction factors that were mentioned as some of the common factors in crashes were not paid enough attention among scholars. Hence, it motivates the authors to conduct the research by considering distraction factors as different factors in crash modeling. There have been few studies on the effects of distraction on the severity of crashes so far. Some of these studies have just considered distraction as a whole rather than accurately study the effects of each kind of distraction on the severity of crashes. Chang and Mannering (1999) have considered the inattention of drivers in analyzing crash severity. The results they obtained showed that this factor reduces crash severities. Altwaijri, Quddus, and Bristow (2011) analyzed the severity of crashes that occurred in Saudi Arabia. They also found that distraction decreases crash severity. In the model of a later version of the described manuscript (Altwaijri, Quddus, & Bristow, 2012), the t-stat of the distraction coefficient is not significant. This may be due to poor recording of distraction by the Saudi Police and a number of other factors.

Hanley and Sikka (2012) studied the effects of distraction on the severity of crashes in the United States. The results mean that more light accidents are associated with distraction than injurious ones. This result is caused by mixing different types of crashes (bumps at street lights and serious crashes) and the fact that distraction may be more prevalent in light crashes in urban areas. In contrast, the majority of the studies found that distraction is associated with increased severity levels (in particular fatal accidents), although it is also associated with damage only ones. For instance, the results of Holdridge, Shankar, and Ulfarsson (2005) clearly show that for the same type of crashes, distraction is associated with higher crash severity which is reasonable because distraction prevents drivers from responding to events in due time or responding at all.

Neyens and Boyle (2008) studied the effects of different distracting factors on the crash severity of teenage drivers. For this purpose, they used an ordered logit model to anticipate the severity of injuries of the driver and passengers, and the GES dataset of 2003. The data were limited to 16 to 19-year-old drivers, who were driving the car, which initiated contact. They even omitted the crashes on vehicles that had no passengers (e.g. motorcycles, tractors and etc.). In their study, the dependent variable is five levels of severity ranging from no injuries to death. There are four main factors of distraction: distraction due to the presence of other passengers, distraction due to the usage of cellphones, distraction due to in-vehicle activities and cognitive distraction. The results showed that factors such as telephone usage, female drivers and speeding increased the severity of the crash. Whereas factors such as using a seat belt, unfavorable weather conditions and in-vehicle activities have decreased crash severities. Generally, female drivers, who violated the speed limit and were distracted by cellphones, experienced more severe crashes. According to Australian National Crash In-depth Study (ANCIS), the “in-vehicle distraction” factor (e.g., presence of passengers) is the common factor in crashes which are occurred as a result of distraction (Beanland, Fitzharris, Young, & Lenné, 2013). Kaplan and Prato (2012) found a significant effect of the distraction of bus accident severity for the light accident and fatal crashes in the U.S. Weiss, Kaplan, and Prato (2014) found that distraction increases the likelihood of fatal crashes among young drivers in New Zealand.

Liu and Donmez (2011) studied the effects of distraction on the injury severity of police-related crashes. Severity criterion is the severity of injuries of the involved individual (most injured occupant) by using the GES dataset between 2003 and 2008 which were limited to two-vehicle crashes. They differentiated between in-vehicle distraction and cognitive distraction of police officers versus civilians and found that the former is associated with increased injury severity and the latter with lighter injury severity. Since again it is unknown whether the cognitive distraction is found among police officers in different types of driving (for example slow driving, standing in street light, etc.), the results should be interpreted with caution. Also, Police officers drive significantly different than civilians and their level of both in-vehicle tasking and thus in-vehicle distraction versus cognitive burden is completely different and cannot be compared to normal driving conditions.
An in-depth crash study that considers different distraction factors besides other crash-related factors with a newer GES dataset rather than similarly conducted studies by a different modeling technique from the aforementioned studies motivates the authors to start this study. In other words, the new data should capture current types of behaviors and current technology types that might not exist in older databases; however, the authors declare that using the last version of the GES data set could reflect the effect of smartphones and tablets proliferation on driving.

3. Methodology
This section talks about the introductory background on the logit-based models, followed by describing the dataset and the models that are developed for this study.

3.1. Introduction to the logit-based models
To develop an Ordered-Logit based model, there is a null-hypothesis that there is always a connection between one continuous latent variable and one discrete observed one. The general form of these types of models is written in Equation (1):

$$Y_n = \beta X_n + \epsilon_n$$  \hspace{1cm} (1)

In which, $Y_n$ is the dependent latent variable which can take various values for different states represented by $n$, $X_n$ is the descriptive variable, $\theta$ is the coefficient vector of descriptive variables and $\epsilon_n$ is the imperceptible errors (Greene & Hensher, 2010). The Equality of the coefficient for the choices in the mentioned model is called the Parallel Regression Assumption (Parallel Line assumption) (Brant, 1990; Clogg & Shihadeh, 1994). This study considers different levels of severities as different states, so Equation (1) is extended to Equation (2), to reflect the various states.

$$Y_n = \begin{cases} 
1 & \text{if } \mu_0 \leq \beta X_n + \epsilon_n \leq \mu_1 \\
2 & \text{if } \mu_1 \leq \beta X_n + \epsilon_n \leq \mu_2 \\
3 & \text{if } \mu_2 \leq \beta X_n + \epsilon_n \leq \mu_3 \\
4 & \text{if } \mu_3 \leq \beta X_n + \epsilon_n \leq \mu_4 
\end{cases}$$  \hspace{1cm} (2)

The defined upper bounds and lower bounds are considered as the severity thresholds in this study. In Equation (2), $u_0$ and $u_4$ are considered as $-\infty$ and $+\infty$, respectively. The model is calibrated using the maximum likelihood method. According to that, the logarithm of likelihood can be written as:

$$\log L = \sum_{n=1}^{N} \sum_{j=0}^{J} m_{nj} \log \left[ F(\mu_j - \beta X_n) - F(\mu_{j-1} - \beta X_n) \right]$$  \hspace{1cm} (3)

In Equation (3), the amount $m_{nj}$ is equal to 1. Maximization of Equation (3) is subjected to the limitations of $\mu_0$ and $\mu_4$ which are considered as $-\infty$ and $+\infty$ respectively, and where this assumption does not hold, the Generalized Ordered Logit (GOL) model should be used. GOL considers the ordered nature of the choices and provides different coefficients for each level of severity. In this case, Equation (2) is extended in the form of Equation (4):

$$Y_n = \begin{cases} 
1 & \text{if } \mu_0 \leq \beta X_{n1} + \epsilon_n \leq \mu_1 \\
2 & \text{if } \mu_1 \leq \beta X_{n2} + \epsilon_n \leq \mu_2 \\
3 & \text{if } \mu_2 \leq \beta X_{n3} + \epsilon_n \leq \mu_3 \\
4 & \text{if } \mu_3 \leq \beta X_{n4} + \epsilon_n \leq \mu_4 
\end{cases}$$  \hspace{1cm} (4)

In the cases where the parallel assumption holds and the effects of variables are similar for each of the states, the Proportional Odds (PO) model should be used (Clogg & Shihadeh, 1994). In the case where the beta coefficient within the states are similar for some variables and different for another one, the PO model should be used as it is described in Equation (5) (just take three variables as an example):

$$Y_n = \begin{cases} 
1 & \text{if } \mu_0 \leq \beta_{11} X_{n1} + \beta_{21} X_{n2} + \beta_{31} X_{n3} + \epsilon_n \leq \mu_1 \\
2 & \text{if } \mu_1 \leq \beta_{12} X_{n1} + \beta_{22} X_{n2} + \beta_{32} X_{n3} + \epsilon_n \leq \mu_2 \\
3 & \text{if } \mu_2 \leq \beta_{13} X_{n1} + \beta_{23} X_{n2} + \beta_{33} X_{n3} + \epsilon_n \leq \mu_3 \\
4 & \text{if } \mu_3 \leq \beta_{14} X_{n1} + \beta_{24} X_{n2} + \beta_{34} X_{n3} + \epsilon_n \leq \mu_4 
\end{cases}$$  \hspace{1cm} (5)
Equation (5) shows that the first two variables have the same effect within all stages, while the case is different for the third variable. \( \beta \) values can be demonstrated by two values of \( \gamma \) parameters which shows the “deviation from decency”.

\[
\begin{align*}
\beta_{31} &= \beta_3 \\
\beta_{32} &= \beta_3 + \gamma_2 \\
\beta_{33} &= \beta_3 + \gamma_3
\end{align*}
\] (6)

The model estimates \( \gamma_2 \) and \( \gamma_3 \) in Equation (6). The model has one \( \beta \) for the variables that hold the Parallel Line assumption. In other words, the model initially estimates multiple coefficients for such variables and then the equality of the coefficients of each variable will be tested using the Wald test. If coefficients are statistically equal, only one \( \beta \) coefficient will be assigned to all levels of severity (Brant, 1990).

3.2. Data

In this article, the authors used the data from General Estimates Systems (GES) which is a subset and a branch of the National Automotive Sampling System (NAAS). This database has gathered national data from 1988 and updates the data annually with a random sample from 6 million crashes reported by the police. Well-known scholars have used this data to conduct their research, which shows the reliability of this data (Eluru, Paleti, Pendyala, & Bhat, 2010; Mahmoudzadeh, Razi-Ardakani, & Kermanshah, 2019; Razi-Ardakani, Kermanshah, & Mahmoudzadeh, 2017; Razi-Ardakani, Mahmoudzadeh, & Kermanshah, 2018; Xie, Zhang, & Liang, 2009; Yan, Harb, & Radwan, 2008). The data that we used were from crashes of 2010, which includes characteristics of the crash, vehicle type, characteristics of the driver, distracting factors, the type of violation that the driver has committed, maneuvers before collision, obstacles to the driver’s vision, physical factors imposed on the driver (e.g. fatigue or drowsiness) and vehicle’s technical deficiencies. The first database that we used to elicit the final sample includes 81228 vehicles with characteristics of the driver, vehicle, crash. This study considers only light vehicles. Furthermore, due to complications of multi-vehicle crashes, this article is limited to single-vehicle and two-vehicle crashes, which are 93.5% of all crashes.

According to the goals of this article, 13 distracting factors recorded in the crash database has been divided into 5 categories (similar to the study of Neyens and Boyle (Neyens & Boyle, 2007)). In other words, some categories did not have much data for adding into the model, so the authors aggregate the data set into five groups of distractions to have more data in each category. The categories and descriptions of each category are depicted in Table 2. The difference of this article with Neyen’s and Boyle’s is that we have separated the in-vehicle and out-vehicle distracting factors.

| Distraction category | Description |
|----------------------|-------------|
| Cognitive            | Looked but did not see |
|                      | Inattentive or lost in thought |
| Passenger Related    | By other occupants |
| In-vehicle tasks     | By moving an object in the vehicle |
|                      | While adjusting audio or climate controls |
|                      | While using other component/controls integral to the vehicle |
|                      | While using or reaching for device/object brought into vehicle |
|                      | Eating or drinking |
|                      | Smoking-related |
| Out-Vehicle          | Distracted by an outside person, object or event |
| Cellphone            | While talking or listening to cellular phone |
|                      | While manipulating cellular phone, |
|                      | Other related factors |

Table 2. Distraction categories
After omitting the incomplete observations, the final sample used in the severity section includes 30217 drivers that considering weighted parameters from sample data represent 4,455,581 drivers involved in the crash. The authors used the injury severity of the driver as a crash severity criterion. It should be noticed that injury severity and crash severity may not be the same thing and with improvements in the design of vehicles and safety systems, more severe crashes may not be correlated with severe injuries. However, it is somewhat well known that there are moderating factors that influence how severe an injury is from how severe a crash. Moreover, the crashes involved pedestrian, heavy vehicles, bikes and motorcycles were not considered in developing the model. It should be noted that since deadly crashes were scarce, we have combined crashes that cause death and crashes that cause incapacitating injury in one level. The distribution of severity levels in the final sample has been compared to the distribution of the severity levels in the initial data by a statistical test. No statistical difference has been found, which shows that there are no systematic errors after omitting the incomplete observations. The obtained results can be generalized to represent the whole. In the data that we have used, 84.4% of the drivers were not injured, 9.8% had probable injuries, 4.6% were injuries without incapacitating injury and 1.2% of the drivers died or suffered incapacitating injury. Table 3 presents descriptive statistics for the final data, which are related to the driver's distraction. For instance, in the final used data set, cognitive distraction causes 4.9 % of crashes. Other related factors are depicted in Table A3 (available in Appendix).

| Variable            | Percentage |
|---------------------|------------|
| No distraction      | 92.4       |
| Cognitive           | 4.9        |
| Passenger Related   | 3          |
| In-Vehicle Tasks    | 1.1        |
| Out-Vehicle         | 0.6        |
| Cellphone           | 0.7        |

3.3. Modeling
The variables have entered the model all in once at the beginning, using STATA. Then, their significance was measured using the t-test. The nature of some variables such as Age is changed from continuous to categorical or logarithmic to keep them in the model. The nature of categorical variables was changed by generating multiple dummy variables, each of which represents a single state of the original categorical variable. In the final model, we eliminated all the variables, which coefficients had no statistical difference with zero with a significant level of 5%. The t values of all the coefficients are higher than 1.96, which means that coefficients of all the variables are in the 5% significant level. Kutner, Nachtsheim, Neter, and Lie, (2004) suggested a VIF of 5 as the threshold that indicates the presence of serious multicollinearity. For our models, none of the variables had the VIF in excess of 4.

