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Crash risk factors associated with injury severity of teen drivers

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ABSTRACT

This paper focuses on identifying crash risk factors associated with injury severity of teen drivers. Crash data obtained from the Highway Safety and Information System (HSIS) for the entire state of North Carolina, for years 2011 to 2013, was used for analysis and modeling. Among all the crashes during the study period, a total of 62,990 crashes involving teen drivers (15 to 19 years) were analyzed. A partial proportionality odds model was developed to identify factors contributing to injury severity of teen drivers. The results obtained indicate that teen drivers driving sports utility vehicles and pickup trucks are more likely to be severely injured when compared to teen drivers driving passenger cars. Teen drivers are more likely to be severely injured on weekdays, particularly during peak hours. The chances of teen drivers getting involved in severe injury crashes on Tuesdays and Fridays is higher when compared to Sundays. Age, gender, road configuration, terrain, adverse weather condition, and access control are observed to have a significant effect on teen driver's injury severity.

1. Introduction

Motor vehicle crashes are the leading cause of deaths among teenagers in the United States. According to the National Highway Traffic Safety Administration (NHTSA)'s traffic safety facts [1], 1866 young drivers (ages 15–20) were killed and 195,000 were injured in motor vehicle crashes in the year 2015, an increase by 9% and 14%, respectively, from year 2014 to year 2015. Lack of experience and maturity are one of the primary reasons of higher crash risk among teenage drivers (ages 16–19) when compared to any other age group. In fact, per every mile driven, teen drivers (ages 16–19) are nearly three times more likely to be involved in a fatal crash compared to their older counterparts, resulting in total costs exceeding $80 billion each year [2].

Researchers in the past investigated various factors associated with crashes involving teen drivers, such as gender [3]; exceeding speed limit [4]; driver age [5–8]; distracted driving [9–11]; risk perception [9,12–15]; cellphone use [16]; experience [12,14,17]; time-of-the-day and day-of-the-week [18]; risky behavior [19]; alcohol [20]; and night-time driving [18,21,22].

According to the Center for Disease Control and Prevention (CDC), critical errors such as lack of examining, detecting and responding to the hazards, driving faster than the posted speed limit, and distracted driving contribute to 75% of the crashes involving teen drivers [2]. Therefore, the need for skill-building and driving supervision for new teen drivers has become even more important [21]. Graduated Driver Licensing (GDL) programs have become more prominent to educate and train teen drivers. Further, technology could act as a teen occupant and undermine safety or it can act as an adult occupant and enhance safety from the GDL and its safety benefits [6].

The two most important decisions parents can make to reduce teens' driving risk are to delay licensure and impose limits on high-risk driving conditions during the first year of licensure [23]. Simons-Morton [12] explained that, within the limits of training, safety effects can be achieved through countermeasures that delay licensure or limit novice teen driving under high-risk driving conditions while novices gain experience and develop safety competence. Williams et al. [21] interviewed parents when their teens got their learner's permit. The survey was undertaken when the state did not have a midnight restriction or an occupant restriction. The survey concluded that parents do not seem to see or understand the risk of having even one teen occupant in the vehicle.

Keating and Halpern-Felsher [8] presented relevant features of contemporary research on adolescent development. The understanding of adolescent development focuses on the provision of appropriate and effective scaffolding, utilizing the contexts of importance to adolescent's parents, peers, and the broader culture of driving to support safe driving and to manage the inherent risks in leaning. Similarly, Allen and Brown [24] examined a range of developmental and structural factors that possibly increase the risk associated with adolescent driving, by considering potential influences such as passive and active distraction and direct disruption of driving.

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Chen et al. [25] examined the relationship between driver's age and child occupant's restraint status. They explored whether there was an excess injury risk to child occupants in teen crashes compared to those in adult crashes, by examining the contributing factors. They further explored how GDL laws may be enhanced to better protect child occupants from the injury risk associated with teen crashes. Peek-Asa et al. [7] used logistic regression to identify driver and crash characteristics associated with increased odds of fatal or severe injury, among urban and rural crashes, based on the crash data involving drivers aged 10 through 18 years.

