Contributing Circumstances Impact on Missouri Teenage Driver Crash Fatalities

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Missouri data from 2002-2011 are used to analyze the major circumstances that increase the risk of fatality in crashes involving teenage drivers, given a motor vehicle crash occurs. The frequencies of contributing circumstances among teenage and older drivers are compared and a multinomial logistic regression model is used to predict the probability of crash severity under different circumstances. For crashes involving teenage drivers, it is found that driving too fast for conditions, speeding, inattention, and driving on the wrong side are the most frequent circumstances cited in fatal crashes, and are major factors that increase the likelihood of a fatality occurring.

INTRODUCTION

Motor vehicle traffic crashes are the leading cause of death for United States teenagers (Miniño 2010), accounting for the loss of over 2,800 teen lives in 2012 alone (Insurance Institute for Highway Safety 2014). It has been found that teenagers often lack adequate driving skills and exhibit poor driving judgment (University of Michigan Transportation Research Institute 2002), and teenage drivers are more likely than older drivers to exhibit reckless and risky behavior: i.e., drive at excessive speeds, violate traffic signals, follow too closely, overtake other vehicles in a risky manner, allow too little time to merge, and fail to yield to pedestrians (Williams 2003). Accordingly, much research has examined the effect of specific factors on teenage driver fatalities and focused upon preventive measures to enhance teenage driver safety.

Graduated Drivers Licensing (GDL) programs have been shown to enhance teenage driver safety and significantly reduce the rate of teenage driver fatalities. Yet, it has been claimed that "reductions in fatal crashes were greatest in states that had enacted other restrictions on young drivers" (U.S. Department of Health and Human Services, National Institute of Health 2011). As a result, the purpose of this study is to analyze circumstances that may contribute to Missouri teenage driver fatalities and to produce information relevant for the enhancement of Missouri's GDL program. The analysis compares the frequency of contributing circumstances occurrences leading to fatal crashes of drivers 16 to 19 years old and older drivers, determines the probability of a fatal crash for teenage drivers given a contributing circumstance or combination of contributing circumstances, as well as explores the impact of contributing circumstances in combination with varying speed limits and environmental factors, (road surface, road alignment, road profile, road conditions, weather condition, light conditions) while controlling for the crash location (on or off the roadway) and number of occupants. The paper concludes with findings that will be useful for legislation and education to aid in diminishing crash injury severity for teenage drivers.

LITERATURE REVIEW

In order to protect U.S. teenage and other drivers, all 50 states and the District of Columbia have imposed GDL restrictions on drivers under the age of 21. GDL programs are designed to delay full licensure and phase in driving privileges (National Highway Traffic Safety Administration n.d.) with the intent to "encourage new drivers to acquire critical driving skills and experience in low-risk and monitored settings" (Dee et al. 2005). In a three-staged GDL program, new drivers begin

in an instructional, supervised practice phase, proceed to a provisional license that temporarily restricts unsupervised driving, and then graduate to an under 21 full driver's license (Williams 2003, Mayhew et al. 1998). Requirements for progressing through GDL's three stages (learner's permit, provisional licensure, and full licensure) vary across jurisdictions (Insurance Institute for Highway Safety, Highway Loss Data Institute 2011), but typically include adult supervision, restriction on nighttime driving, and limitations on transportation of young passengers (University of Michigan Transportation Research Institute 2002).