Two models of Ordered and Generalized Ordered Logit were developed. As it was mentioned earlier, the proposed ordered model has the parallel-lines assumption (Brant, 1990). To illustrate that, if a variable has different effects on the severity levels, biased coefficients are estimated in the ordered logit model. Therefore, a generalized ordered logit (partial proportional odds), which provides different coefficients for different levels of severity is developed as well. A diagnostic tool for evaluating the proportional odds assumption is called the Brant test (Brant, 1990). Brant test measures the disparity effects of a variable on different levels of crash severity.
4. Result and discussion

To discuss the results, this type of model, the positive sign of the descriptive variable indicates that by increasing the variable, the chances of having a more severe crash increase. In the final model, all the coefficients of distraction variables were in the 5% significant level. The negative sign of cognitive distraction factor implies that drivers who are lost in thoughts are less probable to have severe crashes; in other words, cognitive distraction decreases crash severity. This effect is a bit unfamiliar and interpreting this result needs more accurate research. Likewise, the negative sign of the factor of distraction due to the presence of passengers shows that drivers distracted by other passengers experienced less severe crashes which contradicts what Neyens and Boyle (2008) found. Instead, it might be due to the proliferation of TV programs related to accidents. In the last decade, safety ads have focused on the importance of distraction caused by passengers; hence, it might cause passengers to be quieter than they were a decade ago (the previous GES dataset which Neyens et.al. utilized). From a different perspective, it might be due to the temporal stability behavior of the variables; however, the exact reason for this behavior is not really known. The positive sign of in-vehicle tasks shows that this factor increases the injury severity of drivers which supports what “The effect of distractions on the crash types of teenage drivers” (Neyens & Boyle, 2008) and police drivers (Liu & Donmez, 2011) have stated. As we have mentioned before, in-vehicle activities are non-driving related tasks that are done in the car and distract the driver, e.g. working with vehicle equipment or other devices in the car. The study of the effects of in-vehicle non-diving-related task on drivers by Strayer and Drews (2004) shows that this factor increases the reaction time. It also increases the following distance. The article figured that an increase in reaction times increases the chance of a crash.

Other scholars have revealed the effect of this factor on stoppage time and gaps between vehicles (Lansdown, Brook-Carter, & Kersloot, 2004). The distraction caused by out-vehicle stimulis decreases the probability of severe crashes as its sign is negative in the model. It is worth mentioning that the effects of this type of distraction have not been considered until now.

Brant test results for the ordered model are provided in Table 4. These variables that have different coefficients for each level of severity are specified with a “*” mark in Table 4. As the table shows, female driver, age higher than 60, driving under the influence of alcohol or drug, not using seatbelts, speed limits higher than 50 mph and rear-end collisions have different values for each level of severity. For other variables, the coefficients in the ordered logit model is constant at all the states. Based on the characteristics of the model that are shown in Table 3, the measure of goodness of fit is 0.055.

It might be based on a faster driver’s response time in this situation. The primary response of a driver in the critical situation is a reduction in the speed; hence the speed at the impact is lower (Kamrani, Arvin, & Khattak, 2019). The Positive sign of the distraction caused by cellphones implies that cellphone usage (such as making a phone call or sending a text message) while driving increases drivers’ severity of injuries in crashes. In recent years, the study of the effects of cellphone usage has gained a lot of attention, and its negative effects on the quality of driving and increasing the threat of crashes have been proven (Backer-Grøndahl & Sagberg, 2011; de Waard, Schepers, Ormel, & Brookhuis, 2010; McEvoy et al., 2005; Motamedi, Hasheminejad, & Choe, 2015; Reimer, Mehler, Coughlin, Roy, & Dusek, 2011). Some of these studies even showed that this factor increases the death rate of the drivers (Fowles, Loeb, & Clarke, 2010; Loeb, Clarke, & Anderson, 2009).

A driver’s gender is one of the factors that has not satisfied the parallel lines hypothesis and has been estimated separately for each level. Female drivers are more likely to have more severe crashes but the effects of gender on the severity of crashes are different at each level. According to $\gamma_j$, which is $-0.186$ for $j > 2$, effects of this variable on possible injury is lower than on the two other levels. The contrast of injury severity of men and women is due to their physical differences. The
## Table 4. Crash severity estimation results

| Variable                          | Ordered |         | Generalized Ordered |         |
|-----------------------------------|---------|---------|---------------------|---------|
|                                   | Coefficient | t  | Coefficient | t  |
| **Characteristics of the driver** |          |       |          |       |
| Driver’s gender                   |          |       |          |       |
| Female*                           | 0.491   | 13.56  | 0.503     | 13.71  |
| Driver’s age                      |          |       |          |       |
| 16–24                             | −0.293  | −6.51  | −0.295    | −6.62  |
| 60 above*                         | 0.115   | 2.16   | 0.096     | 1.75   |
| Driver’s Impairment               |          |       |          |       |
| Under the Influence of Alcohol, Drugs* | 1.157 | 11.95  | 1.003     | 10.94  |
| Asleep or Fatigue                 | 1.094   | 7.55   | 1.039     | 7.73   |
| **Safety Equipment**              |          |       |          |       |
| Not Using Seatbelts*              | 1.184   | 16.21  | 1.054     | 14.89  |
| Wrong Use of Equipment            | 0.942   | 4.4    | 0.793     | 4.07   |
| **Driver’s Distraction**          |          |       |          |       |
| Cognitive                         | −0.421  | −4.93  | −0.419    | −4.93  |
| Passenger Related                 | −0.780  | −2.23  | −0.745    | −2.17  |
| In-Vehicle Tasks                  | 0.304   | 2.11   | 0.290     | 2.06   |
| Out-Vehicle                       | −0.483  | −2.14  | −0.480    | −2.15  |
| Cellphone                         | 0.386   | 2.11   | 0.397     | 2.21   |
| Speeding                          |          |       |          |       |
| Driving Over the Speed Limit*     | 0.203   | 3.81   | 0.173     | 3.25   |
| **Conditional and environmental properties** |          |       |          |       |
| Passenger                         |          |       |          |       |
| Presence of Passengers            | 0.124   | 3.04   | 0.126     | 3.09   |
| Driver and Passengers Age: 16–24  | 0.214   | 2.3    | 0.209     | 2.26   |
| Light condition                   |          |       |          |       |
| Dark—Not Lighted                  | 0.293   | 4.48   | 0.276     | 4.31   |
| Weather condition                 |          |       |          |       |
| Rainy                             | 0.209   | 2.42   | 0.211     | 2.46   |
| Snowy                             | −0.395  | −3.43  | −0.379    | −3.34  |
| Time of Day                       |          |       |          |       |
| Morning Peak Hour                 | −0.161  | −3.13  | −0.159    | −3.11  |
| **Characteristics of the vehicle** |          |       |          |       |
| Vehicle Type                      |          |       |          |       |
| SUVs                              | −0.108  | −2.34  | −0.113    | −2.46  |
| Vans                              | −0.267  | −3.67  | −0.271    | −3.74  |
| Pickups                           | −0.322  | −6.25  | −0.325    | −6.38  |
| Vehicle Age                       |          |       |          |       |
| Up to 7                           | 0.182   | 4.68   | 0.181     | 4.67   |
| 12 Above                          | 0.415   | 8.91   | 0.410     | 8.88   |
| **Characteristics of the road**   |          |       |          |       |
| Road alignment                    |          |       |          |       |
| Curves                            | 0.153   | 3.41   | 0.144     | 3.25   |

(Continued)
results obtained from our proposed model concur with previous studies on this subject (Kockelman & Kweon, 2002; Ulfarsson & Mannering, 2004).

Crashes of young drivers were less severe than crashes of middle-aged drivers. Moreover, the result shows that young drivers (aged between 16 to 24) tend to have less severe crashes while

| Variable                              | Ordered Coefficient | t   | Generalized Ordered Coefficient | t   |
|---------------------------------------|---------------------|-----|---------------------------------|-----|
| Dry                                   | 0.182               | 2.96| 0.179                           | 2.95|
| Junction Type                         |                     |     |                                 |     |
| Intersections                         | 0.098               | 2.45| 0.096                           | 2.4 |
| Speed Limit                           |                     |     |                                 |     |
| Up to 35 mi/hr                        | −0.397              | −7.86| −0.372                         | −7.75|
| Above 50 mi/hr*                       | 0.521               | 11.38| 0.478                           | 10.33|
| Traffic way Description               |                     |     |                                 |     |
| Two Way—Not Physically Divided       | 0.117               | 3.01| 0.106                           | 2.77|
| Characteristics of the crash         |                     |     |                                 |     |
| Collision Type                        |                     |     |                                 |     |
| Rear-End*                             | −0.326              | −6.80| −0.282                         | −5.79|
| Head-On                               | 1.144               | 14.84| 1.134                           | 15.14|
| Angle or Sideswipe                   | 0.313               | 6.16| 0.319                           | 6.35|
| Other Types                           | −0.885              | −2.41| −0.883                         | −2.42|
| γ2                                   |                     |     |                                 |     |
| Female                                | −                    | −    | 0.186                           | −5.13|
| 60 above                              | −                    | −    | 0.162                           | 2.94|
| Under the Influence of Alcohol, Drugs| −                    | −    | 0.281                           | 5.05|
| Not Using Seatbelts                   | −                    | −    | 0.293                           | 5.76|
| Driving over the speed limit          | −                    | −    | 0.231                           | 4.78|
| Above 50 mi/hr                        | −                    | −    | 0.232                           | 6.21|
| Rear End                              | −                    | −    | −0.634                         | −12.15|
| γ3                                   |                     |     |                                 |     |
| 60 above                              | −                    | −    | 0.326                           | 3.08|
| Under the Influence of Alcohol, Drugs| −                    | −    | 0.668                           | 5.40|
| Not Using Seatbelts                   | −                    | −    | 0.460                           | 4.16|
| Above 50 mi/hr                        | −                    | −    | 0.643                           | 8.16|
| Rear End                              | −                    | −    | −0.891                         | −7.60|
| μ                                     |                     |     |                                 |     |
| No injury or possible injury          | 2.497               | 30.4| 2.488                           | 30.5|
| Non-incapacitating                    | 3.661               | 43.2| 3.552                           | 41.8|
| Incapacitating or fatal               | 5.356               | 59.6| 5.550                           | 56.7|
| Model                                 |                     |     |                                 |     |
| Observation                           | 30217               | −    | 30217                           | −    |
| Observation (Weighted)                | 4455581             | −    | 4455581                         | −    |
| Log-Likelihood at start               | −17036.16           | −    | −17036.16                       | −    |
| Log-Likelihood at the convergence     | 016095.05           | −    | −15906.95                       | −    |
| $p^2$                                 | 0.055               | −    | 0.066                           | −    |

* the significant variables of the ordered model that has different effects across different levels of severity.
they are more risk taken, which might be caused by unobserved characteristics (Azimi, Asgari, Rahimi, & Jin, 2019; Mokhtarimousavi, Anderson, Azizinamini, & Hadi, 2019). Drivers that are older than 60 have experienced more severe crashes. These results agree with several similar studies on this subject (Paleti, Eluru, & Bhat, 2010; Xie et al., 2009). According to the positive value of \( \gamma_2 \) and \( \gamma_3 \), the effects of age on the chances of having crashes that result in injuries with or without incapacitating injury or death is greater than crashes with no or probable injuries.