Dissanayake and Amarasingha [22] explained that young drivers are more likely to be involved in crashes when driving with an invalid license, driving without wearing seat belts, driving at night, during weekends, on wet roads, or gravel/brick-tops. Carney et al. [16] examined over 400 rear-end crashes, involving teen drivers, captured by vehicle event recorders. Attending to occupants and use of a cell phone was observed as a leading cause for high frequency of rear-end crashes involving teen drivers.

Shope and Bingham [13] examined the trends in fatal crash rates for male and female drivers. Occupants may affect male teen driver crashes through, both, distraction and risk promoting pathways, while female teen drivers' involvement in crashes is primarily through internal distraction. Drivers of all ages are more susceptible to distractions inside the vehicle than distractions coming from outside [11]. Mostly, crash rates during the teenage years are higher than at any other age, for both males and females [26]. Also, teen drivers are more likely to make a critical decision error when compared to adult drivers [27,28].

Teen drivers that were distracted at an intersection by occupants or cognitively were more likely to be involved in rear-end and angular collisions when compared to fixed-object collisions [10]. Driver error was by far the most common reason for crashes as opposed to vehicle or environmental factors. Among crashes with a driver error, a teen made the error 80% of the time [29]. Moreover, the presence of male teen occupants was associated with risky driving behavior among teen drivers [30]. Multi-level interventions are recommended to reduce teen driver's exposure to high-risk driving conditions [13].

Primary access of novice teen drivers to vehicles is highly prevalent in the United States [31]. Fewer parental restriction and a lower grade point average (GPA) were also observed to be associated with a higher crash risk. Male gender, a lower GPA and living in a rural area were also observed to be associated with a higher citation rate or traffic rule violations [4]. Delayed high school start times may increase the sleep of adolescents and decrease their risk of motor vehicle crashes [4].

Most of the past research evaluated various contributing factors associated with teen crashes. Many compared these factors with other age groups (adults). However, a comprehensive analysis of factors contributing to injury severity of teen drivers involved in crashes was meagerly explored in the past. Also, there could be a significant variation in the effect of factors contributing to injury severity of all crashes and teen driver crashes alone. Therefore, the focus of this paper is to identify crash risk factors associated with injury severity of teen drivers, considering crash data involving teen drivers alone. The research findings are helpful to better understand teen driver crashes and reduce teen driver injury severities by adopting effective solutions. Based on the extensive review of several methods that were adopted in the past to study injury severity in crashes, a proportionality odds model was developed to examine injury severity of teen drivers.

2. Data collection

Crash data for years 2011 to 2013 was obtained from the Highway Safety and Information System (HSIS) for the entire state of North Carolina. HSIS gathers and maintains a multi-state crash database which are collected by selected states to investigate causal factors and improve highway safety. The crash data obtained from HSIS require some data processing, as it consists of four different data files; crash file (consists of all the variables related to each reported crash), road file (consists of road characteristics of all crashes in the crash database), vehicle file (consists of characteristics of vehicles involved in crashes in the crash database), and occupant file (consists of characteristics of drivers and occupants involved in crashes in the crash database). The data is processed by combining all the four data files into a single crash database based on a unique identification number provided for each crash. The combined database consists of almost all variables that can be classified into five categories: crash/driver characteristics, road characteristics, vehicle characteristics, environmental characteristics, and occupant characteristics.

Overall, a total of 792,487 vehicles were involved in 482,312 crashes that occurred on state- maintained roads in North Carolina during the study period (2011−2013). As the purpose of the study is to investigate injury severity of teen drivers, all pedestrian and bicycles crashes were removed from the database. Along with non-motorized crashes, crashes that has driver age 20 years or older and <15 years were also removed from the database.

The final resulting database consists of crash details involving drivers in age group 15–19 years (considered as teen drivers in this research). Two new variables, time-of-the-day and day-of-the-week, were created using the date and time of crash information available for each crash. The time-of-the-day is further divided in to eight 3-h time periods. Table 1 summarizes frequency and distribution of all the variables that were considered for analysis of teen driver's injury severity. All records that have incomplete data for one or more variables mentioned in Table 1 were removed from the database. The resulting database consists of 62,990 teen driver injury severity records.