Many studies have been conducted to determine if these GDL policies are effective in reducing teenage crashes. Foss et al. (2001) assessed crash rates before and after North Carolina's GDL program implementation, and discovered that crash rates declined sharply among 16-year-old drivers. Likewise, Shope and Molnar (2004) evaluated the effectiveness of Michigan's GDL program by assessing the difference between motor-vehicle crash data for 16-year-old drivers pre-GDL and post-GDL. Results indicated that risk reduction for crash injury severity for all fatal and non-fatal injuries were substantial and impressive, and it was claimed that the "GDL remains promising." Fohr et al. (2005) considered the implementation of Wisconsin's GDL, and discovered that for 16- and 17-year-olds both general and injury crash rates declined. The authors claimed that the decline was the result not of safer driving of teens, but rather due to reduced exposure to the risk of collision. Rios et al. (2006) developed a generalized linear model to assess the impact of Georgia's Teenage and Adult Drivers Responsibility Act (TADRA) on the reduction of teenage driver fatalities. Findings indicated that speed-related teenage fatal crashes and alcohol-related teenage fatal crashes significantly decreased after the TADRA was enacted. Additionally, Hyde et al. (2005) assessed if crash rates of 16-year-old drivers decreased after implementation of Utah's GDL by examining overall crash rates, crash severity indicators, nighttime crashes, licensure status, seat belt usage, and citations. Using an interventional time series analysis, findings implied that the GDL program may have contributed to minimal reduction in teenage driver crashes, compared with other GDL evaluations. Ehsani et al. (2013) also used a time-series analysis to assess the impact of GDL on crash injury severity of 16-, 17- and 18-year-old drivers in Maryland, Florida, and Michigan. Results suggested that crash rates for drivers 16 and 17 years old declined in all three states following GDL implementation or revision, while crash rates for possible injury/property damage only for 18-year-old drivers decreased in Maryland, increased in Michigan, and did not significantly change in Florida following GDL implementation or revision. Other recent studies have focused on the impact of contributing circumstances on crash injury severity for young people. Amarasingha and Dissanayake (2013) developed a multinomial model to examine the impact of contributory factors on crash severity for young drivers involved in crashes in Kansas. Findings suggested that failure to give time/attention, failure to yield, driving too fast for conditions, falling asleep, following too closely, and distraction/inattention increased the crash risk for young drivers, and such findings can be useful in teen driving safety efforts. Similar to Amarasingha and Dissanayake (2013) and Ehsani et al. (2013), this study estimates the impact of contributing circumstances on crash injury severity for young drivers and considers the impact of these factors on the GDL policy. Yet, unlike the reviewed literature, this study concentrates specifically on the state of Missouri and explores possible scenarios to aid in enhancing Missouri teenage licensing policy.

Missouri Graduated Drivers Licensing Program

The Missouri GDL program was enacted as part of Senate Bill (SB) 19 passed in the 1999 legislative session, and put into effect January 1, 2001. The legislation requires that all first-time drivers between the ages of 15 and 18 years old complete a period of driving with a licensed driver followed by a period of restricted driving before graduating to an under 21 full driver's license (Missouri Department of Revenue 2014).

The 2001 Missouri GDL program implemented three significant policies: (1) a six month mandatory holding period of the learner permit, (2) prohibition of unsupervised driving from 1:00 a.m. to 5:00 a.m. during the intermediate license phase, and (3) the requirement of 20 hours of supervised driving instruction. Significant revisions to the GDL program were enacted in 2006 and 2007 to include: (1) restrictions on passengers in vehicles operated by drivers in the intermediate phase, whereby in the first six months no more than one passenger under the age of 19 and thereafter, no more than three passengers under the age of 19 are permitted, and (2) first-time drivers between the ages of 15 and 18 to require 40 hours of driving instruction, including a minimum of 10 hours of nighttime driving with a parent, legal guardian, grandparent, qualified driving instructor or certified trainer (Missouri Department of Revenue 2014). All current GDL requirements for Missouri teenage drivers may be found in Appendix A, and a comparison of Missouri's policy with the remaining states and Washington D.C. GDL policies is presented in Table 1.

DATA

The Missouri State Highway Patrol (MSHP) Traffic Division is the statewide repository for traffic crash reports. The MSHP collects and preserves crash report data to provide computerized records for research and analysis purposes. The Traffic Division codes and classifies the reports for entry in the Statewide Traffic Accident Records System (STARS) database, and is "responsible for maintaining the official count of motor vehicle crash fatalities for the State of Missouri" (Missouri

Table 1: Comparison of GDL Laws

		Lerner Stage		Intermediate Stage		Full License	
	Minimum Age (Years/Months)	Minimum Duration (Days or Months)	Required Supervised Driving Hours (Night Hours)	Minimum Age (Year/Months)	Nighttime Driving Restrictions	Passenger Restrictions	Minimum Age (Years/Months)
Restriction (# of states)[1]	14 (6) 14 / 6 (2) 14 / 9 (1) 15 (MO + 22) 15 / 6 (9) 15 / 9 (1) 16 (8 + D.C.)	None (1) 10 days (1) 4 mos. (1) 6 mos. (MO + 34 + D.C.) 180 days (1) 9 mos. (3) 12 mos. (8)	Some supervised driving (MO + 45 + D.C.) None (4)	14 + 180 days (1) 15 (2) 15 / 6 (2) 16 (MO + 33) 16 / 3 (1) 16 / 4 (1) 16 / 6 (8 + D.C.) 17 (1)	Some nighttime restrictions (MO + 48 + D.C.) None (1)	Some passenger restrictions (MO + 46 + D.C.) None (3)	16 (3) 16 / 6 (11) 16 / 9 (1) 17 (14) 17 / 6 (1) 18 (MO + 7 + D.C.) Varies (12)