Alcohol and drug use amplify the severity of crash injuries. The effect of this variable is not uniform for different levels and its factor has been estimated freely. This effect has been proven in other studies as well (Wang & Abdel-Aty, 2008). \( \gamma_3 \) is greater than \( \gamma_2 \) which means alcohol use affects the fourth level of injuries more. All of the related studies have stated the effect of alcohol use on crash severity (de Lapparent, 2008; Morgan & Mannering, 1852–1863). Drowsiness and fatigue also increase crash severity.

As anticipated, the lack of seatbelt use increases the severity of a crash. All of the studies on this subject show the same results which are presented in Table A1 (available in Appendices). Based on the positive value of \( \gamma_3 \) for \( j > 2 \) this factor affects the increase of crash severity of the no-incapacitating injury level more than no-injury level. The value of \( \gamma_3 \) is also greater than \( \gamma_2 \) for \( j > 2 \) and implies that the effect of not using seatbelts on crashes with incapacitating injury or death is more significant than other levels of severity. The variable that represents the incorrect use of safety equipment has a positive factor. Speeding is another factor that increases crash severity. A notable point is the different effects on the different levels of severity. The positive value of \( \gamma_2 \) for \( j > 2 \) shows that the effect of speeding on the severity level of injuries with non-incapacitating injury is more than the severity level of with-no injuries or probable injuries. These results demonstrate that assuming equal factors for variables on each level will lead us to wrong conclusions.

The positive factor for the variable of passenger existence states the increasing effect of this situational-environmental feature on increasing the severity of crashes. Lee and Abdel-Aty (2008) study the effects of the presence of passengers on increasing the severity of crashes and obtained the same results. It seems that the movements of passengers in the event of a crash and their collision with the driver increases the severity of the driver’s injuries (Savolainen & Ghosh, 2008). It is noteworthy that the interaction of different parameters like passengers’ and drivers’ age has been taken into consideration during modeling. Finally, the drivers that are accompanied by young passengers are more likely to have severe crashes. It can be due to the reckless actions of young ones during a drive or negligence of the driver.

 Darkness and absence of artificial lighting have increased the severity of crashes. This can be due to insufficient visibility. This result has been reported by other scholars as well (Gray, Quddus, & Evans, 2008). Rainy weather is another environmental factor that affects the severity of crashes and increases it. Several scholars have found the relationship between rainy weather and crashes as well (Ahangari, Jeihani, & Jarju, 2018; Parsa, Taghipour, Derrible, & Mohammadian, 2019). It seems that due to insufficient visibility and pavement conditions the severity of crashes increases. Results show that crashes in snowy weather are less severe than those in rainy weather. This peculiar result was reported by Shankar, Mannering, and Barfield (1996). There is this possibility that the driver’s lack of attention, while it is raining in comparison with the meticulous precaution of the driver in snowy weather, is the reason for this difference. Crashes that have occurred in the peak of traffic i.e. 6 to 9 in the morning are less severe. We can justify this by explaining that there are more vehicles on the road in heavy traffic and drivers are more careful and attentive. On the subject of type of car, SUVs vans and pickups had experienced less severe crashes than normal cars. The reasons might be the heavier weight or characteristics of their bodies (Chang & Mannering, 1999). Between these three types of vehicles, pickups had the least severe crashes followed by vans in second place. This conclusion can be related to the size and structure of the pickup body in comparison with other types of vehicles.
Regarding car-related factors, the positive signs and the values of the two variables that are related to the car’s age (i.e. up to 7 years old vehicle and the vehicle that is older than 12 years) show that the older the car the more severe the crashes are. In order to justify this effect, we can say that old cars do not possess the new technologies and safety features of up-to-date cars, and these results to more severe crashes. This interval scheme is based on the data and is used by Ulfarsson and Mannering as well (2004). It should be mentioned that there might be a possibility of having an old car equipped with new technologies. While, on the other side, it is not economically affordable to equip a car established at the beginning of 2000 with cruise control or lane changing features. So, by assuming a little bit violation of this assumption i.e., if we assume only a very few portions of owners equipped their cars with such features, the results are still valid.

Factors regarding road characteristics show that crashes that occurred on curves were more severe. Most studies have reported the same result. There are two main reasons as to why crashes on curves are more severe (Hu & Donnell, 2011a). First, drivers are not aware of the dangers of curves. Second, drivers do not have a good perception or estimation of how much curvature they are encountering (Pratt & Bonneson, 2008), while some scholars mentioned that by increasing the turn radius, the total crashes might decrease (Azizi & Sheikholeslami, 2013; Azizi, Sheikholeslami, & Khalili, 2012). Other scholars also considered other type of intersections such as R-CUT, which can make the travel much safer (Ulak et al., 2019). The positive sign of the variable representing dry pavement show that this condition increases crash severity. The drivers may speed on dry pavement more often, which results in more severe crashes (Ismael & Razzaq, 2017). This issue is supported by the work Savolainen and Mannering (2007) did on single-vehicle crashes and other scholars work on multi-vehicle crashes (Christoforou, Cohen, & Karlaftis, 2010; Xie et al., 2009). Crashes that occurred in intersections tended to be more severe. This finding was reported by Huang, Chin, & Haque (2008) as well. There are more conflicts in intersections and crashes are right-angled and the results of our research show side crashes are more severe.

Speed limits have been identified as one of the most important factors affecting crash severity. The signs of the two variables that represent speed limits lower than 35 and speed limits greater than 50 respectively, show that increasing the speed limits will increase crash severity. Malyshkina and Mannering (2008) agree with this concept. Speed is an undeniable factor that is directly related to the kinetic energy released when two vehicles collide (Regan, 2006). In roads with higher speed limits, drivers drive at a higher speed and if they have a crash, this crash will be more severe. On the other hand, “speed limit up to 35” forces drivers to drive at lower speeds. Therefore, the crashes that happened at lower speeds result in lower severity. Crashes that occurred in two-way streets without intermediate separation were more severe because crashes in such roads are mainly front to front, which is the most serious type of crashes (Gärder, 2006). This is achieved by Rifaat and Tay (2009).

Based on the Brant test and the generalized ordered logit model, the coefficient of rear-end crashes differ in different levels of severity. Values of $\gamma_{2}$ for $j > 2$ and $\gamma_{3}$ for $j > 3$ shows that as severity level increases the effect of this factor gets more negative which means in this type of crash severe injuries are less probable. Normally this type of crash happens in crowded places where drivers drive at a lower speed, therefore, the crashes are not as extreme. The majority of researches that study this effect have achieved similar results (Altwajri et al., 2011).
5. Conclusion
In this study, the effects of different factors on the severity of a crash (or in the technical term, the severity of the injury) are examined. The severity of crashes categorized into four levels; crashes without injuries crashes with probable injuries, crashes that cause non-incapacitating injury, and crashes that result in a fatality or incapacitating injury. Due to the ordinal nature of the crash severity, a generalized ordered logit model was developed. Among different distraction-related factors, in-vehicle activities (i.e., the activity that are not related to driving) increase the crash severity. Implementation of new technologies that facilitates using stuff while driving will facilitate driving and performing in-vehicle tasks, simultaneously. For example, using voice-activated devices could limit driver distraction, which limits the chance of occurring a crash. Also, easier accessibility to electronic keys controlling stereo and air conditioning can reduce distraction. These methods will minimize the vision’s distraction. Also, as food consumption or smoking while driving increases the chances of having a severe crash, enacting new laws can lead to lessen the severity or quantity of crashes. The results confirm that cellphone usage is the most significant reason for having a severe crash. While, the pandemic use of cellphone on driving for navigation is inevitable, increasing the fine and increasing public awareness regarding other cellphone usage activities can promote traffic safety. This study considered other variables that contribute to having a severe crash as well. The variables that have the highest impact on increasing the severity of crashes are Not using seatbelts and using alcohol. In addition to correcting the wrong habits of the drivers, installing cameras on the roadway may be a solution to decrease crash severity. Collisions that occur in curves are more severe, therefore, decreasing the number of curves in a road, bettering their design and increasing the arc radius will decrease the severity of the collision.

6. Future work
Using a newer version of GES data set or the naturalistic driving data (Arvin, Kamrani, & Khattak, 2019) might reflect the proliferation of tablets and smartphone usage better in calling, texting, and using social media apps. It should be noticed that using a simulator for investigating the relationship between distraction and car crashes would be another direction for future research.

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Author details
Hesamoddin Razi-Ardakani1
E-mail: razi@mehr.sharif.ir
Ahmadreza Mahmoudzadeh2
E-mail: A.mahmoudzadeh@tamu.edu
ORCID ID: http://orcid.org/0000-0001-5792-6371
Mohammad Kermanshah1
E-mail: m.kermanshah@sharif.edu

1 Department of Civil Engineering, Sharif University of Technology, Azadi Avenue, P.O. Box 11365-8639, Tehran, Iran.
2 Zachry Department of Civil and Environmental Engineering, Texas A&M University, 301E Dwight Look Engineering Building, College Station, TX, 77843, USA.

Correction
This article has been republished with minor changes. These changes do not impact the academic content of the article.

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References
Abdel-Aty, M. (2003). Analysis of driver injury severity levels at multiple locations using ordered probit models. Journal of Safety Research, 34, 597–603. doi:10.1016/j.jsr.2003.05.009
Abdel-Aty, M., & Abdelwahab, H. (2004). Modelling rear-end collisions including the role of driver’s visibility and light truck vehicles using a nested logit structure. Accident Analysis & Prevention, 36, 447–456. doi:10.1016/S0001-4575(03)00040-X
Abdel-Aty, M., Ekram, -A.-A., Huang, H., & Choi, K. (2011). A study on crashes related to visibility obstruction due to fog and smoke. Accident Analysis & Prevention, 43, 1730–1737. doi:10.1016/j.aap.2011.04.003
Abdel-Aty, M., & Keller, J. (2005). Exploring the overall and specific crash severity levels at signalized intersections. Accident Analysis & Prevention, 37, 417–425. doi:10.1016/j.aap.2004.11.002
Abhari, M., Tabibi, M., Nejad, F. M., Khansari, E. R., & Amini, E. (1888–1896). The effect of playing video advertisement inside a car on driver visual distraction. Civil Engineering Journal, 4, 2018.
Ahangari, S., Jehhani, M., & Jarju, A. (2018). Drivers’ behavior analysis under rainy weather conditions using a driving simulator. Washington, DC: Transportation Research Board.
Al-Ghamdi, A. S. (2002). Using logistic regression to estimate the influence of accident factors on accident severity. Accident Analysis & Prevention, 34, 729–741. doi:10.1016/S0001-4575(01)00073-2
Altwaijri, S., Quddus, M., & Bristow, A. (2011). Factors affecting the severity of traffic crashes in Riyadh City. 90th Annual Meeting, Washington, DC: Transportation Research Board. https://trid.trb.org/view/1092996
Altwaijri, S., Quddus, M., & Bristow, A. (2012). Analysing the severity and frequency of traffic crashes in Riyadh city using statistical models. *International Journal of Transportation Science and Technology, 1*, 351–364. doi:10.1260/2046-0430.1.4.351

Alver, Y., Demirel, M. C., & Mutlu, M. M. (2014). Interaction between socio-demographic characteristics: Traffic rule violations and traffic crash history for young drivers. *Accident Analysis & Prevention, 72*, 95–104. doi:10.1016/j.aap.2014.06.015

Amarasinghe, N., & Dissanyake, S. (2014). Gender differences of young drivers on injury severity outcome of highway crashes. *Journal of Safety Research, 49*, 113.e1–120. doi:10.1016/j.jsr.2014.03.004

Anastasopoulos, P. C., & Manning, F. L. (2011). An empirical assessment of fixed and random parameter logit models using crash- and non-crash-specific injury data. *Accident Analysis & Prevention, 43*, 1140–1147. doi:10.1016/j.aap.2010.12.024

Arvin, R., Kamrani, M., & Khattak, A. J. (2019). The role of pre-crash driving instability in contributing to crash intensity using naturalistic driving data. *Accident Analysis & Prevention, 132*, 105226. doi:10.1016/j.aap.2019.07.002

Azimi, G., Asgari, H., Rahimi, A., & Jin, X. (2019). Investigation of heterogeneity in severity analysis for large truck crashes. Washington, DC: Transportation Research Board. [https://trid.trb.org/view/1658006](https://trid.trb.org/view/1658006)

Azimi, G., Rahimi, A., Asgari, H., & Jin, X. (2020). Severity analysis for large truck rollover crashes using a random parameter ordered logit model. *Accident Analysis & Prevention, 135*, 105355. doi:10.1016/j.aap.2019.105355

Aziz, H. M. A., Ukkusuri, S. V., & Hasan, S. (2013). Exploring the determinants of pedestrian-Vehicle crash severity in New York City. *Accident Analysis & Prevention, 50*, 1298–1309. doi:10.1016/j.aap.2012.09.034

Azizi, L., & Sheikholeslami, A. (2013). Safety effect of U-Turn Conversions in Tehran: Empirical bayes observational before-and-after study and crash prediction models. *Journal of Transportation Engineering, 139*, 101–108. doi:10.1061/(ASCE)TE.1943-9446.0000469

Azizi, L., Sheikholeslami, A., & Khalili, F. B. (2012). Safety analysis of unconventional U-Turn using neural network and crash prediction model. 10th International Congress on Advances in Civil Engineering (pp. 17–19). Ankara, Turkey.

