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Analysis of factors affecting injury severity for riders or occupants of all-terrain vehicles and golf carts involved in police-reported crashes

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ABSTRACT

In recent years, the popularity of all-terrain vehicles (ATVs) in the United States (US) has increased, and the number of ATV driver and passenger deaths have also increased substantially in the last few decades. Riders or occupants of ATVs as well as golf carts are particularly vulnerable to injury, not only due to the lack of protection and safety equipment offered by their vehicles, but also the propensity for ejection in the event of a crash. Given the vulnerability of these road users, it's critical to understand factors which may affect injury severity to plan effective countermeasures aimed at reducing these injuries and fatalities. To better understand factors affecting the injury severity of ATV and golf cart riders or occupants involved in police-reported crashes, this study presents an analysis using six years of crash data from the US state of Arizona. Over the analysis period, there were 1769 drivers/passengers of these vehicle types involved in police-reported crashes. Of these occupants/riders, 67.7% were injured or killed as a result of the crash; a proportion significantly higher than police-reported crashes involving most other vehicle types, exhibiting the need to examine factors leading to these injuries and fatalities. In order to analyse factors affecting the injury severity of ATV and golf cart occupants/riders, a random parameters (RP) ordered logit statistical model was developed, which was most appropriate given the ordered nature of injury-severity data. Several person- vehicle- roadway- and environmental-related variables were found to significantly affect the injury severity of riders or occupants of ATVs and golf carts. Given the vulnerability of these road users, it's important for transportation agencies to explore effective countermeasures aimed at reducing the severity of crashes involving these vehicle types. The results of this study provide important insights which can assist in developing effective engineering-, enforcement-, education, or policy-related countermeasures.

1. Introduction and background

In recent years, the popularity of all-terrain vehicles (ATVs) in the United States (US) has increased, and the number of ATV driver and passenger deaths have also increased substantially in the last few decades. (IIHS, 2013). Riders or occupants of these vehicles are particularly vulnerable to injury, not only due to the lack of protection and safety equipment offered by their vehicles, but also the propensity for ejection in the event of a crash. Additionally, many types of these vehicles are prone to roll over in the event of a crash (IIHS, 2013). ATVs, as well as golf carts, can often be driven on public roadways legally so long as they meet certain requirements. For example, in the US state of Arizona, ATVs can legally be driven on public roadways if they have a license plate light, horn, proper insurance, and meet certain emissions requirements (AZ Game and Fish Department, 2016). Additionally, riders of golf carts are not required to wear helmets, while only those riders of ATVs under age 18 are required to wear a helmet in Arizona (AZ Game and Fish Department, 2016). It should be noted that ATV regulations vary from state to state in the US (as well as from country to country) in terms of minimum age, light requirements, and helmet requirements (ATV Safety Institute, 2019). Some states having no helmet requirements, while others only requiring helmets for young riders (under age 16 or 18 depending on the state), or on certain public lands (ATV Safety Institute, 2019). Given the vulnerability of these road users in the event of a crash, it is critical to understand factors which may affect rider or occupant injury severity in order to plan effective countermeasures aimed at reducing these injuries and fatalities.

In the state of Arizona, ATVs are defined as "a motor vehicle that is primarily for recreational non-highway all-terrain travel, is 50 or fewer inches in width, weighs less than 1200 pounds, and travels on 3 or more non-highway tires" (Arizona Revised Statutes, 2018). A golf cart is defined as "a motor vehicle that has not less than 3 wheels in contact

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Fig. 1. Examples of ATVs (top row) and golf carts (bottom row).

with the ground, has an unladen weight of less than 1800 pounds, is designed to be and is operated at not more than twenty-five miles per hour, and is designed to carry not more than four persons including the driver" (Arizona Revised Statutes, 2018). Examples of ATVs and golf carts are shown in Fig. 1.

Currently, sparse research exists specifically focused on traffic crashes involving ATVs or golf carts. According to a National Highway Traffic Safety Administration (NHTSA) report, 3360 persons were killed in on-road ATV crashes in the US from 2004 to 2013, representing approximately one percent of total motor vehicle fatalities (National Highway Traffic Safety Administration (NHTSA, 2015). NHTSA also noted that the majority of persons killed in ATV crashes were (in no specific order and mutually exclusive): male, unhelmeted, killed during the night-time, killed during the weekend, and killed between May and September (National Highway Traffic Safety Administration (NHTSA, 2015). Additionally, NHTSA noted that 39% of ATV operators involved in fatal crashes had a blood alcohol concentration greater than 0.08 g/decilitre, compared with 28% for motorcycles and 23% for passenger cars, indicating alcohol use may be a significant factor impacting ATV-related fatalities (National Highway Traffic Safety Administration (NHTSA, 2015).