[1]The information provided in parentheses indicates the total number of states (excluding Missouri) that adheres to the relevant policy and/or if Missouri (MO) or Washington DC (D.C.) adhere to the relevant policy.
Source: Governors Highway Safety Association (2014)

Traffic Records Committee 2002). Traffic, personal, and vehicle crash data from 2002-2011 were obtained from the STARS database. Approximately 2.3 million usable records of Missouri drivers in a crash were analyzed to determine if a significant relationship exists between the contributing circumstances indicated below and teenage driver fatalities.

After a crash occurs, at least one, but no more than five, of the following contributing circumstances at the driver level are identified per vehicle as determined by the crash investigator (Missouri Traffic Records Committee 2002).

1. Vehicle Defects
2. Traffic Control Inoperable/Missing
3. Improperly Stopped on Roadway
4. Speed – Exceeded Limit
5. Too Fast for Conditions
6. Improper Passing
7. Violation Signal /Sign
8. Wrong Side (not passing)
9. Following Too Close
10. Improper Signal
11. Improper Backing
12. Improper Turn
13. Improper Lane Usage / Change
14. Wrong Way (One-Way)
15. Improper Start From Park
16. Improperly Parked
17. Failed to Yield
18. Alcohol
19. Drugs
20. Physical Impairment
21. Inattention
22. None

METHODOLOGY

Cross-Tabulation

Cross-tabulation is employed to examine the frequency of fatal crashes in order to determine if contributing circumstances are more or less prevalent among teenage drivers. Table 2 below illustrates that driving too fast for conditions (25.9%), speeding (20.6%), inattention (18.3%), driving on the wrong side of the road (14.9%), alcohol (14.1%), and improper lane usage (13.6%) are the most frequent contributory circumstances cited in fatal crashes involving teenage drivers. Additionally, Table 2 presents chi-square tests to determine if significant differences exist between the frequency of contributing circumstances for 16- to 19-year-old drivers and older drivers, given a fatal crash occurs. Results from the chi-square tests indicate that, between the two age groups, the contributing circumstances of speeding, driving too fast for conditions, improper passing, driving on the wrong side of the road, alcohol, physical impairment, and inattention are significantly different at the 0.05 level. All significantly different circumstances are more prevalent for teenage drivers than for older drivers, with the exceptions of alcohol intoxication and physical impairment. Furthermore, the significantly lower prevalence of no contributing circumstance (i.e., none) in the 16- to 19-year-old age group suggests that teenagers are more likely to be a contributory driver, given a fatal crash occurs. As Table 2 indicates, 80.6% of teenage drivers involved in a fatal crash contributed to the crash (1-[260/1,338]), while only 63.6% of other drivers did (1-[3,688/10,135])!

Table 2: Frequency and Chi-Square Tests for Contributing Circumstances Leading to Fatalities in Years 2002-2011 for Drivers Aged 16 to 19 and Older Drivers

	Drivers Age		Chi-Square	
Contributing Circumstances	16-19	Other	Value	Sig.
Vehicle Defects	12	114	0.565	0.452
Speeding	275	1,077	112.034	0.000
Too Fast for Conditions	346	1,726	62.267	0.000
Improper Passing	36	181	5.213	0.022
Violation Signal /Sign	55	326	2.943	0.086
Wrong Side	199	954	38.979	0.000
Following Too Close	19	134	0.086	0.769
Improper Turn	10	79	0.160	0.900
Improper Lane Usage/Change	182	1,200	3.465	0.063
Failed to Yield	115	800	0.792	0.373
Alcohol	188	1,742	8.313	0.004
Drugs	37	263	0.135	0.714
Physical Impairment	28	373	8.833	0.003
Inattention	245	1,414	18.159	0.000
All Other Circumstances[1]	11	121	1.436	0.231
None	260	3,688	150.577	0.000
Total Number of Cases[2]	1,338	10,135		

[1] All Other Circumstances include Traffic Control Inoperable/Missing, Improperly Stopped on Roadway, Improper Signal, Improper Backing, Improper Start from Park, Improperly Parked, and Wrong Way.
[2] Total number of cases does not equal the sum of the frequency of contributing circumstances, since more than one circumstance may be present in a given crash.