Bocker-Grondahl, A., & Sagberg, F. (2011). Driving and telephoning: Relative accident risk when using hand-held and hands-free mobile phones. *Safety Science, 49*, 324–330. doi:10.1016/j safsci.2010.09.009

Beanland, V., Fitzharris, M., Young, K. L., & Lenné, M. G. (2013). Driver inattention and driver distraction in serious casualty crashes: Data from the Australian national crash in-depth study. *Accident Analysis & Prevention, 54*, 99–107. doi:10.1016/j.aap.2012.02.043

Bedard, M., Guyatt, G. H., Stones, M. J., & Hirdes, J. P. (2002). The independent contribution of driver, crash, and vehicle characteristics to driver fatalities. *Accident Analysis & Prevention, 34*, 717–727. doi:10.1016/S0001-4575(01)00072-0

Behnood, A., & Manning, F. L. (2015). The temporal stability of factors affecting driver-injury severities in single-vehicle crashes: Some empirical evidence. *Analytic Methods in Accident Research, 8*, 7–32. doi:10.1016/j.mar.2015.07.001

Behnood, A., & Manning, F. L. (2016). An empirical assessment of the effects of economic recessions on pedestrian-injury crashes using mixed and latent-class models. *Analytic Methods in Accident Research, 12*, 1–17. doi:10.1016/j.mar.2016.07.002

Behnood, A., Roshandeh, A. M., & Manning, F. L. (2014). Latent class analysis of the effects of age, gender, and alcohol consumption on driver-injury severities. *Analytic Methods in Accident Research 3*, 56–91. doi:10.1016/j.mar.2014.10.001

Behnood, A., Roshandeh, A. M., & Modiri Gharehveran, M. (2015). The effects of drivers’ behavior on driver-injury severities in Iran: An application of the mixed-logit model. *Science Iranica, 23* (6), 2429–2440.

Boufous, S., de Rome, L., Senserrick, T., & Ivers, R. (2012). Risk factors for severe injury in cyclists involved in traffic crashes in Victoria, Australia. *Accident Analysis & Prevention, 49*, 404–409. doi:10.1016/j.aap.2012.03.011

Brant, R. (1990). Assessing proportionality in the proportional odds model for ordinal logistic regression. *Biometrics, 46*, 1171–1178. doi:10.2307/2532457

Carson, J., & Manning, F. (2001). The effect of ice warning signs on ice-accident frequencies and severities. *Accident Analysis & Prevention, 33*, 99–109. doi:10.1016/S0001-4575(00)00020-8

Castro, M., Paleti, R., & Bhat, C. R. (2013). A spatial generalized ordered response model to examine highway crash injury severity. *Accident Analysis & Prevention, 49*, 188–203. doi:10.1016/j.aap.2012.12.009

Celik, A. K., & Oktay, E. (2014). A multinomial logit analysis of risk factors influencing road traffic injury severities in the Erzurum and Kars Provinces of Turkey. *Accident Analysis & Prevention, 72*, 66–77. doi:10.1016/j.aap.2014.06.010

Chang, L.-Y., & Manning, F. (1998). Predicting vehicle occupancies from accident data: An accident severity approach. *Transportation Research Record: Journal of the Transportation Research Board, 1635*, 93–104. doi:10.3141/1635-13

Chang, L.-Y., & Manning, F. (1999). Analysis of injury severity and vehicle occupancy in truck- and non-truck-involved accidents. *Accident Analysis & Prevention, 31*, 579–592. doi:10.1016/S0001-4575(99)00015-7

Chen, C., Zhang, G., Tarefder, R., Ma, J., Wei, H., & Guan, H. (2015). A multinomial logit model-Bayesian network hybrid approach for driver injury severity analyses in rear-end crashes. *Accident Analysis & Prevention, 80*, 76–88. doi:10.1016/j.aap.2015.03.036

Choiu, Y. C., Hwang, C. C., Chang, C. C., Fu, C., Chiu, Y.-C., Hwang, Y.-C., ... Fu, C. (2013). Modeling two-vehicle crash severity by a bivariate generalized ordered probit approach. *Accident Analysis & Prevention, 51*, 175–184. doi:10.1016/j.aap.2012.11.008

Choiu, Y. C., Lan, L. W., & Chen, W. P. (2013). A two-stage mining framework to explore key risk conditions on one-vehicle crash severity. *Accident Analysis & Prevention, 50*, 405–415. doi:10.1016/j.aap.2012.05.017

Christoforou, Z., Cohen, S., & Karlaftis, M. G. (2010). Vehicle occupant injury severity on highways: An empirical investigation. *Accident Analysis & Prevention, 42*, 1606–1620. doi:10.1016/j.aap.2010.03.019

Chung, Y., Song, T.-J., & Yoon, B.-J. (2019). An empirical assessment of fixed and random parameters of young drivers on injury severity outcome in New York City. *Driving and Traffic Safety*, 76. doi:10.1016/j.jsr.2014.03.004

Chung, Y., Song, T.-J., & Yoon, B.-J. (1994). Gender differences of young drivers on injury severity outcome of highway crashes. *Journal of Safety Research, 25* (6), 2429–2440.

Clogg, C., & Shihadeh, E. S. (1996). Statistical models for ordinal variables (Advanced quantitative techniques in the social sciences series, Vol. 4).
California: A mixed logit analysis of heterogeneity due to age and gender. Accident Analysis & Prevention, 50, 1073–1081. doi:10.1016/j.aap.2012.08.011
Kockelman, K. M., & Kweon, Y.-J. (2002). Driver injury severity: An application of ordered probit models. Accident Analysis & Prevention, 34, 313–321. doi:10.1016/S0001-4575(01)00028-8
Konen, D. W., Flannagan, C. A. C., & Wang, S. C. (2011). Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes. Accident Analysis & Prevention, 43, 112–122. doi:10.1016/j.aap.2010.07.018
Kutner, M. H., Nachtsheim, C. J., Neter, J., & Li, W. (2004). Applied linear regression models. Boston: McGraw-Hill/Irwin.
Landsdown, T. C., Brook-Carter, N., & Kersloot, T. (2006). Distraction from multiple in-vehicle secondary tasks: Vehicle performance and mental workload implications. Ergonomics, 47, 91–104. doi:10.1080/00139290410001629775
Lee, C., & Abdel-Aty, M. (2008). Presence of passengers: Does it increase or reduce driver’s crash potential? Accident Analysis & Prevention, 40, 1703–1712. doi:10.1016/j.aap.2008.06.006
Lee, C., & Li, X. (2014). Analysis of injury severity of drivers involved in single- and two-vehicle crashes on highways in Ontario. Accident Analysis & Prevention, 71, 286–295. doi:10.1016/j.aap.2014.06.008
Lee, J., & Mannering, F. (2002). Impact of roadside features on the frequency and severity of run-off-roadway accidents: An empirical analysis. Accident Analysis & Prevention, 34, 149–161. doi:10.1016/S0001-4575(01)00009-4
Lemp, J. D., Kockelman, K. M., & Unnikrishnan, A. (2011). Analysis of large truck crash severity using heteroskedastic ordered probit models. Accident Analysis & Prevention, 43, 370–380. doi:10.1016/j.aap.2010.09.006
Li, Z., Liu, P., Wang, W., & Xu, C. (2012). Using support vector machine models for crash injury severity analysis. Accident Analysis & Prevention, 45, 478–486. doi:10.1016/j.aap.2011.08.016
Liu, Z., & Donmez, B. (2011). Effects of distractions on injury severity in police-involved crashes. Transportation Research Record (pp. 1–13). Washington, DC.
Loeb, P. D., Clarke, W. A., & Anderson, R. (2009). The impact of cell phones on motor vehicle fatalities. Applied Economics, 41, 2905–2914. doi:10.1080/00036840701858133
Ma, L., Wang, G., Yan, X., & Weng, J. (2016). A hybrid finite mixture model for exploring heterogeneous ordering patterns of driver injury severity. Accident Analysis & Prevention, 89, 62–73. doi:10.1016/j.aap.2016.01.004
Mahmoudzadeh, A., Razi-Ardakani, H., & Kermanshah, M. (2019). Studying crash avoidance maneuvers prior to an impact considering different types of driver’s distractions. Transportation Research Procedia, 37, 203–210. doi:10.1016/J.TRPRO.2018.12.184
Maloushkina, N., & Mannering, F. (2008). Effect of increases in speed limits on severities of injuries in accidents. Transportation Research Procedia: Journal of the Transportation Research Board, 2083, 122–127. doi:10.3141/2083-14
Malyskhina, N. V., & Mannering, F. L. (2010). Empirical assessment of the impact of highway design exceptions on the frequency and severity of vehicle accidents. Accident Analysis & Prevention, 42, 131–139. doi:10.1016/j.aap.2009.07.013
Manner, H., & Wünsch-Ziegler, L. (2013). Analyzing the severity of accidents on the German Autobahn. Accident Analysis & Prevention, 57, 40–48. doi:10.1016/j.aap.2013.03.022
Mansourkhaki, A., Karimpour, A., & Sadoghi Yazdi, H. (2016). Non-stationary concept of accident prediction. Proceedings of the Institution of Civil Engineers (pp. 140–151). Thomas Telford Ltd. doi:10.1142/S2424835516400063
Mansourkhaki, A., Karimpour, A., & Yazdi, H. S. (1912–1918). Introducing prior knowledge for a hybrid accident prediction model. KSCE Journal of Civil Engineering, 21, 2017.
McEvoy, S. P., Stevenson, M., McCart, A. T., Woodward, M., Howarth, C., Polamara, P., & Cecarelli, R. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: A case–crossover study. Bmj, 331, 428. doi:10.1136/bmj.38537.397512.55
McEvoy, S. P., Stevenson, M. R., & Woodward, M. (2006). Phone use and crashes while driving: A representative survey of drivers in two Australian states. Medical Journal of Australia, 185, 630–634. doi:10.5594/mpj.2006.185.issue-11-12
Mergia, V. W., Eustace, D., Chimba, D., & Qumsiyeh, M. (2013). Exploring factors contributing to injury severity at freeway merging and diverging locations in Ohio. Accident Analysis & Prevention, 55, 202–210. doi:10.1016/j.aap.2013.03.008
Michalaki, P., Quddus, M. A., Pitfield, D., & Huetson, A. (2013). Exploring the factors affecting motorway accident severity in England using the generalised ordered logistic regression model. Journal of Safety Research, 55, 89–97. doi:10.1016/j.jsr.2015.09.004
Milton, J. C., Shankar, V. N., & Mannering, F. L. (2008). Highway accident severities and the mixed logit model: An exploratory empirical analysis. Accident Analysis & Prevention, 40, 260–266. doi:10.1016/j.aap.2007.06.006
Mohamed, M. G., Saunier, N., Miranda-Moreno, L. F., & Ulkkusu, S. V. (2013). A clustering regression approach: A comprehensive injury severity analysis of pedestrian–Vehicle crashes in New York, US and Montreal, Canada. Safety Science, 54, 27–37. doi:10.1016/j.ssci.2012.11.001
Mokhtarimousavi, S. (2019). A time of day analysis of pedestrian-involved crashes in California: Investigation of injury severity, a logistic regression and machine learning approach using HSIS data. Institute of Transportation Engineers ITE Journal, 89, 25–33.
Mokhtarimousavi, S., Anderson, J. C., Azizinamini, A., & Hadi, M. (2019). Improved support vector machine models for work zone crash injury severity prediction and analysis. Transportation Research Record, 2673, 680–692. doi:10.1177/0361198119845899
Mooradian, J., Ivan, J. N., Ravishanker, N., & Hu, S. (2013). Analysis of driver and passenger crash injury severity using partial proportional odds models. Accident Analysis & Prevention, 58, 53–58. doi:10.1016/j.aap.2013.06.022
Moore, D. N., Schneider, W. H., IV, Savolainen, P. T., & Farzaneh, M. (2011). Mixed logit analysis of bicyclist injury severity resulting from motor vehicle crashes at intersection and non-intersection locations. Accident Analysis & Prevention, 43, 621–630. doi:10.1016/j.aap.2010.09.015
Moran, A., & Mannering, F. L. (1852–1863). The effects of road-surface conditions, age, and gender on driver-injury severities. Accident Analysis & Prevention, 43, 2011.
Motamedi, S., Hasheminejad, M., & Choe, P. (2015). Driving safety considered user interface of a smartphone: An experimental comparison, in: International Conference on Cross-Cultural Design (pp. 150–160), Springer. doi:10.1177/1753193414524589

National Highway Traffic Safety Administration (NHTSA). (2017). Traffic safety facts, distracted driving in fatal crashes.