HSIS defines the injury severity in crashes as five levels; fatal, incapacitating injury, capacitating injury, possible injury, and property damage only (PDO). In this research, these five levels were aggregated into three levels; severe injury, moderate injury, and PDO. Severe injury is created by combining fatal and incapacitating injury, whereas, moderate injury is created by combining capacitating injury and possible injury.

About 0.47% (295) of crashes observed during the study period are severe injury (Table 1). Literature documents that the number of observations should be five to ten times the number of independent variables [32,33], for adopting methods such as those used in this research. Therefore, the sample size was considered reasonable for analysis and modeling even using severe injury crash data.

3. Method

The levels of injury severity of the teen driver are ordinal in nature. One of the most popularly used generalized ordered outcome model variant for the analysis of ordinal data is the proportionality odds model, a class of logistic models [34–36]. The basic assumption of the proportionality odds model is that the effect of the independent variables is identical across the categories of the dependent variable (equal slopes) i.e., for a response category with a natural ordering of $Y = 1, 2, 3, \ldots, j$, with $j > 1$, the proportional odds model with X_1, X_2, X_3, …X_p independent variables has (j-1) intercepts with ‘p’ slopes. The model is expressed as follows [35].

$$\ln(Y'_j) = \text{logit}[\pi(x)] = \ln\left(\frac{\pi(x)}{1-\pi(x)}\right) = \propto_j + (\beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \ldots\ldots \beta_pX_p).$$

The prediction in the logistic model represents that the expected logit for being the category ‘j’ or above and Y'_j represents the odds of being in higher proficiency categories. These predicted logits can be transformed to odds and then to estimate probability using the following Eq. [34].

$$P(Y \geq j) = \frac{\exp\left(\ln\left(Y'_j\right)\right)}{1 + \exp\left(\ln\left(Y'_j\right)\right)}$$

Table 1
Frequency and distribution of variables.

Variable	Categories	Frequency (%)
Driver Injury Severity (Dependent Variable)	PDO	50,718 (80.52)
	Moderate Injury	11,977 (19.01)
	Severe Injury	295 (0.47)
Road Surface Condition	Dry	49,735 (78.96)
	Wet	12,148 (19.29)
	Water Standing/Moving (WSM)	435 (0.69)
	Ice	360 (0.57)
	Snow	192 (0.30)
	Slush	82 (0.13)
	Other	38 (0.06)
Weather Condition	Clear	43,774 (69.49)
	Cloudy	11,110 (17.64)
	Rain	7277 (11.55)
	Snow	216 (0.34)
	Fog, Smog, Smoke (FSS)	337 (0.54)
	Sleet, Hall, Freezing Rain/Drizzle (SHFR)	240 (0.38)
	Severe Crosswinds (SC)	36 (0.06)
Light Condition	Daylight	45,028 (71.48)
	Dusk	1466 (2.33)
	Dawn	747 (1.19)
	Dark - Lighted Roadway (DLR)	5434 (8.63)
	Dark - Roadway Not Lighted (DRL)	10,249 (16.27)
	Dark - Unknown Lighting (DUL)	66 (0.10)
Road Characteristics	Straight Level	53,618 (85.13)
	Curve Level	9363 (14.87)
	Unknown	9 (~0.00)
Road Classification	Interstate (IN)	4656 (7.39)
	US Route (USR)	10,265 (16.30)
	NC Route (NCR)	11,219 (17.81)
	State Secondary Route (SSR)	18,733 (29.74)
	Local Road (LS)	17,743 (28.17)
	Public Vehicular Area (PVA)	301 (0.48)
	Private Road, Driveway (PRD)	16 (0.03)
	Other	57 (0.09)
Road Configuration	One-Way, Not Divided	1563 (2.48)
	Two-Way, Not Divided (TWND)	42,412 (67.33)
	Two-Way, Divided, Unprotected Median (TWDUM)	11,381 (18.07)
	Two-Way, Divided, Positive Median Barrier (TWDPM)	7634 (12.12)
Access	No Access Control	48,562 (77.09)
	Partial Control (PC)	8921 (14.16)
	Full Control (FC)	5507 (8.74)
Terrain	Flat	13,262 (21.05)
	Rolling	45,329 (71.96)
	Mountainous (MOUN)	4399 (6.98)
Speed Limit	≤25 mph	951 (1.51)
	26–45 mph	36,563 (58.05)
	46–55 mph	20,590 (32.69)
	>55 mph	4886 (7.76)
Drivers' Physical Condition	Apparently Normal	61,057 (96.93)
	Illness	26 (0.04)
	Fatigue	167 (0.27)
	Fell Asleep, Fainted, Loss of Consciousness (FFLC)	728 (1.16)
	Impairment Due to Medications, Drugs, Alcohol (IMDA)	959 (1.52)
	Medical Condition (MC)	53 (0.08)
Drivers' Gender	Male	33,379 (52.99)
	Female	29,611 (47.01)
Drivers' Age	Age 15	880 (1.40)
	Age 16	9721 (15.43)
	Age 17	14,034 (22.28)
	Age 18	18,836 (29.90)
	Age 19	19,519 (30.99)
Work Zone Area	Construction Work Area (CA)	805 (1.28)
	Maintenance Work Area (MA)	142 (0.23)
	Utility Work Area (UA)	25 (0.04)
	Intermittent / Moving Area (IMA)	30 (0.05)
	No Work Zone	61,988 (98.41)
Functional Class	Rural Arterial Road	6263 (10.26)
	Rural Local Road	30,324 (49.66)
	Urban Arterial Road	14,903 (24.41)
	Urban Local Road	11,500 (15.67)
Number of Occupants	1 Occupant	41,339 (65.63)
	2 Occupants	14,828 (23.54)
	3 Occupants	4530 (7.19)
	4 Occupants	1, 624 (2.58)
	5 Occupants	669 (1.06)
Rural-Urban Identification	Rural	33, 565 (53.29)
	Urban	29,425 (46.71)
Drivers' Vehicle Type	Passenger Car	41,769 (66.31)
	Pickup/Light Truck/Van (PLTV)	9761 (15.50)
	Sports Utility Vehicle (SUV)	10,967 (17.41)
	Truck/Tractor or Truck/Tractor Trailer (TT)	120 (0.19)
	Farm Vehicle (FV)	19 (0.03)
	Motorcycle (MC)	317 (0.50)
	Other	37 (0.06)
Day-of-the-week	Sunday (1)	6461 (10.24)
	Monday (2)	8866 (14.08)
	Tuesday (3)	9132 (14.50)
	Wednesday (4)	9082 (14.42)
	Thursday (5)	9351