In another analysis examining ATV fatalities in the US from 2007 to 2011, it was determined that 90% of fatally injured ATV drivers were 16 or older (3.2% were age 12 or younger while 6.7% were age 13–15) and 90% were male, while half of ATV passenger deaths were teenagers or younger, and majority were female (Williams et al., 2014). Additionally, it was found that 43% of fatally injured ATV drivers had BAC's of 0.08 or higher, and 75% of fatal crashes involved single ATVs (Williams et al., 2014). It should be noted that these findings were based on summary statistics and no statistical analysis was conducted. Another study used multivariate logistic regression to compare relative risk factors between on-road and off-road ATV crashes and found that females and youths under 16 years old were four times as likely to be passengers whether on- or off-road, adult on-road operators were two times more likely to test positive for alcohol than off-road operators, and on-road ATV crash victims were half likely to be helmeted (Denning et al., 2013). Some findings from the previously mentioned analyses of ATV crash data were in agreement with the results of a survey of ATV riders, which found that 66% of ATV riders had ridden on public roads, about 50% never wore a helmet, and males and younger adults were more likely to have been involved in an ATV crash (Jennissen et al., 2016).

The literature is extremely limited with respect to crashes involving golf carts, though one study did find that on a commercially available shuttle type golf cart, restraints were not adequate to prevent ejection of a rear facing passengers during rapid accelerations (Schau and Masory, 2013). Overall, previous research examining factors affecting the severity of ATV and golf cart crashes has been quite limited, and further investigation is warranted given the vulnerability of these road users.

In order to better understand factors affecting the injury severity of ATV and golf cart riders or occupants involved in police-reported crashes, this study presents an analysis using six years (2010–2015) of crash data from the US state of Arizona. Over the analysis period, there were 1769 occupants/riders of these vehicle types involved in police-reported crashes. Of these occupants/riders, 67.7% were injured or killed as a result of the crash. This proportion is significantly higher than police-reported crashes involving most other vehicle types, exhibiting the need to examine factors leading to these injuries and fatalities. To analyze factors affecting the injury severity of ATV and golf cart occupants/riders, several types of statistical methods were explored. Ultimately, an ordered logit statistical model was developed, which was most appropriate given the ordered nature of injury-severity data. Additionally, to account for unobserved heterogeneity, random parameters (RP) were introduced and the RP ordered logit model provided a superior fit as compared to a standard ordered logit model with fixed parameters. Several person-, vehicle-, roadway- and environmental-related variables were found to significantly affect the injury severity of riders or occupants of ATVs and golf carts, and the results of this study provide important insights which can be used in developing effective engineering-, enforcement-, education, or policy-related countermeasures.

2. Data description

Crash data for this analysis were obtained from the Arizona Department of Transportation (ADOT) and include all police-reported crashes in the US State of Arizona from 2010 through 2015. The data were then filtered to include only crash-involved persons driving or riding ATVs or golf carts. Ultimately, the data set utilized for this analysis included 1769 persons. The injury severity of each crash-involved person is recorded as one of five discrete ordered categories known as the "KABCO" injury scale. The injury severity levels are defined as follows (Arizona Department of Transportation (ADOT, 2010):

- K-injury (fatal injury) - Any injury that results in death within thirty 24 h periods (i.e. 30 days) after the crash occurred.
- A-injury (incapacitating injury) - Any injury, other than a fatal

injury, which prevents the injured person from walking, driving or normally continuing the activities the person was capable of performing before the injury occurred. This is often defined as “needing help from the scene,” and includes: severe lacerations, broken or distorted limbs, skull or chest injuries, abdominal injuries, and/or unconsciousness when taken from the crash scene.
- B-injury (non-incapacitating injury) - Any injury, other than a fatal injury or an incapacitating injury, which is evident to observers at the scene of the crash in which the injury occurred. Examples: contusions (bruises), laceration, bloody nose, lump on head, or abrasions.
- C-injury (possible injury) - Complaint of pain without visible injury. Includes – momentary unconsciousness, claim of injuries not evident, limping, complaint of pain, nausea or hysteria.
- O-no injury - No complaint or treatment was required by the person.