Neyens, D. M., & Boyle, L. N. (2007). The effect of distractions on the crash types of teenage drivers. Accident Analysis & Prevention, 39, 206–212. doi:10.1016/j.aap.2006.07.004

Neyens, D. M., & Boyle, L. N. (2008). The influence of driver distraction on the severity of injuries sustained by teenage drivers and their passengers. Accident Analysis & Prevention, 40, 254–259. doi:10.1016/j.aap.2007.06.005

NHTSA (2008). Driver Electronic Device Use. DOT HS 811.

N.H.T.S. NHTSA. (2015). Traffic safety facts: Research note. Distracted driving 2013 (Report No. DOT HS 812 132).

NHTSA’s National Center for Statistics and Analysis. (2015). DOT HS 812 326 Traffic Safety Facts, Research Note Driver Electronic Device Use in 2015, 2013, 1–8.

O’Donnell, C. J., & Connor, D. H. (1996). Predicting the severity of motor vehicle accident injuries using models of ordered multiple choice. Accident Analysis & Prevention, 28, 739–753. doi:10.1016/0001-4575(96)00050-4

Obeng, K. G. (2011). Gender differences in injury severity risks in crashes at signalized intersections. Accident Analysis & Prevention, 43, 1521–1531. doi:10.1016/j.aap.2011.03.004

Oh, J. T. (2006). Development of severity models for vehicle accident injuries for signalized intersections in rural areas. KSCE Journal of Civil Engineering, 10, 219–225. doi:10.1007/BF02824064

Palei, R., Eluru, N., & Bhat, C. R. (2010). Examining the influence of aggressive driving behavior on driver injury severity in traffic crashes. Accident Analysis & Prevention, 42, 1839–1854. doi:10.1016/j.aap.2010.05.005

Parsa, A. B., Chauhan, R. S., Taghipour, H., & Derrible, S. (2019). Applying deep learning to detect traffic accidents in real time using spatiotemporal sequential data, ArXiv Prepr. ArXiv1912.06991 [Stat. ML].

Parsa, A. B., Movahedi, A., Taghipour, H., Derrible, S., & Mohammadian, A. (2020). Toward Safer Highways, Application of XGBoost and SHAP for Real-Time Accident Detection and Feature Analysis. Accident Analysis & Prevention, 136, 105405. doi:10.1016/j.aap.2019.105405

Parsa, A. B., Taghipour, H., Derrible, S., & Mohammadian, A. (2019). Real-time accident detection: Coping with imbalanced data. Accident Analysis & Prevention, 129, 202–210. doi:10.1016/j.aap.2019.05.014

Patil, S., Reddy, S., & Reddy, S. (2012). Analysis of crash severities using nested logit model-accounting for the underreporting of crash data. Accident Analysis & Prevention, 45, 646–653. doi:10.1016/j.aap.2011.09.034

Peek-Asa, C., Britton, C., Young, T., Pavlovich, M., & Falb, S. (2010). Teenage driver crash incidence and factors influencing crash injury by rurality. Journal of Safety Research, 41, 487–492. doi:10.1016/j.jsr.2010.10.002

Pei, X., Wong, S. C., & Sze, N. N. (2012). The roles of exposure and speed in road safety analysis. Accident Analysis & Prevention, 48, 464–471. doi:10.1016/j.aap.2012.03.005

Pour-Rouholamin, M., & Zhou, H. (2016). Analysis of driver injury severity in wrong-way driving crashes on controlled-access highways. Accident Analysis & Prevention, 94, 80–88. doi:10.1016/j.aap.2016.05.022

Pratt, M., & Bonnese, J. (2008). Assessing curve severity and design consistency using energy- and friction-based measures. Transportation Research Record: Journal of the Transportation Research Board, 2075, 8–15. doi:10.3141/2075-02

Quddus, M. A., Wang, C., & Ison, S. G. (2009). Road traffic congestion and crash severity: Econometric analysis using ordered response models. Journal of Transportation Engineering, 136, 424–435. doi:10.1061/(ASCE)TE.1943-5436.0000044

Rana, T., Sikder, S., & Pinjari, A. (2010). Copula-based method for addressing endogeneity in models of severity of traffic crash injuries: Application to two-vehicle crashes. Transportation Research Record: Journal of the Transportation Research Board, 2147, 75–87. doi:10.3141/2147-10

Razi-Ardakani, H., Kermanshah, M., & Mahmoudzadeh, A. (2017). A copula-based estimator for estimating nested logit model: Special focus on distraction-related factors. Transportation Research Board, Washington D.C., No. 17–06836.

Razi-Ardakani, H., Mahmoudzadeh, A., & Kermanshah, M. (2016). A nested logit analysis of the influence of distraction on types of vehicle crashes. European Transport Research Review, 10, 44. doi:10.1186/s12544-018-0316-6

Regan, M. (2006). Preventing traffic accidents by mobile phone users. Medical Journal of Australia, 185, 628–629. doi:10.5694/mja2.2006.185.issue-11-12

Reimer, B., Meher, B., Coughlin, J. F., Roy, N., & Dusek, J. A. (2011). The impact of a naturalistic hands-free cellular phone task on heart rate and simulated driving performance in two age groups. Transportation Research Part F: Traffic Psychology and Behaviour, 14, 13–25. doi:10.1016/j.trf.2010.09.002

Renski, H., Khattak, A., & Council, F. (1999). Effect of speed limit increases on crash injury severity: Analysis of single-vehicle crashes on North Carolina interstate highways. Transportation Research Record: Journal of the Transportation Research Board, 1665, 100–108. doi:10.3141/1665-14

Rifaa, S., & Tay, R. (2009). Effects of street patterns on injury risks in two-vehicle crashes. Transportation Research Record: Journal of the Transportation Research Board, 2102, 61–67. doi:10.3141/2102-08

Rifaa, S. M., Tay, R., & De Barros, A. (2012). Severity of motorcycle crashes in Calgary. Accident Analysis & Prevention, 49, 44–49. doi:10.1016/j.aap.2011.02.025

Rifaa, S. M., Tay, R., & De Barros, A. (2013). Effect of street pattern on the severity of crashes involving vulnerable road users. Accident Analysis & Prevention, 57, 276–283. doi:10.1016/j.aap.2010.08.024

Roque, C., Moura, F., & Cardoso, J. L. (2005). Detecting unforgiving roadside contributors through the severity analysis of run-off-road crashes. Accident Analysis & Prevention, 37, 262–273. doi:10.1016/j.aap.2015.02.012

Sesidharan, L., & Menéndez, M. (2014). Partial proportional odds model—An alternate choice for analyzing pedestrian crash injury severities. Accident Analysis & Prevention, 72, 330–340. doi:10.1016/j.aap.2014.07.025
Savolainen, P., & Ghosh, I. (2008). Examination of factors affecting driver injury severity in Michigan's Single-Vehicle—Deer Crashes. Transportation Research Record: Journal of the Transportation Research Board, 2078, 17–25. doi:10.3141/2078-03

Savolainen, P., & Manering, F. (2007). Probabilistic models of motorcyclists’ injury severities in single- and multi-vehicle crashes. Accident Analysis & Prevention, 39, 955–963. doi:10.1016/j.aap.2006.12.016

Savolainen, P. T., Manering, F. L., Lord, D., & Quddus, M. A. (2011). The statistical analysis of highway crash-injury severities: A review and assessment of methodological alternatives. Accident Analysis & Prevention, 43, 1666–1676. doi:10.1016/j.aap.2011.03.025

Schneider, W., IV, Savolainen, P., & Zimmermann, K. (2009). Driver injury severity resulting from single-vehicle crashes along horizontal curves on rural two-lane highways. Transportation Research Record: Journal of the Transportation Research Board, 2102, 85–92. doi:10.3141/2102-11

Shaheed, M. S. B., Gkritza, K., Zhang, W., & Hans, Z. (2013). A mixed logit analysis of two-vehicle crash severities involving a motorcycle. Accident Analysis & Prevention, 61, 119–128. doi:10.1016/j.aap.2013.05.028

Shankar, V., & Manering, F. (1996). An exploratory multinomial logit analysis of single-vehicle motorcycle accident severity. Journal of Safety Research, 27, 183–194. doi:10.1016/0022-4379(96)00010-2

Shankar, V., Manering, F., & Barfield, W. (1996). Statistical analysis of accident severity on rural freeways. Accident Analysis & Prevention, 28, 391–401. doi:10.1016/0001-4575(96)00009-7

Ship, D. F., Newman, I. M., Córdova-Cazar, A. L., & Heese, J. M. (2015). Driver education and teen crashes and traffic violations in the first two years of driving in a graduated licensing system. Accident Analysis & Prevention, 82, 45–52. doi:10.1016/j.aap.2015.05.011

Shirani, N, Doustniamhmadii, M., Haleem, K., & Anderson, M. (2018). Safety investigation of nonmotorized crashes in the City of Huntsville, Alabama, using count regression models. Washington, DC: Transportation Research Board.

Siskind, V., Steinhardt, D., Sheehan, M., O’Connor, T., & Hanks, H. (2011). Risk factors for fatal crashes in rural Australia. Accident Analysis & Prevention, 43, 1082–1088. doi:10.1016/j.aap.2010.12.016

Strayer, D. L., & Drews, F. A. (2004). Profiles in driver distraction: Effects of cell phone conversations on younger and older drivers. Human Factors: the Journal of the Human Factors and Ergonomics Society, 46, 640–649. doi:10.1518/0018720046806

Tay, R. (2016). Comparison of the binary logistic and skewed logistic (Scobit) models of injury severity in motor vehicle collisions. Accident Analysis & Prevention, 88, 52–55. doi:10.1016/j.aap.2015.12.009

Ulak, M. B., Ozgunen, E., Karabag, H. H., Ghorbanzadeh, M., Moses, R., & Dubebnetis, M. (2019). Development of safety performance functions for Restricted Crossing U-Turn (RCUT) intersections. Journal of Transportation Engineering Part A: Systems. doi: 10.1061/ JTEPRA.000346

Ulfarsson, G. F., & Manering, F. L. (2004). Differences in male and female injury severities in sport-utility vehicle, minivan, pickup and passenger car accidents. Accident Analysis & Prevention, 36, 135–147. doi:10.1016/S0001-4575(02)00135-5

Wang, X., & Abdel-Aty, M. (2008). Analysis of left-turn crash injury severity by conflict pattern using partial proportional odds models. Accident Analysis & Prevention, 40, 1674–1682. doi:10.1016/j.aap.2008.06.001

Wang, Z., Chen, H., & Lu, J. (2009). Exploring impacts of factors contributing to injury severity at freeway diverge areas. Transportation Research Record: Journal of the Transportation Research Board, 2102, 43–52. doi:10.3141/2102-06

Weiss, H. B., Kaplan, S., & Prato, C. G. (2014). Analysis of factors associated with injury severity in crashes involving young New Zealand drivers. Accident Analysis & Prevention, 65, 142–155. doi:10.1016/j.aap.2013.12.020