Table 1 (continued)

Variable	Categories	Frequency (%)
		(14.85)
	Friday (6)	11,714 (18.60)
	Saturday (7)	8384 (13.31)
Time-of-the-day	12:00 AM – 03:00 AM (1)	2115 (3.36)
	03:00 AM – 06:00 AM (2)	1144 (1.82)
	06:00 AM – 09:00 AM (3)	7729 (12.27)
	09:00 AM – 12:00 PM (4)	6157 (9.77)
	12:00 PM – 03:00 PM (5)	11,246 (17.85)
	03:00 PM – 06:00 PM (6)	18,594 (29.52)
	06:00 PM – 09:00 PM (7)	10,342 (16.42)
	09:00 PM – 12:00 PM (8)	5663 (8.99)

Odd proportionality tests were performed using SAS to check if the effect of independent variables is identical across the categories of the dependent variable. The SAS output of proportional odds test gave a p-value <0.05. This indicates that the null hypothesis should be rejected at a 95% confidence interval. Therefore, separate parameters are needed across the categories for at least one or more independent variables. In case, the basic assumption of the proportionality odds model does not hold, i.e., the effect of one or more independent variables is not identical across the categories of the dependent variable (unequal slopes), a partial proportional odds model or a non-proportional odds model is developed. A partial proportionality odds model is expressed as follows.

$$\ln(Y_j) = \ln\left(\frac{\pi_j(x)}{1-\pi_j(x)}\right) = \propto_j + (\beta_{1j}X_1 + \beta_{2j}X_2 + \beta_{3j}X_3 + \dots \beta_{pj}X_p).$$

A partial proportionality odds model was developed in SAS using both equal and unequal slope option, enabling all equal and unequal slope parameters available for effect selection. The stepwise selection process was used to test unequal slope parameters for each independent variable to include in the model, if significant at a 95% confidence level. Table 2 shows the analysis of effects of all variables considered before eliminating insignificant variables. All the variables considered are observed to have a statistically significant effect on injury severity of teen drivers, except for work zone at a 95% confidence level. Similarly, variance inflation factors (VIF) were computed to check for any multicollinearity between the independent variables considered in the model development. The computed VIF's were observed to be less than two (<2.0) for all the independent variables. This indicates that none of the independent variables considered in this research are correlated to each other.