Due to their impact and significance, factors that lead to driver inattention are further differentiated as: Cell Phone; Stereo/Audio/Video Equipment; Computer Equipment/GPS/Electronic Game/etc.; Passenger; Tobacco Use; Eating/Drinking; Reading; Grooming; Other; and Unknown. As depicted in Table 3, cell phone use and passengers in the vehicle are the two largest identified specific causes of inattention for drivers aged 16 to 19. For the 16- to 19-year-old age group, inattention caused by cell phone use not only has the highest relative percentage relating to teenage fatalities (with the exception of the combined "Other" category), but also a higher percentage when compared with older drivers.

Table 3: Causes of Inattention Relating to Fatalities from 2002-2011

	Frequency		
	Driver Age		
Cause of Inattention	16-19	Other	Total
Cell Phone	23	57	80
Stereo/Audio/Video Equipment	5	14	19
Computer/GPS/Electronic Game/etc.	0	2	2
Passenger	13	37	50
Tobacco Use	0	6	6
Eating/Drinking	0	12	12
Reading	0	3	3
Grooming	0	1	1
Other[1]	190	1,197	1,387
Total[2]	231	1,329	1,560

[1] Potential causes include external distractions, adjusting vehicle controls, adjusting safety devices, hands-free communication devices, etc.

[2] Unknown factors leading to inattention are not included in total.

Multinomial Logistic Regression

Focusing on drivers who contributed to a crash, a multinomial logistic regression is employed to estimate the probability that when specific combinations of contributing circumstances are present the crash severity is either fatal (1), personal injury - disabling major (2), personal injury - evident (3), personal injury - probable (4), or property damage only (5). Many studies have chosen the multinomial logit approach to control for possible systematic differential under-reporting when assessing crash injury severity (e.g., Shankar and Mannering 1996; Carson and Mannering 2001; Ulfarsson and Mannering 2004; Khorashadi et al. 2005; Islam and Mannering 2006; Kim et al. 2007; Malyshkina and Mannering 2008; Savolainen and Ghosh 2008; Schneider et al. 2009; Malyshkina and Mannering 2010; Rifatt et al. 2011; Schneider and Salovainen 2011; Yasmin and Eluru 2013; Ye and Lord 2014).

Since not all crashes are reported, other crash prediction models, such as ordered logit and probit models, can lead to biased parameter estimates (Ye and Lord 2014). Multinomial logit models do not consider the natural ordering of outcomes and therefore might be considered less parsimonious than ordered models; however, given a systematically under-reported outcome, a multinomial logit model offers greater explanatory power due to the additional exogenous effects that may be explored (Eluru 2013).

The multinomial logit model, where β_i is a vector of estimable parameters and X_{in} is a vector of observable variables that may impact the probability of crash severity outcome i for observation n (Savolainen et al. 2011) is presented in equation (1).

$$(1)\quad P_n(i) = \frac{\mathrm{EXP}[\beta_i^T \bullet \mathrm{X}_{in}]}{\sum_i \mathrm{EXP}\,[\beta_i^T \bullet \mathrm{X}_{in}]}$$

Savelonien et al. (2011) and Mannering and Bhat (2014) completed extensive reviews of the literature where multinomial logit methodologies were used to analyze crash injury severity. From a review of the identified studies, numerous variables are suggested to impact crash injury severity. These variables include driver's age (Schneider et al. 2009; Rifatt et al. 2011; Yasmin and Eluru 2013), passenger presence/number of passengers (Khorashadi et al. 2005; Islam and Mannering

2006; Savolainen and Ghosh 2008; Schneider et al. 2009), speed limit (Islam and Mannering 2006; Savolainen and Ghosh 2008; Schneider et al. 2009; Malyshkina and Mannering 2010; Yasmin and Eluru 2013), crash location (Savolainen and Ghosh 2008; Schneider et al. 2009), lighting conditions (Savolainen and Ghosh 2008; Rifatt et al. 2011; Yasmin and Eluru 2013), road conditions, surface and profile (Khorashadi et al. 2005; Kim et al. 2007; Malyshkina and Mannering 2008; Schneider et al. 2009), and weather conditions (Kim et al. 2007; Schneider and Salovainen 2011). As a result, these variables, in conjunction with contributory circumstances, have been included in the multinomial model since each may contribute to different crash severity outcomes.