The final state-wide dataset consisted of the following injury-severity frequencies: 79 K-injuries, 333 A-injuries, 556 B-injuries, 230 C-injuries, and 571 persons with no injuries.

In addition to injury severity, several other person-, vehicle-, roadway-, and environmental-related variables were extracted from the analysis dataset and converted into binary indicator variables (taking the value of 0 or 1) for use in statistical modelling. Table 1 presents summary statistics of person- and vehicle- related variables, while Table 2 presents summary statistics for roadway- and environment-related variables. Collectively, consideration of how these person-, vehicle-, roadway-, and environmental-related variables may affect severity of crashes involving ATVs or golf carts and will aid transportation agencies in identifying the appropriate countermeasures aimed at reducing the severity of such crashes.

3. Statistical methodology

In order to analyse the effects of various factors on the injury severity of crash-involved persons, a random parameters (RP) ordered logit model was developed. This statistical framework is appropriate given the discrete ordered nature of the dependent variable (injury severity), and this framework has been utilized frequently in past studies examining crash injury severities (Mannering and Bhat, 2014; Savolainen et al., 2011). The ordered logit model is derived by specifying a latent variable, Z, which is specified as a linear function for each injury severity observation, such that (Washington et al., 2011):

$$Z = \beta X + \varepsilon \tag{1}$$

where: Z: latent variable used as the basis for modelling the ordinal ranking of the observed injury severity data, X: vector of variables determining the discrete ordering for each injury severity observation, β: vector of estimable parameters, ε: disturbance term

With this specification, the observed ordered data, y, for each occupant injury observation is defined as (Washington et al., 2011):

$$\begin{aligned} y &= 0 \ \text{if} \ Z \le \mu 0, \\ y &= 1 \ \text{if} \ \mu 0 < Z \le \mu 1, \\ y &= 2 \ \text{if} \ \mu 1 < Z \le \mu 2, \\ y &= 3 \ \text{if} \ \mu 2 < Z \le \mu 3, \\ y &= 4 \ \text{if} \ Z > \mu 3, \end{aligned} \tag{2}$$

where: μ_i: estimable threshold parameters that define y, which corresponds to the ordered injury severity categories (0 = no injury, 1 = C-injury, 2 = B-injury, 3 = A-injury, 4 = K-injury)

The μ thresholds are parameters which are estimated jointly with the model parameters β. It should be noted that the first threshold (i.e. μ_0) is set to 0 without loss of generality, and the error term, ε, is

Table 1
Summary Statistics for Person- and Vehicle-Related Variables.