Table 2
Analysis of effects.

Independent variables	Wald chi-square	P-value
Physical Condition	650.84	<0.0001
Drivers' Gender	375.33	<0.0001
Number of Occupants	77.49	<0.0001
Rural-Urban Identification	26.77	<0.0001
Road Surface Condition	17.95	0.006
Light Condition	23.59	0.0003
Road Characteristics	580.01	<0.0001
Road Class	41.37	<0.0001
Road Configuration	31.92	<0.0001
Access	14.73	0.0006
Work Zone Area	8.18	0.085
Functional Class	25.73	0.0002
Terrain	14.96	0.0006
Vehicle Type	590.11	<0.0001
Speed Limit	188.97	<0.0001
Driver Age	39.73	<0.0001
Day-of-the-week	22.43	0.001
Time-of-the-day	41.41	<0.0001

4. Results

Table 3 shows the partial proportionality odds model developed for injury severity of teen drivers. The coefficients of each variable can be used to estimate the odds. They are computed and presented in Table 4. A positive coefficient for an independent variable indicates that the injury severity of a teen driver is more likely to be a severe injury when compared to moderate injury and PDO. Similarly, a negative coefficient for an independent variable indicates that the injury severity of a teen driver is less likely to be a severe injury when compared to moderate injury and PDO.

Teen drivers 16 to 19 years in age are involved in relatively higher number of crashes when driving with occupants than when driving alone [16,18]. However, when it comes to severity of these crashes, teen drivers with more than one occupant in the vehicle are less likely to be involved in a crash with moderate injury and severe injury when compared to PDO crash. As the number of occupants increased, the likelihood of severe injury and moderate injury in a teen crash is decreased. The odds of severe injury in teen crashes is 9%, 13%, 20%, and 38% less likely when the number of occupants is 2, 3, 4, and 5, respectively when compared to driving alone i.e., the injury severity of teen crashes is observed to decrease as the number of occupants increased. This could due to higher attentiveness and cautious approach adopted by teen drivers with an increase in the number of occupants or when accompanied by adults.

Crashes on wet road surface condition are more likely to result in severe injuries to teen drivers when compared to dry road surface condition [22]. Involvement in a crash is 8%, 18%, 49%, and 40% more likely to result in a severe injury to teen drivers, during adverse weather condition such as wet roads, ice, snow, and slush, when compared to dry road condition. The higher injury severity to teen drivers during adverse weather condition could be due to inefficiency in braking, difficulty in controlling the vehicle by teen drivers on wet, icy, snowy roads, that could result vehicles to skid, drag, hydroplane, run-off the road, etc. during such weather condition.

Past research indicates that the crash involvement rates of 16–19-year-old drivers are higher than those of 20–24-year-old and 25–59-year-old drivers in most of situations, but that they were substantially higher during weekends, and at night-time compared to their older counterparts [18,22]. However, except Monday and Saturday, all other days of the week are observed to have a statistically significant effect on injury severity of teen drivers. Among all the days of the week, crashes involving teen drivers on Tuesdays and Fridays are 17% more likely to be severe injury when compared to Sundays, which are followed by Thursdays (13%), Wednesdays (12%) and Mondays (7%).

Mountainous terrain is more likely to result in severe injury to teen drivers, which can be attributed to their low skill level in driving in these terrain conditions. The odds of severe injury to teen drivers is 17% higher in mountainous terrain and 2% lower in rolling terrain when compared to flat terrain. However, crashes on curve roads are less likely to be severe injury when compared to straight roads for teen drivers. Compared to straight roads, teen drivers are 49% less likely to be severely injured and 63% less likely to be moderately injured in crashes on curved roads.