Wu, Q., Chen, F., Zhang, G., Liu, X. C., Wang, H., & Bogus, S. M. (2014). Mixed logit model-based driver injury severity investigations in single- and multi-vehicle crashes on rural two-lane highways. Accident Analysis & Prevention, 72, 105–115. doi:10.1016/j.aap.2014.06.014

Wu, Q., Zhang, G., Zhu, X., Liu, X. C., & Tarefder, R. (2016). Analysis of driver injury severity in single-vehicle crashes on rural and urban roadways. Accident Analysis & Prevention, 94, 35–45. doi:10.1016/j.aap.2016.03.026

Xie, Y., Zhang, Y., & Liang, F. (2009). Crash injury severity analysis using Bayesian ordered probit models. Journal of Transportation Engineering, 135, 18–25. doi:10.1061/(ASCE)0733-947X(2009)135:1(3)
Yu, R., & Abdel-Aty, M. (2014). Using hierarchical Bayesian binary probit models to analyze crash injury severity on high speed facilities with real-time traffic data. Accident Analysis & Prevention, 62, 161–167. doi:10.1016/j.aap.2013.08.009

Zhang, G., Yau, K. K. W., & Chen, G. (2013). Risk factors associated with traffic violations and accident severity in China. Accident Analysis & Prevention, 59, 18–25. doi:10.1016/j.aap.2013.05.004

Zhang, J., Lindsay, J., Clarke, K., Robbins, G., & Mao, Y. (2000). Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. Accident Analysis & Prevention, 32, 117–125. doi:10.1016/S0001-4575(99)00039-1

Zhu, X., & Srinivasan, S. (2011a). Modeling occupant-level injury severity: An application to large-truck crashes. Accident Analysis & Prevention, 43, 1427–1437. doi:10.1016/j.aap.2011.02.021

Zhu, X., & Srinivasan, S. (2011b). A comprehensive analysis of factors influencing the injury severity of large-truck crashes. Accident Analysis & Prevention, 43, 49–57. doi:10.1016/j.aap.2010.07.007
Table A1. Affective factors on crash injury severity

| Variable          | Increase crash severity | Decrease crash severity |
|-------------------|--------------------------|-------------------------|
| **Characteristics of the driver** |                          |                         |
| Male              |                          |                         |
| (Weiss et al., 2014, Kim, Ulfarsson, Kim, & Shankar, 2013, Zhang, You, & Chen, 2013, Shankar & Mannering, 1996, Renski, Khattak, & Council, 1999, Zhang, Lindsay, Clarke, Robbins, & Mao, 2000) | (Hanley & Sikka, 2012, Yasmin & Eluru, 2013, Jiang et al., 2013, Chiou et al., 2013) |
| Female            |                          |                         |
| (Donmez & Liu, 2015, Lee & Li, 2014, Yasmin, Eluru, Pinjari, & Tay, 2014, Mergia, Eustace, Chimba, & Qumsiyeh, 2013, Wu, Zhang, Zhu, Liu, & Tareffler, 2016, Wu et al., 2014, Yasmin, Eluru, Bhat, & Tay, 2014, Ma, Wang, Yan, & Weng, 2016, Castro, Paleti, & Bhat, 2013) | (Roque, Moura, & Cardoso, 2015) |
| Young drivers    | (Chang & Mannering, 1999, Jiang et al., 2013, Lee & Li, 2014) |                         |
| Elderly drivers  | (Chang & Mannering, 1999, Hanley & Sikka, 2012, Paleti et al., 2010, Wang & Abdel-Aty, 2008, Anastasopoulos & Mannering, 2011, Kim et al., 2013, Zhang et al., 2000, Yasmin & Eluru, 2013, Chiou et al., 2013, Donmez & Liu, 2015, Yasmin et al., 2014, Wu et al., 2016, Wu et al., 2014, Yasmin et al., 2014, Haleem & Gan, 2011, Xie et al., 2012, Khattak et al., 1998, Rana et al., 2010, Abdel-Aty, 2003, Haleem & Abdel-Aty, 2010, Chiou, Lan, & Chen, 2013, Celik & Oktay, 2014, Zhu & Sirivavan, 2011, 2013) | (Castro et al., 2013, Yasmin et al., 2015, Pour-Rouholamin & Zhou, 2016, Haleem & Gan, 2013) |
| Increase in age   | (Altwaijri et al., 2011, Xie et al., 2009, Kockelman & Kwean, 2002, O’Donnell & Connor, 1996, Khattak, 2001, Al-Ghamdi, 2002, Bedard, Guyatt, Stones, & Hirdes, 2002, Yamamoto, Hashi, & Shankar, 2008, Schneider, Savolainen, & Zimmerman, 2009) | (Lee & Li, 2014, Mergia et al., 2013, Roque et al., 2015, Manner & Wunsch-Ziegler, 2013) |

(Continued)
| Variable                        | Increase crash severity                                                                 | Decrease crash severity                                                                 |
|--------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Alcohol or drug impairment     | (Chang & Mannering, 1999, Hanley & Sikka, 2012, Holdridge et al., 2005, Weiss et al., 2014, Xie et al., 2009, Paletti et al., 2010, Wang & Abdel-Aty, 2008, Lee & Abdel-Aty, 2008, Shankar et al., 1996, Rifaat & Tay, 2009, Obeng, 2011, Anastasopoulos & Mannering, 2011, Kim et al., 2013, Zhang et al., 2013, Renski et al., 1999, Zhang et al., 2000, Yasmin & Eluru, 2013, Chiou et al., 2013, Donmez & Liu, 2015, Lee & Li, 2014, Mergia et al., 2013, Wu et al., 2016, Wu et al., 2014, Haleem & Gan, 2011, Yasmin et al., 2015, Khattak et al., 1998, Rana et al., 2010, Chiou et al., 2013, Zhu & Srinivasan, 2011a, Pour-Rouholamin & Zhou, 2016, O'donnell & Connor, 1996, Bedard et al., 2002, Yamamoto et al., 2008, Schneider et al., 2009, Chang & Mannering, 1998, Carson & Mannering, 2001, Lee & Mannering, 2002, Das, Pande, Abdel-Aty, & Santos, 2008, Wang, Chen, & Lu, 2009, Peek-Asa, Britton, Young, Pawlovich, & Falb, 2010, Li, Liu, Wang, & Xu, 2012, Chen et al., 2015, Amarasingha & Dissanayake, 2014, Siskind, Steinhardt, Sheehan, O'Connor, & Hanks, 2011) |  |
| Drowsy, sleepy, fatigued       | (Holdridge et al., 2005, Weiss et al., 2014, Obeng, 2011, Anastasopoulos & Mannering, 2011, Zhang et al., 2000, Lee & Li, 2014, Yamamoto et al., 2008, Schneider et al., 2009, Islam & Mannering, 2006, Michalaki, Quddus, Pittfield, & Huetson, 2015) |  |
| Not using seatbelts            | (Chang & Mannering, 1999, Hanley & Sikka, 2012, Holdridge et al., 2005, Weiss et al., 2014, Ulforsson & Mannering, 2004, Paletti et al., 2010, Wang & Abdel-Aty, 2008, Savolainen & Ghosh, 2008, Shankar et al., 1996, Hu & Donnell, 2011a, Obeng, 2011, Anastasopoulos & Mannering, 2011, Kim et al., 2013, Zhang et al., 2000, Donmez & Liu, 2015, Lee & Li, 2014, Yasmin et al., 2014, Yasmin et al., 2014, Ma et al., 2016, Castro et al., 2013, Khattak & Rocha, 2003, Abdel-Aty, 2003, Chiou et al., 2013, Zhu & Srinivasan, 2011a, Pour-Rouholamin & Zhou, 2016, O'donnell & Connor, 1996, Bedard et al., 2002, Yamamoto et al., 2008, Schneider et al., 2009, Chang & Mannering, 1998, Peek-Asa et al., 2010, Chen et al., 2015, Amarasingha & Dissanayake, 2014, Islam & Mannering, 2006, Hu & Donnell, 2011b, Jung, Qin, & Noyce, 2010, Kononen, Flannagan, & Wang, 2011) |  |
| Airbag deployed                | (Yasmin & Eluru, 2013, Zhu & Srinivasan, 2011a, Pour-Rouholamin & Zhou, 2016, Amarasingha & Dissanayake, 2014, Ye & Lord, 2014) |  |
| Distraction                    | (Holdridge et al., 2005, Weiss et al., 2014, Donmez & Liu, 2015, Ma et al., 2016, Chiou et al., 2013, Michalaki et al., 2015) | (Chang & Mannering, 1999, Altwaijri et al., 2011, Hanley & Sikka, 2012) |
Table A1. (Continued)

| Variable | Increase crash severity | Decrease crash severity |
|----------|--------------------------|-------------------------|
| Speeding | (Chang & Mannering, 1999, Altwaijri et al., 2011, Holdridge et al., 2005, Ulfarsson & Mannering, 2004, Rifaat & Tay, 2009, Zhang et al., 2013, Donmez & Liu, 2015, Mergia et al., 2013, Khattak et al., 1998, Abdel-Aty, 2003, O’Donnell & Connar, 1996, Yamamoto et al., 2008, Schneider et al., 2009, Chang & Mannering, 1998, Lee & Mannering, 2002, Siskind et al., 2011, Islam & Mannering, 2006, Hassan & Al-Faleh, 2013) | (Shankar et al., 1996) |
| Unfamiliarity with the place | (Weiss et al., 2014, Yasmin et al., 2014, Chen et al., 2015) | (Zhu & Srivivasan, 2011a) |
| Conditional and Environmental Properties | | |
| Presence of passengers | (Weiss et al., 2014, Ulfarsson & Mannering, 2004, Renski et al., 1999, Donmez & Liu, 2015, Castro et al., 2013, Schneider et al., 2009, Chang & Mannering, 1998, Islam & Mannering, 2006, Michalaki et al., 2015, Oh, 2006) | (Weiss et al., 2014, Kockelman & Kweon, 2002, Paleti et al., 2010, Lee & Abdel-Aty, 2008, Yasmin et al., 2014, Yasmin et al., 2014, Ma et al., 2016, Zhu & Srivivasan, 2011a, Yamamoto et al., 2008, Malyshkina & Mannering, 2010) |
| Vision obscured | (Zhang et al., 2013, Manner & Wünsch-Ziegler, 2013, Das et al., 2008) | |
| Light or daytime | (Ma et al., 2016) | (Lee & Li, 2014, Manner & Wünsch-Ziegler, 2013, Michalaki et al., 2015, Shaheed, Gkritza, Zhang, & Hans, 2013) |
| Dark or night | (Chang & Mannering, 1999, Altwaijri et al., 2011, Weiss et al., 2014, Xie et al., 2009, Kockelman & Kweon, 2002, Gray et al., 2008, Rifaat & Tay, 2009, Zhang et al., 2013, Zhang et al., 2000, Chiu et al., 2013, Donmez & Liu, 2015, Wu et al., 2014, Roque et al., 2015, Rana et al., 2010, Abdel-Aty et al., 2011, Haleem & Abdel-Aty, 2010, Pour-Rouholamin & Zhou, 2016, Khattak, 2001, Chang & Mannering, 1998, Wang et al., 2009, Peck-Asa et al., 2010, Li et al., 2012, Chen et al., 2015, Hu & Donnell, 2011b, Jung et al., 2010) | (Ulfarsson & Mannering, 2004, Xie et al., 2012, Al-Ghamdi, 2002, Das et al., 2008, Ye & Lord, 2014, Quddus, Wang, & Ison, 2009) |
| Lighted dark | (Yasmin et al., 2014, Haleem & Gan, 2011, Pour-Rouholamin & Zhou, 2016) | (Savolainen & Ghosh, 2008, Ye & Lord, 2014) |
| Not lighted dark | (Weiss et al., 2014, Kim et al., 2013, Zhang et al., 2013, Chiu et al., 2013, Pour-Rouholamin & Zhou, 2016) | (Haldridge et al., 2005, Savolainen & Ghosh, 2008, Yasmin et al., 2014) |
| Dawn or dusk | (Zhang et al., 2000, Wu et al., 2014, Yasmin et al., 2014) | (Savolainen & Ghosh, 2008, Haleem & Gan, 2011, Haleem & Abdel-Aty, 2010, Khattak, 2001) |
| Fog | (Castro et al., 2013, Ye & Lord, 2014) | |
| Bad weather | (Zhang et al., 2000) | (Gray et al., 2008, Jiang et al., 2013, Donmez & Liu, 2015, Mergia et al., 2013) |