Variable	Occupant Injuries by Severity Level					
	No Injury	C-Injury	B-Injury	A-Injury	K-Injury	Total
Vehicle Type						
All-Terrain Vehicle	319 (26.6%)	156 (13%)	399 (33.3%)	266 (22.2%)	58 (4.8%)	1198 (100%)
Golf Cart	252 (44.1%)	74 (13%)	157 (27.5%)	67 (11.7%)	21 (3.7%)	571 (100%)
Occupant Type						
Driver	374 (30.8%)	152 (12.5%)	392 (32.3%)	236 (19.4%)	60 (4.9%)	1214 (100%)
Passenger	197 (35.5%)	78 (14.1%)	164 (29.5%)	97 (17.5%)	19 (3.4%)	555 (100%)
Occupant Age						
Ages 24 or Less	213 (31.1%)	94 (13.7%)	231 (33.8%)	136 (19.9%)	10 (1.5%)	684 (100%)
Ages 25–54	182 (30.7%)	68 (11.5%)	185 (31.2%)	119 (20.1%)	39 (6.6%)	593 (100%)
Ages 55 and Over	156 (33.3%)	64 (13.7%)	140 (29.9%)	78 (16.7%)	30 (6.4%)	468 (100%)
Unknown	20 (83.3%)	4 (16.7%)	0 (0%)	0 (0%)	0 (0%)	24 (100%)
Occupant Gender						
Male	378 (31.7%)	146 (12.2%)	378 (31.7%)	228 (19.1%)	62 (5.2%)	1192 (100%)
Female	171 (31%)	81 (14.7%)	177 (32.1%)	105 (19.1%)	17 (3.1%)	551 (100%)
Unknown	22 (84.6%)	3 (11.5%)	1 (3.8%)	0 (0%)	0 (0%)	26 (100%)
Occupant Safety Device Use						
Safety Device Used	219 (45.6%)	59 (12.3%)	129 (26.9%)	63 (13.1%)	10 (2.1%)	480 (100%)
Safety Device Not Used	352 (27.3%)	171 (13.3%)	427 (33.1%)	270 (20.9%)	69 (5.4%)	1289 (100%)
Occupant Ejection						
Occupant Ejected	12 (3.6%)	49 (14.5%)	156 (46.3%)	115 (34.1%)	5 (1.5%)	337 (100%)
Occupant Not Ejected	559 (39%)	181 (12.6%)	400 (27.9%)	218 (15.2%)	74 (5.2%)	1432 (100%)
Vehicle Rollover						
Vehicle Rolled Over	116 (18.4%)	83 (13.2%)	249 (39.5%)	149 (23.7%)	33 (5.2%)	630 (100%)
Vehicle Did Not Rollover	455 (39.9%)	147 (12.9%)	307 (27%)	184 (16.2%)	46 (4%)	1139 (100%)
Person Alcohol/Drug Use						
Used Alcohol/Drugs	4 (9.3%)	0 (0%)	3 (7%)	2 (4.7%)	34 (79.1%)	43 (100%)
No Alcohol/Drug Use	567 (32.9%)	230 (13.3%)	553 (32%)	331 (19.2%)	45 (2.6%)	1726 (100%)
Collision Manner						
Single-Vehicle Crash	207 (20%)	137 (13.2%)	380 (36.7%)	255 (24.6%)	57 (5.5%)	1036 (100%)
Angle/Left-Turn Crash	146 (44.8%)	47 (14.4%)	84 (25.8%)	34 (10.4%)	15 (4.6%)	326 (100%)
Other (Rear-end, etc…)	218 (53.6%)	46 (11.3%)	92 (22.6%)	44 (10.8%)	7 (1.7%)	407 (100%)
Grand Total	**571 (32.3%)**	**230 (13.0%)**	**556 (31.4%)**	**333 (18.8%)**	**79 (4.5%)**	1769 **(100%)**

Table 2
Summary Statistics for Roadway- and Environment-Related Variables.

Variable	Occupant Injuries by Severity Level					
	No Injury	C-Injury	B-Injury	A-Injury	K-Injury	Total
Road Alignment						
Tangent	483 (34.2%)	194 (13.7%)	425 (30.1%)	251 (17.8%)	61 (4.3%)	1414 (100%)
Curve	88 (24.8%)	36 (10.1%)	131 (36.9%)	82 (23.1%)	18 (5.1%)	355 (100%)
Road Grade						
Level	471 (35.5%)	182 (13.7%)	404 (30.4%)	225 (16.9%)	46 (3.5%)	1328 (100%)
Downgrade	48 (19.9%)	27 (11.2%)	87 (36.1%)	65 (27%)	14 (5.8%)	241 (100%)
Upgrade	22 (27.5%)	9 (11.3%)	26 (32.5%)	20 (25%)	3 (3.8%)	80 (100%)
Transition/Other	30 (25%)	12 (10%)	39 (32.5%)	23 (19.2%)	16 (13.3%)	120 (100%)
Speed Limit						
35 mph or Less	370 (33.4%)	147 (13.3%)	349 (31.5%)	198 (17.9%)	43 (3.9%)	1107 (100%)
40 mph or Greater	90 (42.3%)	28 (13.1%)	51 (23.9%)	38 (17.8%)	6 (2.8%)	213 (100%)
Not Posted	111 (24.7%)	55 (12.2%)	156 (34.7%)	97 (21.6%)	30 (6.7%)	449 (100%)
Surface Condition						
Paved Road - Dry	468 (34.7%)	173 (12.8%)	412 (30.6%)	251 (18.6%)	44 (3.3%)	1348 (100%)
Paved Road - Wet/Icy	20 (36.4%)	8 (14.5%)	20 (36.4%)	5 (9.1%)	2 (3.6%)	55 (100%)
Gravel/Mud Surface	68 (21.9%)	45 (14.5%)	111 (35.7%)	67 (21.5%)	20 (6.4%)	311 (100%)
Other/Unknown	15 (27.3%)	4 (7.3%)	13 (23.6%)	10 (18.2%)	13 (23.6%)	55 (100%)
Lighting Condition						
Daylight	395 (32%)	166 (13.5%)	413 (33.5%)	222 (18%)	38 (3.1%)	1234 (100%)
Dark/Dawn/Dusk Light	176 (32.9%)	64 (12%)	143 (26.7%)	111 (20.7%)	41 (7.7%)	535 (100%)
Season						
Winter	135 (40.5%)	36 (10.8%)	91 (27.3%)	54 (16.2%)	17 (5.1%)	333 (100%)
Spring	183 (31.3%)	76 (13%)	181 (30.9%)	121 (20.7%)	24 (4.1%)	585 (100%)
Summer	95 (24.4%)	47 (12.1%)	154 (39.5%)	75 (19.2%)	19 (4.9%)	390 (100%)
Fall	158 (34.3%)	71 (15.4%)	130 (28.2%)	83 (18%)	19 (4.1%)	461 (100%)
Day of Week						
Weekend	237 (29.4%)	104 (12.9%)	244 (30.2%)	176 (21.8%)	46 (5.7%)	807 (100%)
Weekday	334 (34.7%)	126 (13.1%)	312 (32.4%)	157 (16.3%)	33 (3.4%)	962 (100%)
Grand Total	**571 (32.3%)**	**230 (13.0%)**	**556 (31.4%)**	**333 (18.8%)**	**79 (4.5%)**	1769 **(100%)**