Compared to two-way divided roads, one-way undivided roads are more likely to result in severe injury and less likely to result in moderate injury to teen drivers. When the road configuration is one-way undivided, it is 17% more likely to be a severe injury when compared with two-way divided roads with a protected median. Further, roads that are two-way undivided and two-way divided with unprotected median

Table 3
Partial proportional odds model for driver injury severity.

Variable	Categories	Estimate (severe injury)	Estimate (moderate injury)	Variable	Categories	Estimate (severe injury)	Estimate (moderate injury)
Intercept	Severity	2.90*	8.01*	Speed Limit ® > 55mph	≤25 mph	−0.44*	
Number of Occupants ®-1 Occupant	2 Occupants	−0.09*	−0.14		26-45 mph	−0.78*	
	3 Occupants	−0.13*	−0.77*		46-55 mph	−0.65*	
	4 Occupants	−0.20*	−0.69	Functional Class ®-Interstates	Arterial Roads	−0.06	1.42*
	5 occupants	−0.45*	−1.59*		Collector Roads	−0.17*	0.94
Road Surface Condition ®-Dry	Wet	0.08*			Local Roads	−0.12	1.12*
	Water Standing/Moving (WSM)	−0.11		Drivers' Gender ®-Male	Female	−0.43*	−0.14
	Ice	0.17		Location ®-Urban	Rural	−0.15*	−0.55
	Snow	0.40		Road Classification ®-Interstate	USR	−0.26*	
	Slush	0.34			NCR	−0.31*	
	Other	−0.17			SSR	−0.35*	
					LS	−0.26*	
					PVA	1.19*	
Day-of-the-week ®-Sunday	Monday	0.07			PRD	−0.34	
	Tuesday	0.16*			Other	−0.65	
	Wednesday	0.11*					
	Thursday	0.12*		Road Characteristics ®-Straight Level	Curve Level	−0.67*	−0.99*
	Friday	0.16*					
	Saturday	0.07					
Terrain ®-Flat	Rolling	−0.01					
	MOUN	0.15*					
Road Configuration ®-Two Way Divided	OWND	−0.32*	−2.11				
	TWND	−0.27*	−0.86				
	TWDUM	−0.20*	−0.58	Access ®-No Access Control	PC	−0.04	
Drivers' Physical Conditions ®-Apparently Normal	Illness	−0.47	0.15		FC	0.14*	
	Fatigue	−1.02*	−1.03	Drivers' Vehicle Type ®-Passenger Car	PLTV	0.16*	−0.30*
	FFLC	−1.30*	−1.24*		SUV	0.11*	−0.03
	IMDA	−1.20*	−1.76*		TT	0.91*	−1.16
	MC	−1.78*	−1.28		FV	0.76	0.19
					MC	−3.37*	−2.93*
					Other	−1.59*	−2.00
Drivers' Age ®-Age 19	Age 15	0.44*		Time-of-the-day ®-12:00 AM – 03:00-AM	03:00 AM-06:00 AM	−0.03	
	Age 16	0.13*			06:00 AM-09:00 AM	0.15*	
	Age 17	0.07*			09:00 AM-12:00 PM	−0.00	
	Age 18	0.02			12:00 PM-03:00 PM	0.10	
					03:00 PM-06:00 PM	0.14*	
					06:00 PM-09:00 PM	0.05	
					09:00 PM-12:00 PM	−0.04	

* Indicates significance at a 95% Confidence Level (p-value <0.05).

are 25% and 19% less likely to result in severe injury to teen drivers, respectively. All road configurations such as one-way undivided, two-way undivided, and two-way divided with unprotected median are 88%, 58%, and 45% less likely to result in moderate injury to teen drivers when compared to two-way divided roads, respectively.

Teen driver's physical condition such as fatigue, fall asleep, impairment due to drugs, alcohol, medication, and medical condition are observed to have a statistically significant effect on their injury severity. Teen drivers are 17% more likely to be moderately injured when they are ill compared to normal physical condition. Crashes occurring under fatigue, fall asleep, impairment due to drugs, alcohol, medication, and medical condition are less likely to result in severe injury to teen drivers when compared to a PDO crash. This is because, as the age limit for alcohol consumption is 21 years, it is relatively less likely for teen drivers to be driving under the influence of alcohol.