(Continued)
| Variable                | Increase crash severity                                                                 | Decrease crash severity                                                                 |
|-------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| Fair/cloudy weather     | (Chang & Mannering, 1999, Hanley & Sikka, 2012, Xie et al., 2009, Kim et al., 2013,    | (Haleem & Gan, 2011, Abdel-Aty, 2003, Celik & Oktay, 2014, Das et al., 2008, Wang et al., 2009, Li et al., 2012) |
|                         | Khattak et al., 1998, Schneider et al., 2009, Chang & Mannering, 1998, Lee &          |                                                                                         |
|                         | Mannering, 2002, Michalaki et al., 2015)                                                |                                                                                         |
| windy weather           | (Yasmin et al., 2014, Chen et al., 2015)                                                | (Yasmin et al., 2014)                                                                  |
| Rainy or snowy weather  | (Zhang et al., 2000, Yasmin et al., 2014, Yasmin et al., 2014)                           | (Ulfarsson & Manering, 2004, Paleti et al., 2010, Gray et al., 2008, Zhang et al., 2000,  |
|                         |                                                                                         | Yasmin & Eluru, 2013, Wu et al., 2016, Wu et al., 2014, Castro et al., 2013, Yamamoto et al., 2008, Islam & Manering, 2006, Pei, Wang, & Sze, 2012) |
| Winter                  | (Chang & Mannering, 1999, Zhang et al., 2013, Yasmin et al., 2014)                       | (Manner & Wünsch-Ziegler, 2013)                                                        |
| Peak of traffic         |                                                                                         | (Chang & Manering, 1999, Ulfarsson & Manering, 2004, Paleti et al., 2010, Gray et al., 2008, Zhang et al., 2013, Wu et al., 2016, Yasmin et al., 2014, Roque et al., 2015, Haleem & Gan, 2011, Khattak et al., 1998, Celik & Oktay, 2014, Haleem & Gan, 2013, Khattak, 2001, Chang & Mannering, 1998, Wang et al., 2009, Michalaki et al., 2015, Quddus et al., 2009) |
| Higher traffic volume   | (Khattak, 2001, Das et al., 2008, Wang et al., 2009)                                     | (Lee & Abdel-Aty, 2008, Mergia et al., 2013, Abdel-Aty et al., 2011, Haleem & Abdel-Aty, 2010, Oh, 2006, Quddus et al., 2009) |
| AADT                    | (Mergia et al., 2013)                                                                    | (Jiang et al., 2013, Ye & Lord, 2014)                                                  |
| Weekend                 | (Gray et al., 2008, Zhang et al., 2013, Zhang et al., 2000, Chang & Mannering, 1998,    | (Lee & Abdel-Aty, 2008)                                                                |
|                         | Michalaki et al., 2015, Hassan & Al-Faleh, 2013, Quddus et al., 2009)                    |                                                                                         |

Table A1. (Continued)
### Table A1. (Continued)

| Variable                        | Increase crash severity                                                                 | Decrease crash severity                                                                 |
|---------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| **Trucks**                      | (Lee & Li, 2014; Mergia et al., 2013; Wu et al., 2014; Castro et al., 2013; Haleem & Gan, 2011; Khattak et al., 1998; Chiu et al., 2013; Chang & Manering, 1996; Chen et al., 2015) | (Rifaat & Tay, 2009; Abdel-Aty, 2003; Haleem & Gan, 2013; Yamamoto et al., 2008; Maner & Wünsch-Ziegler, 2013) |
| **Heavy vehicles**              | (Weiss et al., 2014; Michalaki et al., 2015)                                            |                                                                                       |
| **Old vehicles/Increase in vehicles age** | (Hanley & Sikka, 2012; Xie et al., 2009; Kockelman & Kweon, 2002; Kim et al., 2013; Yasmin & Eluru, 2013; Lee & Li, 2014; Yasmin et al., 2014; Yasmin et al., 2014; O’Donnell & Connor, 1996; Bedard et al., 2002; Amarasingha & Dissanayake, 2014) | (Ulfarsson & Manering, 2004; Donmez & Liu, 2015; Rana et al., 2010; Khattak, 2001; Yamamoto et al., 2008; Islam & Manering, 2006; Malyshkina & Manering, 2010) |
| **Characteristics of the road** |                                                                                        |                                                                                        |
| **Steep roads**                 | (Xie et al., 2009; Yasmin et al., 2014; Roque et al., 2015; Al-Ghamdi, 2002; Wang et al., 2009; Quddus et al., 2009; Pei et al., 2012; Yu & Abdel-Aty, 2014) | (Xie et al., 2012; Rana et al., 2010)                                                |
| **Curves**                      | (Xie et al., 2009; Savolainen & Ghosh, 2008; Shankar et al., 1996; Hu & Donnell, 2011a; Anastasopoulos & Manering, 2011; Zhang et al., 2000; Donmez & Liu, 2015; Lee & Li, 2014; Wu et al., 2016; Das et al., 2008; Wang et al., 2009; Hu & Donnell, 2011b; Jung et al., 2010; Ye & Lord, 2014; Quddus et al., 2009; Pei et al., 2012; Hosseinpour, Yahaya, & Sadullah, 2014) |                                                                                       |
| **Multiple lane width**         | (Mergia et al., 2013; Wu et al., 2016; Ma et al., 2016; Castro et al., 2013)              | (Lee & Li, 2014; Zhu & Srinivasan, 2011a)                                             |
| **Increase lane width**         |                                                                                        |                                                                                        |
| **Unpaved**                     | (Jiang et al., 2013; Lee & Li, 2014)                                                    | (Jiang et al., 2013; Lee & Li, 2014; Castro et al., 2013)                            |
| **Dry surface**                 | (Chang & Manering, 1999; Xie et al., 2009; Hu & Donnell, 2011a; Wu et al., 2014; Haleem & Gan, 2011; Manner & Wünsch-Ziegler, 2013; Chang & Manering, 1998; Lee & Manering, 2002; Das et al., 2008; Wang et al., 2009; Michalaki et al., 2015; Hu & Donnell, 2011b; Shaheed et al., 2013; Quddus et al., 2009) | (Holdridge et al., 2005; Gray et al., 2008; Obeng, 2011; Kim et al., 2013; Renski et al., 1999; Zhang et al., 2000; Ma et al., 2016; Khattak et al., 1998; Pour-Rouholamin & Zhou, 2016; Li et al., 2012; Islam & Manering, 2006) |
| **Wet surface**                 | (Ulfarsson & Manering, 2004; Rifaat & Tay, 2009; Lee & Li, 2014; Zhu & Srinivasan, 2011a; Khattak, 2001; Lee & Manering, 2002) | (Holdridge et al., 2005; Gray et al., 2008; Shankar et al., 1996; Rifaat & Tay, 2009; Renski et al., 1999; Wu et al., 2016; Khattak et al., 1998; Rana et al., 2010; Yamamoto et al., 2008; Malyshkina & Manering, 2010) |
| **Ice/frost surface**           | (Zhang et al., 2000; Khattak, 2001)                                                     |                                                                                       |

(Continued)
| Variable                           | Increase crash severity                                                                 | Decrease crash severity                                                                 |
|-----------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Intersection                      | (Holdridge et al., 2005, Rifaat & Tay, 2009, Zhang et al., 2000, Chiou et al., 2013, Yasmin et al., 2014, Islam & Mannering, 2006, Hassan & Al-Faleh, 2013, Malyshkina & Mannering, 2010) | (Xie et al., 2009, Ulfarsson & Mannering, 2004, Gray et al., 2008, Donmez & Liu, 2015, Yasmin et al., 2015, Haleem & Abdel-Aty, 2010, Al-Ghamdi, 2002, Yamamoto et al., 2008) |
| Roads with low speed limit        | (Weiss et al., 2014, Savolainen & Ghosh, 2008, Anastasopoulos & Mannering, 2011, Zhang et al., 2000, Yasmin & Eluru, 2013, Lee & Li, 2014, Yasmin et al., 2014, Yasmin et al., 2015, Khattak & Rocha, 2003, Rana et al., 2010, Chiou et al., 2013, Lee & Mannering, 2002, Amarasingha & Dissanayake, 2014, Siskind et al., 2011, Islam & Mannering, 2006, Michalaki et al., 2015, Hu & Donnell, 2011b) | (Chang & Mannering, 1999, Weiss et al., 2014, Paleti et al., 2010, Haleem & Gan, 2011, Haleem & Abdel-Aty, 2010, Chang & Mannering, 1998, Amarasingha & Dissanayake, 2014) |
| Roads with high speed limit       | (Weiss et al., 2014, Savolainen & Ghosh, 2008, Anastasopoulos & Mannering, 2011, Zhang et al., 2000, Yasmin & Eluru, 2013, Lee & Li, 2014, Yasmin et al., 2014, Yasmin et al., 2015, Khattak & Rocha, 2003, Rana et al., 2010, Chiou et al., 2013, Lee & Mannering, 2002, Amarasingha & Dissanayake, 2014, Siskind et al., 2011, Islam & Mannering, 2006, Michalaki et al., 2015, Hu & Donnell, 2011b) | (Chang & Mannering, 1999, Weiss et al., 2014, Paleti et al., 2010, Haleem & Gan, 2011, Haleem & Abdel-Aty, 2010, Chang & Mannering, 1998, Amarasingha & Dissanayake, 2014) |
| Traffic control device            | (Yasmin et al., 2015)                                                                    | (Hanley & Sikka, 2012, Yasmin & Eluru, 2013, Yasmin et al., 2014, Celik & Oktay, 2014) |
| Interstate highway               | (Celik & Oktay, 2014, Islam & Mannering, 2006)                                           | (Chang & Mannering, 1999, Donmez & Liu, 2015, Xie et al., 2012, Zhu & Srinivasan, 2011a, Chang & Mannering, 1998, Malyshkina & Mannering, 2010) |
| Urban zones                       | (Celik & Oktay, 2014, Shaheed et al., 2013)                                              | (Chang & Mannering, 1999, Malyshkina & Mannering, 2008, Khattak et al., 1998, Rana et al., 2010, Abdel-Aty et al., 2011, Chang & Mannering, 1998, Islam & Mannering, 2006, Malyshkina & Mannering, 2010) |
| Rural                             | (Weiss et al., 2014, Donmez & Liu, 2015, Pour-Rouholamin & Zhou, 2016, Amarasingha & Dissanayake, 2014) | (Hanley & Sikka, 2012, Yasmin & Eluru, 2013, Yasmin et al., 2014, Celik & Oktay, 2014) |
| Two-way road                      | (Ulfarsson & Mannering, 2004, Rifaat & Tay, 2009)                                       | (Chang & Mannering, 1999, Donmez & Liu, 2015, Xie et al., 2012, Zhu & Srinivasan, 2011a, Chang & Mannering, 1998, Malyshkina & Mannering, 2010) |
| Characteristics of the crash     |                                                                                        |                                                                                          |
| Fixed object (tree, pillar, ...)   | (Chang & Mannering, 1999, Holdridge et al., 2005, Gray et al., 2008, Shankar et al., 1996, Renski et al., 1999, Wu et al., 2016, Wu et al., 2014, Xie et al., 2012, O’donnell & Connor, 1996, Al-Ghamdi, 2002, Schneider et al., 2009, Chang & Mannering, 1998, Peek-Asa et al., 2010, Islam & Mannering, 2006, Qudduas et al., 2009) | (Holdridge et al., 2005, O’donnell & Connor, 1996) |
| Single-Vehicle                    | (Chang & Mannering, 1999, Paleti et al., 2010, Shankar et al., 1996, Zhang et al., 2000, Khattak et al., 1998, Celik & Oktay, 2014, O’donnell & Connor, 1996, Peek-Asa et al., 2010, Michalaki et al., 2015, Qudduas et al., 2009) | (O’donnell & Connor, 1996) |