assumed to be logistically distributed across observations.

Given the fact that certain parameters may vary across observations due to unobserved heterogeneity and potentially lead to biased parameter estimates if not accounted for (Mannering and Bhat, 2014; Savolainen et al., 2011; Train, 2009), random parameters (RP) were incorporated into this analysis. RP allow for the effects of certain parameters to vary across observations and are incorporated into the ordered logit model as follows (Greene and Heshner, 2010):

$$\beta_i = \beta + w_i \tag{3}$$

where β_i is a vector of estimable parameters, w_i is a randomly distributed term (i.e. normally distributed with mean zero and variance σˆ2) and *i* represents each observation within the sample data set.

To improve the efficiency of model estimation, Halton draws were utilized as recommended by prior research (Bhat, 2003; Halton, 1960; Train, 2009). During the modelling process, variables that showed significant variability (as evidenced by statistically significant standard deviations) were modelled as random and the remainder were retained as fixed parameters. Practically speaking, a variable exhibiting significant variability indicates the effect of that variable is not constant across all observations (for example, the overall effect of old age may increase probability of severe outcomes, but there may be older drivers who do not exhibit in increased risk of severe outcomes due to some other unobserved differences besides age). Marginal effects were also estimated which are used to determine the direction and magnitude of effects of each variable on each injury severity level. For details on how marginal effects are calculated, see Washington et al., 2011. In the context of this analysis, the numerical marginal effect for each variable represents the change in probability of an injury severity level when that indicator variable is changed from 0 to 1.

With respect to the variables included in the final model for this analysis, all are binary indicator variables as stated previously. There is an ATV vehicle type indicator (as opposed to golf cart), a driver indicator (as opposed to passenger), age group indicators with age 25–54 left out as the reference category, a male gender indicator (as opposed to female), a safety device (helmets or seatbelts) used indicator (as opposed to safety device non-use), and an alcohol/drug use indicator (as opposed to alcohol/drug non-use). There are also indicators for if a person was ejected, and whether a vehicle rolled over at any point during the crash. There are indicators for crash type including single-vehicle and angle/left-turn crash, which are compared against all other crash types. There are indicators for crashes occurring on horizontal curves and downhill grades, as well as for roads with no posted speed limit (as opposed to those with a posted speed limit). Additionally, there are indicators for dry paved roads and wet/icy paved roads (with unpaved roads left out as the reference category), and finally, there are indicators for crashes occurring dark/dawn/dusk light conditions, crashes occurring on weekends, and crashes occurring in the winter season.

4. Results and discussion

4.1. Analysis results

The results of the RP ordered logit model are presented in Table 3, and the marginal effects are presented in Table 4. As stated previously, variables which exhibited significant variability were modelled as random parameters and the remainder were retained as fixed variables. Ultimately fifteen variables (plus the constant term) were modelled as random parameters. While the results of fixed-effect and RP models were somewhat similar, the RP model provided a superior fit as compared to a standard fixed-effect ordered logit model based on the results of a log-likelihood ratio test ($\chi 2$ = 110.21, 13 degrees of freedom, p-value < 0.001). In interpreting the model results, a positive parameter (β) estimate indicates that variable increases the probability of a fatality (K-injury) and reduces the probability of no injury (O); and the converse is true for negative parameter estimates. It should be noted that only parameters whose parameter estimates or standard deviations

Table 3
Results of the RP Ordered Logit Model.