Crashes involving teen drivers of age 15–18 are more likely to result in severe injury when compared to 19-year-old teen drivers. Teen drivers of age 15, 16, 17, and 18 years old are 56%, 14%, 8%, and 2% more likely to be severely injured when compared to 19-year-old in a crash, respectively. This indicates that, teen drivers are less likely to be severely injured, with an increase in the driving experience, when compared to novice drivers.

Crashes on roads with speed limits <55 mph are less likely to result in a severe injury to teen drivers when compared to a PDO crash. Roads with lower speed limit are less likely to result in severe injury to teen drivers when compared to roads with higher speed limit. Compared to roads with speed limit >55 mph, roads with speed limits ≤25mph, 25–45 mph, and 45–55 mph are 37%, 55%, and 48% less likely to result in a severe injury to teen drivers, respectively. The higher severity of crashes on high speed roads could be due to a decrease in the total time to come to a complete stop, higher impact, and difficulty controlling the vehicle in adverse conditions.

Similarly, compared to interstates, crashes involving teen drivers on arterial roads and local roads are more likely to result in moderate injury but less likely to result in severe injury on collector roads. Teen drivers are 317%, 156% and 207% more likely to be moderately injured on arterial roads, collector roads, and local roads when compared to interstates. This could be attributed to the significantly lower speeds and congested conditions on arterial roads, collector roads and local roads compared to interstates. Moreover, compared to interstates, crashes involving teen

Table 4
Odds ratios for severity of driver.

Variable	Categories	Estimate (severe injury)	Estimate (moderate injury)	Variable	Categories	Estimate (severe injury)	Estimate (moderate injury)
Intercept	Severity	–	–	Speed Limit ® > 55 mph	≤25 mph	0.63	
Number of Occupants ®- 1 Occupant	2 Occupants	0.91	0.86		26–45 mph	0.45	
	3 Occupants	0.87	0.45		46–55 mph	0.52	
	4 Occupants	0.81	0.50	Functional Class ®-Interstates	Arterial Roads	0.93	4.17
	5 occupants	0.63	0.20		Collector Roads	0.84	2.56
Road Surface Condition ®-Dry	Wet	1.08			Local Roads	0.87	3.07
	Water Standing/Moving (WSM)	0.89		Drivers' Gender ®-Male	Female	0.65	0.86
	Ice	1.18		Location ®-Urban	Rural	0.85	0.57
	Snow	1.49		Road Classification ®-Interstate	USR	0.77	
	Slush	1.40			NCR	0.73	
	Other	0.83			SSR	0.70	
					LS	0.76	
					PVA	3.30	
Day-of-the-week ®-Sunday	Monday	1.07			PRD	0.70	
	Tuesday	1.17			Other	0.52	
	Wednesday	1.12					
	Thursday	1.13		Road Characteristics ®-Straight Level	Curve Level	0.51	0.37
	Friday	1.17					
	Saturday	1.08					
Terrain ®-Flat	Rolling	0.98					
	MOUN	1.17					
Road Configuration ®-Two Way Divided	OWND	0.72	0.12				
	TWND	0.75	0.42				
	TWDUM	0.81	0.55	Access ®-No Access Control	PC	0.95	
Drivers' Physical Conditions ®-Apparently Normal	Illness	0.62	1.17		FC	1.16	
	Fatigue	0.35	0.35	Drivers' Vehicle Type ®-Passenger Car	PLTV	1.17	0.73
	FFLC	0.27	0.28		SUV	1.12	0.96
	IMDA	0.29	0.17		TT	2.50	0.31
	MC	0.16	0.27		FV	2.14	1.21
					MC	0.03	0.05
					Other	0.20	0.13
Drivers' Age ®-Age 19	Age 15	1.56		Time-of-the-day ®-12:00 AM – 03:00-AM	03:00 AM-06:00 AM	0.96	
	Age 16	1.14			06:00 AM-09:00 AM	1.16	
	Age 17	1.08			09:00 AM-12:00 PM	0.99	
	Age 18	1.02			12:00 PM-03:00 PM	1.10	
					03:00 PM-06:00 PM	1.16	
					06:00 PM-09:00 PM	1.05	
					09:00 PM-12:00 PM	0.95	

drivers are less likely to be severe injury and are more likely to be moderate injury on US roads, NC roads, state secondary roads, and local roads. This could be attributed to higher vehicular speeds on interstates compared to any other roads.