(Continued)
| Variable      | Increase crash severity                                                                 | Decrease crash severity                                                                 |
|--------------|-----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Rear-End     | (Chang & Mannering, 1999, Chiou et al., 2013, Yasmin et al., 2014, Ma et al., 2016,     | (Altwaijri et al., 2011, Kockelman & Kweon, 2002, Rifaat & Toy, 2009, Obeng, 2011,       |
|              | Chang & Mannering, 1998)                                                                 | Yasmin et al., 2013, O’donnell & Connor, 1996, Al-Ghamdi, 2002, Bedard et al., 2002,    |
|              | (Altwaijri et al., 2011, Kockelman & Kweon, 2002, Rifaat & Toy, 2009, Obeng, 2011,     | Peek-Asa et al., 2010, Li et al., 2012)                                                  |
|              | Yasmin et al., 2013, O’donnell & Connor, 1996, Al-Ghamdi, 2002, Bedard et al., 2002,  |
|              | Peek-Asa et al., 2010, Li et al., 2012)                                                  | (Kockelman & Kweon, 2002, O’donnell & Connor, 1996)                                     |
| Head-On      | (Kockelman & Kweon, 2002, Paleti et al., 2010, Obeng, 2011, Anastasopoulos & Mannering, |                                                          |
|              | 2011, Zhang et al., 2000, Yasmin & Eluru, 2013, Lee & Li, 2014, Yasmin et al., 2014,   |                                                          |
|              | Castro et al., 2013, Yasmin et al., 2015, Rana et al., 2010, Zhu & Srinivasan, 2011,   |                                                          |
|              | Pour-Rouholamin & Zhou, 2016, Al-Ghamdi, 2002, Peek-Asa et al., 2010, Amarasingha &    |                                                          |
|              | Dissanayake, 2014, Abdel-Aty & Keller, 2005)                                            |                                                          |
| Angle        | (Chang & Mannering, 1999, Altwaijri et al., 2011, Shankar et al., 1996, Anastasopoulos  | (Kockelman & Kweon, 2002, O’donnell & Connor, 1996)                                     |
|              | & Mannering, 2011, Zhang et al., 2000, Yasmin & Eluru, 2013, Donmez & Liu, 2015, Lee &  |
|              | Li, 2014, Mergia et al., 2013, Yasmin et al., 2014, Ma et al., 2016, Chang & Mannering, |
|              | 1998, Amarasingha & Dissanayake, 2014, Abdel-Aty & Keller, 2005)                         |                                                          |
| Sideswipe    | (Zhang et al., 2000, Lee & Li, 2014, Ma et al., 2016, Castro et al., 2013, Chang &      | (Altwaijri et al., 2011, Rifaat & Toy, 2009, Obeng, 2011, Rana et al., 2010, Al-Ghamdi,  |
|              | Mannering, 1998)                                                                         | 2002, Wang et al., 2009, Peek-Asa et al., 2010, Li et al., 2012)                          |
| Over turn    | (Yasmin & Eluru, 2013, Jang et al., 2013, Wu et al., 2016, Wu et al., 2014, Castro et  |                                                          |
|              | al., 2013, Roque et al., 2015)                                                           |                                                          |
| Driver ejection | (Chang & Mannering, 1999, Shankar et al., 1996, Anastasopoulos & Mannering, 2011,       |                                                          |
|              | Zhang et al., 2000, Yasmin & Eluru, 2013, Lee & Li, 2014, Yasmin et al., 2014, Castro   |                                                          |
|              | et al., 2013, Xie et al., 2012, Yasmin et al., 2015, Khattak & Roche, 2003, Chang &      |                                                          |
|              | Mannering, 1998, Peek-Asa et al., 2010, Amarasingha & Dissanayake, 2014, Islam &        |                                                          |
|              | Mannering, 2006)                                                                        |                                                          |
| Animal       |                                                                                         | (Wu et al., 2016, Wu et al., 2014, Amarasingha & Dissanayake, 2014)                        |
| Model            | Past Researchers                                                                 | Advantages                                                                                                                                                                                                 | Disadvantage                                                                                                                                                                                                 |
|------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Binary Probit or Logit | (Lee & Abdel-Aty, 2008, Hu & Donnell, 201a, Rifaat & Tay, 2009, Zhang et al., 2013, Zhang et al., 2000, Jang et al., 2013, Haleem & Gan, 2011, Khattak et al., 1998, Haleem & Abdel-Aty, 2010, Haleem & Gan, 2013, Al-Ghamdi, 2002, Bedard et al., 2002, Peek-Asa et al., 2010, Amarasinghe & Dissanayake, 2014, Siskind et al., 2011, Kononen et al., 2011, Ye & Lord, 2014, Hassan & Al-Faleh, 2013, Yu & Abdel-Aty, 2014, Boulfous, de Rome, Senserrick, & Ivers, 2012, Chung, Song, & Yoon, 2014, Tay, 2016, Shell, Newman, Córdova-Cazar, & Heese, 2015, Xu, Tarko, Wang, & Liu, 2013) | Provides one coefficient for each variable which makes it easier to interpret. does not have independence from irrelevant alternatives. | Limits levels of severity to only two, assumes similar and independent distributions for errors, assumes that errors follow Gumbel distribution |
| Multinomial Logit | (Hanley & Sikka, 2012, Ulfarsson & Mannering, 2004, Savolainen & Ghosh, 2008, Hu & Donnell, 201a, Malyschina & Mannering, 2008, Yasmin & Eluru, 2013, Yasmin et al., 2014, Ma et al., 2016, Roque et al., 2015, Xie et al., 2012, Abdel-Aty, 2003, Celik & Oktay, 2014, Schneider et al., 2009, Manner & Wünsch-Ziegler, 2013, Carson & Mannering, 2001, Chen et al., 2015, Islam & Mannering, 2006, Ye & Lord, 2014, Abdel-Aty & Abdelwahab, 2004, Rifaat, Tay, & De Barros, 2013, Sasiadharam & Menéndez, 2014, Jung, Jung, Yoon, & Kang, 2014, Behnoody, Rashandeh, & Mannering, 2014, Mohamed, Saunier, Miranda-Moreno, & Ukkusuri, 2013, Makhtarimousavi, 2019) | Provides different coefficients for the effects of each variable on different levels of severity. | Assumes independent and similar distribution of errors. Assumes that errors follow gamble distribution, has independence from irrelevant alternatives. Is difficult to interpret due to estimation of many variables. |
| Nested Logit     | (Chang & Mannering, 1999, Holdridge et al., 2005, Shankar et al., 1996, Savolainen & Mannering, 2007, Wu et al., 2016, Abdel-Aty, 2003, Haleem & Abdel-Aty, 2010, Chang & Mannering, 1998, Lee & Mannering, 2002, Hu & Donnell, 2011, Patil, Reddy, & Reddy, 2012) | Does not have independence from irrelevant alternatives. | Assumes that errors follow gamble distribution, Does not consider the ordered nature of severity of crashes. |

(Continued)
| Model                          | Past Researchers                                                                 | Advantages                                                                 | Disadvantage                                                                                           |
|-------------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Ordered Probit or logit       | (Xie et al., 2009, Kockelman & Kwean, 2002, Wang & Abdel-Aty, 2008, Gray et al., 2008, Obeng, 2011, Renski et al., 1999, Jiang et al., 2013, Danmez & Liu, 2015, Lee & Li, 2014, Yasmin et al., 2014, Ma et al., 2016, Haleem & Gan, 2011, Khattak et al., 1998, Khattak & Rocha, 2003, Abdel-Aty et al., 2011, Abdel-Aty, 2003, Haleem & Abdel-Aty, 2010, Pour-Rouholamin & Zhou, 2016, O’donnell & Connar, 1996, Khattak, 2001, Yamamoto et al., 2008, Das et al., 2008, Wang et al., 2009, Li et al., 2012, Jung et al., 2010, Ye & Lord, 2014, Oh, 2006, Quddus et al., 2009, Abdel-Aty & Keller, 2005, Sasidharan & Menéndez, 2014, Mohamed et al., 2013, Lemp, Kockelman, & Unnikrishnan, 2011, Zhu & Srinivasan, 2011b, Aiz, Ukkusuri, & Hasan, 2013, Feng, Li, G, & Zhang, 2016, Alver, Demirel, & Mutlu, 2014, Azimi, Rahimi, Asgari, & Jin, 2020) | Considers the ordered nature of severity of crashes | Parallel line assumption, similar effect of each variable on different levels of severity, assumes independent and similar distribution of errors. Assumes gamble distribution for errors |
| Generalized ordered logit or Probit | (Kaplan & Prato, 2012, Wang & Abdel-Aty, 2008, Chiu et al., 2013, Mergia et al., 2013, Yasmin et al., 2014, Castro et al., 2013, Wang et al., 2009, Michalaki et al., 2015, Quddus et al., 2009, Hassinepour et al., 2014, Sasidharan & Menéndez, 2014, Rifat, Tay, & De Barros, 2012, Mooradian, Ivan, Ravishanker, & Hu, 2013) | Considers the ordered nature of severity of crashes, provides different coefficients for the effects of each variable on different levels of severity | Assumes independent and similar distribution of errors. Assumes that errors follow gamble distribution |
| Mixed Logit or Probit         | (Altwaijri et al., 2011, Weiss et al., 2014, Morgan & Mannering, 1852-1863, Anastasopoulos & Mannering, 2013, Kim et al., 2013, Wu et al., 2016, Wu et al., 2014, Roque et al., 2015, Yasmin et al., 2015, Chiu et al., 2013, Zhu & Srinivasan, 2011a, Haleem & Gan, 2013, Mann & Wunsch-Ziegler, 2013, Ye & Lord, 2014, Malyshkina & Mannering, 2010, Shaheed et al., 2013, Millon, Shankar, & Mannering, 2008, Moore, Schneider, Savolainen, & Farzaneh, 2011, Islam, Jones, & Dye, 2014, Behmood, Roshandeh, & Modiri Shafehveran, 2015) | Provides different coefficients for the effects of each variable on different levels of severity, does not have independence from irrelevant alternatives | Does not consider the ordered nature of severity of crashes. Lengthy and time-consuming calibration with the software |
| Variable | Percentage | Variable | Percentage |
|----------|------------|----------|------------|
| **Characteristics of the driver** | | **Conditional and Environmental Properties** | |
| Driver's gender | | Passenger presence of passengers | 28.2 |
| Female | 47.1 | | |
| Driver's age | | Driver and passengers age: 16–24 | 4 |
| 16–24 | 24.6 | Vision condition | |
| 25–60 | 62.4 | Vision obscured | 2.7 |
| 60 above | 13 | Light condition | |
| Driver's impairment | | Daylight | 77 |
| Under the influence of alcohol, drugs | | Dark—not lighted | 6.2 |
| Asleep or fatigue | | Dark—lighted | 13.5 |
| Safety equipment | | Dawn or dusk | 3.3 |
| Not using seatbelts | | Weather condition | |
| Wrong use of equipment | | Fair/cloudy weather | 87.1 |
| Driver's distraction | | Rainy | 8.8 |
| No distraction* | 92.4 | Snowy | 3.8 |
| Cognitive | 4.9 | Sleet or foggy | 0.3 |
| Passenger related | 0.3 | Crash day | |
| In-vehicle tasks | 1.1 | Weekend | 22.7 |
| Out-vehicle | 0.6 | Time of day | |
| Cellphone | 0.7 | Regular hour | 52.8 |
| Speeding | | Morning peak hour | 11.7 |
| Driving over the speed limit | 10.8 | Afternoon peak hour | 35.5 |
| **Characteristics of the vehicle** | | **Characteristics of the road** | |
| Vehicle type | | Road alignment | |
| Cars | 57 | steep roads | 18.6 |
| SUVs | 19.2 | Curves | 20.5 |
| Vans | 7.1 | Surface condition | |
| Pickups | 16.8 | Dry | 77.5 |
| Vehicle age | | Junction type | |
| Up to 7 | 44.4 | Intersections | 47.4 |
| 7–Esfand | 37.1 | Speed limit | |
| 12 Above | 18.5 | Up to 35 mi/hr | 22.8 |
| **Characteristics of the crash** | | Above 50 mi/hr | 19.6 |
| Collision type | | Highway type | |
| Single-vehicle | 13.3 | Interstate highway | 7.4 |
| Rear-end | 42.2 | Zone type | |
| Head-on | 3.1 | Urban zone | 48.5 |
| Angle or sideswipe | 40.4 | Traffic way description | |
| Other types | 1 | One way* | 8.9 |
| | | Two way—not physically divided | 33 |
| | | Two way—divided highway | 58.1 |