Variable	β	Std. Error	p-value	Std. Dev.	Std. Error	p-value
Constant	−1.266	0.270	< 0.001	1.087	0.061	< 0.001
All-Terrain Vehicle (ATV)	1.203	0.143	< 0.001	0.245	0.062	< 0.001
Driver*	0.822	0.124	< 0.001	–	–	–
Age ≤ 24 Years	−0.004	0.128	0.973	0.211	0.082	0.010
Age ≥ 55 Years	0.917	0.160	< 0.001	1.760	0.118	< 0.001
Male	−0.086	0.117	0.460	1.801	0.082	< 0.001
Safety Device Used*	−1.554	0.135	< 0.001	–	–	–
Ejected*	1.866	0.144	< 0.001	–	–	–
Rollover	0.206	0.129	0.110	0.225	0.085	0.008
Alcohol/Drugs	22.680	3.426	< 0.001	20.331	3.495	< 0.001
Single Vehicle Crash*	2.072	0.164	< 0.001	–	–	–
Angle/Left-Turn Crash*	0.711	0.178	< 0.001	–	–	–
Horizontal Curve*	0.332	0.141	0.019	–	–	–
Downhill Grade*	0.446	0.163	0.006	–	–	–
No Posted Speed Limit	0.494	0.131	< 0.001	1.420	0.112	< 0.001
Dry Paved Road	−0.204	0.143	0.155	0.830	0.065	< 0.001
Wet/Icy Paved Road	−0.654	0.332	0.049	1.732	0.318	< 0.001
Dark/Dawn/Dusk Light	0.119	0.124	0.336	2.284	0.123	< 0.001
Weekend	0.167	0.111	0.130	0.916	0.083	< 0.001
Winter Season	−0.697	0.143	< 0.001	1.355	0.136	< 0.001
Threshold 1 (μ_1)	1.317	0.082	< 0.001			
Threshold 2 (μ_2)	4.565	0.151	< 0.001			
Threshold 3 (μ_3)	8.941	0.294	< 0.001			
Restricted Log Likelihood (LL)	−2,560.120					
Final LL for Fixed Model	−2,260.395					
Final LL for RP Model	−2,205.291					

* Fixed Parameter.

Table 4
Marginal Effects for RP Ordered Logit Model.

Variable	PDO	C-Injury	B-Injury	A-Injury	K-Injury
All-Terrain Vehicle (ATV)	−0.1232*	−0.1345*	0.1708*	0.0856*	0.0013*
Driver	−0.0794*	−0.0947*	0.1126*	0.0606*	0.0009*
Age ≤ 24 Years	0.0004	0.0005	−0.0005	−0.0004	0.0000
Age ≥ 55 Years	−0.0662*	−0.0989*	0.0731*	0.0906*	0.0015*
Male	0.0072	0.0100	−0.0099	−0.0072	−0.0001
Safety Device Used	0.1781*	0.1639*	−0.2395*	−0.1010*	−0.0015*
Ejected	−0.1062*	−0.1703*	0.0291	0.2425*	0.0048*
Rollover	−0.0171	−0.0238	0.0232	0.0174	0.0003
Alcohol/Drugs	−0.1527*	−0.2495*	−0.5431*	−0.0539*	0.9993*
Single Vehicle Crash	−0.2173*	−0.2081*	0.2635*	0.1593*	0.0026*
Angle/Left-Turn Crash	−0.0505*	−0.0770*	0.0560*	0.0704*	0.0012*
Horizontal Curve	−0.0259*	−0.0376*	0.0335*	0.0296*	0.0005*
Downhill Grade	−0.0331*	−0.0495*	0.0402*	0.0418*	0.0007*
No Posted Speed Limit	−0.0380*	−0.0554*	0.0477*	0.0450*	0.0007*
Dry Paved Road	0.0166	0.0234	−0.0222	−0.0175	−0.0003
Wet/Icy Paved Road	0.0709	0.0756*	−0.1039	−0.0420*	−0.0006*
Dark/Dawn/Dusk Light	−0.0141	−0.0193	0.0194	0.0138	0.0002
Weekend	−0.0100	−0.0138	0.0135	0.0100	0.0002
Winter Season	0.0705*	0.0808*	−0.1023*	−0.0484*	−0.0007*

* Marginal Effect Significant at 95% Confidence Level.

were significant at a 95% confidence level (p-value < 0.05) were included in the final model. Additionally, cases where a variable was reported as "unknown" or "not reported" were excluded during the modelling process, so a total of 1743 cases were utilized for the final model.