Female teen drivers are less likely to be severely injured compared to their male counterparts. They are 35% and 14% less likely to be involved in severe injury and moderate injury when compared to male teen drivers.

Crashes involving teen drivers driving any vehicle other than passenger car are more likely to be a severe injury. Teen drivers driving pickup truck, sports utility vehicle, truck trailer, and farm vehicle are 17%, 12%, 150%, and 114% more likely to be severely injured in a crash when compared to driving a passenger car. This indicates that teen drivers are safer driving passenger cars when compared to other vehicle types. Similarly, teen drivers driving farm vehicle are 21% more likely to be moderately injured in a crash when compared to driving a passenger car. Remaining all vehicle type categories are less likely to result in a moderate injury to a teen driver in a crash.

Roads with access control are more likely to result in severe injury to teen drivers. When there is full access control, teen drivers are 16% more likely to be severely injured in a crash when compared with no access control roads, which can be attributed to sudden variation in speeds at access control locations.

Similarly, teen drivers are 16% more likely to be severely injured during morning peak (06:00 AM - 09:00 AM) and evening peak (03:00 PM - 06:00 PM) hours when compared to late night hours (12:00 AM - 03:00 AM). The fewer number of crashes or lower risk during late night hours could be attributed to night-time driving restrictions. On the other hand, aggressive nature along with the lack of experience to react aptly under congested conditions and in a timely manner during morning and evening peak hours of weekdays could be the reason for increased risk during the weekday peak hours.

5. Conclusions

In this paper, a partial proportionality odds model was developed to research and identify crash risk factors associated with injury severity of teen drivers. The results obtained from the partial proportionality odds model indicate that factors such as road surface condition, mountainous terrain, age, time-of-the-day, day-of-the-week, access control type, and vehicle type are more likely to result in severe injury to teen drivers at a 95% confidence level. Other factors considered, such as the number of occupants, road configuration, road classification, and road characteristics, are less likely to result in severe injury to teen drivers when compared to PDO crash at a 95% confidence level. The lighting condition has a statistically significant effect, while the work zone has a statistically insignificant effect on injury severity of teen drivers.

Wet road condition is positively associated with injury severity of teen drivers. Extreme weather condition can make driving on roads difficult, leading to loss of control, which could affect the ability of teen drivers to maneuver the vehicle appropriately due to their lack of experience.

Speed is observed to play a significant role in teen driver injury severity. Teen drivers are more likely to be severely injured on roads with higher speed limit. Congruent with speed limits, all levels of road classification, with interstate as a base variable, are observed to be negatively associated with teen driver injury severity.

Compared to passenger cars, teen drivers driving sports utility vehicles, pickup truck, and other vehicle types are more likely to be severely injured. This indicates that passenger cars are safer for teen drivers as the suspension, torque, horse power of the vehicle, and speeds could substantially differ when compared to other vehicle types. Moreover, male teen drivers are more prone to severe injury when compared to female teen drivers, which could be attributed to their aggressive driving behavior compared to their female counterparts.

The results obtained indicate that teen drivers are less likely to be severely injured with experience in driving (age). Teen drivers involved in crashes during morning and evening peak hours are more likely to be severely injured. Education programs for teen drivers on maintaining speed limit, driving safely during extreme weather condition, understanding risk associated with roads on uneven terrains with inadequate sight distances, and gaining experience through driving simulators could help reduce the injury severity to teen drivers involved in crashes. Overall, in the past, researchers have discussed various factors associated with teen crashes compared to their older counterparts, whereas, this research identified factors associated with injury severity of just the crashes associated with teen drivers.

Strategies such as better teen driver education programs, stringent driving requirements, strict driving tests, and providing parents with adequate knowledge to educate the teen drivers could help decrease the overall teen crashes. Also, implementing advanced technologies such as automated breaking systems, lane changing sensors and warning systems, better blind spot detection and warning systems, and speed limit warning systems could help in reducing teen crashes and their injury severity in crashes.

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