4.2. Discussion

In interpreting the results of the RP ordered logit model, it is important to note that statistical association of a variable with injury severity does not necessarily infer causation. Discussion of the model results in this section includes discussion regarding why these associations may be present. Based on the results of the RP ordered logit model presented in Table 3, crashes involving ATVs were more likely to result in fatalities as compared with golf carts. Compared to riders of golf carts, riders of ATVs had a 0.13% increased risk of fatality and an 8.6% increased risk of A-injuries, all else being equal. It should be noted that the ATV variable was modelled as a random parameter as it exhibited significant variability. This may be a reflection of the different types of ATV users (i.e. recreational vs. commercial/farm), as well as the different types of ATV models (which were not available in the data set used for this analysis). For example, the crash characteristics of 4-wheeler ATVs in which riders sit on top would likely differ than those of ATVs with a side-by-side seating arrangement which typically are enclosed by a frame and offer better rollover protection. Drivers of any vehicle type were more likely to experience severe injuries as compared to passengers, and this may be a result of more cautious driving behaviour when passengers are present, as compared to those driving alone.

With respect to different age groups, persons age 55 years or older had the highest risk of severe injuries as compared to those less than 55 years old. The variable for Age ≤ 24 years was not statistically significant, however parameter estimates for both age groups included in the model exhibited significant variability. The finding regarding older persons having a higher risk of severe injury may be due to physiological factors such as frailty, slower reflexes, and degraded vision at older ages. Concerning person gender, the male indicator variable was not statistically significant, however, it did exhibit significant variability as evidenced by the statistically significant standard deviation. Given that roughly 68% of observations were male, and past studies have found males more likely to be severely injured (Williams et al., 2014), further research may be warranted into the potential impacts of gender.

Not surprisingly, persons who were using safety devices (helmets and/or seatbelts), were at a significantly lower risk for severe injury compared with those who did not use safety devices (0.2% reduced risk of fatality and 10.1% reduced risk of A-injuries), which is consistent with past research (National Highway Traffic Safety Administration (NHTSA, 2015). Additionally, persons who were ejected from their ATVs or golf carts were at an increased risk of severe injury, also an expected result. With respect to crash type, persons involved in a single-vehicle crash were at the highest risk for severe injuries, followed by those involved in an angle or left turn collision, as compared to all other crash types (e.g. rear-end, sideswipe, etc.). This result is similar to previous summaries of ATV-related fatality data (National Highway Traffic Safety Administration (NHTSA, 2015; Williams et al., 2014), and may be related to the facility or area type where the crash occurred (e.g. multi-vehicle crashes may be more likely to occur in urban or suburban areas).

Several variables related to roadway type were found to be significantly associated with injury outcomes. Crashes occurring on horizontal curves or downhill grades were both associated with higher risk of severe injuries, likely due to potentially limited sight distances and/or the more difficult navigation of horizontal curves and the potential increases in speed on downhill grades. Crashes occurring on roadways with no posted speed limit also resulted in an increased risk of severe injuries, which is likely related to the roadway facility type where the crash occurred. For example, roadways in rural areas or recreational roadways may be more likely to have no posted speed limit as compared with urban or suburban areas. Additionally, riders may exhibit riskier behaviours on roadways where there is no posted speed limit as enforcement may likely be less common on these roadways. With respect to surface type, crashes occurring on paved roads (whether they were dry or wet/icy) resulted in a lower risk of severe injuries as compared with unpaved/gravel roads. Again this is likely related to the area or roadway facility type where the crash occurred, and the type of rider that would be using these unpaved/gravel roads. With respect to time of year, not surprisingly, crashes occurring in winter months resulted in lower risk of severe injuries, likely due to the fact that people may be less likely to use ATVs or golf carts for recreational purposes during these months.

Of all variables included in this analysis, alcohol or drug use was found to be associated with the largest increase in risk of fatalities (99.9% increase in risk of a fatality). This result is consistent with previous analyses of ATV crashes (National Highway Traffic Safety Administration (NHTSA, 2015; Williams et al., 2014; Denning et al., 2013), indicating that alcohol use by riders of these vehicle types is a serious public health concern. Based on the results of this study, any effort to reduce alcohol use by riders of ATVs, or golf carts, whether education- or enforcement-related, would have the greatest potential to prevent fatalities. Additionally, efforts aimed at increasing safety device use (i.e. helmets or seatbelts if available) have the potential to reduce severe injuries, as well as educational safety efforts aimed at younger (< 24 years) and/or older (> 55 years) users of ATVs or golf carts, which stress the importance of safe ATV or golf cart driving practices and safety device use.

5. Conclusions

Given the popularity of all-terrain vehicles (ATVs) in the United States (US) and the vulnerability of these road users, this study aimed to gain a better understanding of factors affecting the injury severity of ATV and golf cart riders or occupants involved in police-reported crashes. The study utilized six years of crash data from the US state of Arizona which included observations for 1769 occupants/riders of these vehicle types; 67.7% of which were injured or killed. An ordered logit statistical model was developed and random parameters (RP) were introduced to account for unobserved heterogeneity which resulted in a superior model fit. Several person- vehicle- roadway- and environmental-related variables were found to significantly affect the injury severity of riders or occupants of ATVs and golf carts, and the results of this study provide important insights which can be used in developing effective engineering-, enforcement-, education, or policy-related countermeasures.

Based on the results of this study, countermeasures aimed at reducing alcohol or drug use by riders of ATVs or golf carts may be the most effective, as alcohol or drug use was found to increase the risk of a fatality by 99.9%. Additionally, safety device use (helmets and/or seatbelts) should be encouraged through education or enforcement as this was found to reduce the risk of fatalities by 0.15% and A-injuries by 10.1%. Focus should also be placed on roadways with no posted speed limits, unpaved/gravel roadways, locations with horizontal curves, and locations with a downhill grade, as ATV and golf cart crashes occurring at these locations were associated with an increased risk of severe injuries. Low-cost countermeasures aimed at improving safety at these locations might include warning or regulatory (e.g. curve warning or advisory speed) signage aimed at users of these vehicle types, particularly in areas where use of these vehicles is popular. Past research has found that curve warning signs can moderately reduce the operating speeds of vehicles (Vest et al., 2005), and therefore potentially reduce impact forces (and resulting severity) if a crash were to occur at one of these locations.

With respect to demographic characteristics, education, enforcement, and/or licensing policies should focus ATV for golf cart riders age 24 or younger and age 55 or older, as crashes involving persons of these age groups were associated with higher risks of severe injuries or exhibited significant variability. The importance of safety device use and dangers of alcohol use should be stressed throughout any educational effort and/or registration/licensing process for these types of vehicles. Additionally, the importance of proper vehicle lighting and/or the use of high-visibility reflective clothing for users of these vehicle types should be emphasised, as crashes occurring during dark/dawn/dusk lighting conditions were found to exhibit significant variability in terms of injury severity, indicating there are certain clusters of these crashes that may result in severe injuries.

It should be noted that one potential limitation of this study is the possibility that some ATV or golf cart crashes (particularly low severity crashes) were not reported to police. As such, this study can be thought of as an analysis of only 'police-reported' ATV and golf cart crashes. This crash underreporting issue applies to other vehicle types as well, and is a well-documented issue in the literature with respect to crash severity analyses (Mannering and Bhat, 2014; Savolainen et al., 2011). Future research on the rate of, and reasons for underreporting of ATV and golf cart crashes (as well as other vehicle types) is warranted.

While this study analysed factors affecting injury severities, future research is warranted which explores factors affecting the *frequency* of ATV or golf cart crashes as use of these vehicle types continues to increase. To explore factors affecting the frequency of crashes involving these vehicle types, additional data would be required including exposure (i.e. traffic volumes), geometric data, and environmental data. In fact, one potential limitation of this study is that only police-reported crash data was available, which is subject to potential issues such the previously mentioned underreporting, as well as accuracy and completeness issues (Mannering and Bhat, 2014; Savolainen et al., 2011). Future studies integrating detailed roadway, environmental, or hospital data may provide further insights into factors affecting the severity of ATV and golf cart crashes.

Additionally, future research involving ATV crashes should explore differences between different types of ATVs if possible (i.e. 3-wheelers vs. 4-wheelers vs. side-by-sides, etc…), as this was a limitation of the current analysis. Moreover, while the results of this study may be transferable to other states or countries, future research on ATVs or golf carts in other areas of the world may be warranted if roadway or traffic characteristics differ significantly than those of the US.

Declaration of Competing Interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

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