The maximum likelihood ratio tests, parameter estimates and equation specific significance tests of the multinomial model with the baseline category of a property damage only severity outcome are presented in Table 4. The overall goodness of fit test with 1,165,745 observations yields a $\chi 2 =$ 140,516.445 with p-value equal to 0.000).

As illustrated in the top panel of Table 4, the likelihood ratio tests indicate that all variables are significant in the model at the 0.000 significance level. The coefficients in the lower panel of Table 4, suggest the magnitude and directional impact of each factor on the level of injury severity (i.e., a term with a positive coefficient in the model will increase the probability of the outcome and a term with a negative coefficient in the model will decrease the probability of the outcome). Additionally, the Fatality column in the lower panel of Table 4 suggests that the presence of speeding, driving too fast for conditions, violating a stop sign or signal, driving on the wrong side of the road, driving while under the influence of alcohol or drugs, and driving while physically impaired are the contributing circumstances that have the greatest ceteris paribus increase on the probability of a fatal outcome, given a crash occurs. In addition, environmental factors of foggy/misty weather conditions and dark, unlit conditions also increase the probability of a fatal outcome. In contrast, wet, snowy or icy road conditions are suggested to decrease the likelihood of a fatal outcome, while rainy and snowy weather conditions have little relative impact. Finally, it is found that as the speed limit increases, the likelihood of a fatal outcome, given a crash occurs, also increases.

The model illustrates that the presence of certain drivers' contributions to a crash can dramatically change the probability of a fatal outcome when a motor vehicle crash occurs. Drawing upon the factors found to be more prevalent in the teenage age group (Table 2), the parameter estimates presented in Table 4 are employed to estimate probabilities of different crash severity outcomes under various scenarios. Table 5 presents the probability of each crash severity outcome for 16 to 19-year-old drivers involved in a crash composed of selected contributing circumstances and environmental factors.

- Base Scenario: A teenage driver who does not contribute to the crash driving during favorable conditions (straight, level, dry concrete road with clear weather conditions during daylight, and crash occurs on the roadway) in a 15 mph or 20 mph speed zone with one occupant (the driver) present in the vehicle.
- Scenario 1: An inattentive teenage driver driving on the wrong side of the road (exhibiting no other contributing behaviors) in a 55 mph or 60 mph speed zone with one occupant present during favorable conditions.
- Scenario 2: A speeding teenage driver driving in a 55 mph or 60 mph speed zone with one occupant present during favorable conditions.
- Scenario 3: A speeding teenage driver driving in a 65 mph or 70 mph speed zone improperly passing with one occupant present during favorable conditions.
- Scenario 4: A teenage driver driving too fast for unfavorable conditions (curvy/hilly dirt road, dark lighting conditions, and foggy/misting weather conditions) in a 55 mph or 60 mph speed zone with one occupant present and the crash occurs off the roadway.
- Scenario 5: A teenage driver speeding during unfavorable conditions (curvy/hilly dirt road, dark lighting conditions, and foggy/misting weather conditions) in a 55 mph or 60 mph speed zone with one occupant present and the crash occurs off the roadway.

Table 4: Multinomial Logistics Estimation Results of Probability of Crash Severity

	Model Fitting Criteria	Likelihood Ratio Tests		
Effect	**-2 Log Likelihood of Reduced Model**	**Chi-Square**	**df**	**Sig.**
Intercept	638,905.2	-	0	
Age Group	639,289.3	384.151	4	0.000
Vehicle Defects	638,968.4	63.189	4	0.000
Speeding	646,778.8	7,873.601	4	0.000
Too Fast for Conditions	642,896.9	3,991.735	4	0.000
Improper Passing	639,195.4	290.267	4	0.000
Violation Stop Sign / Signal	645,558.0	6,652.798	4	0.000
Wrong Side	642,214.4	3,309.268	4	0.000
Following Too Close	642,052.1	3,146.961	4	0.000
Improper Turn	639,055.4	150.209	4	0.000
Improper Lane Usage	639,581.6	676.443	4	0.000
Failed to Yield	644,036.9	5,131.696	4	0.000
Drinking	645,604.9	6,699.689	4	0.000
Drugs	639,456.4	551.199	4	0.000
Physical Impairment	644,158.6	5,253.417	4	0.000
Inattention	639,430.7	525.500	4	0.000
All Other Circumstances1	641,962.6	3,057.390	4	0.000
Number of Occupants	640,440.4	1,535.179	4	0.000
Road Surface	640,179.7	1,274.535	24	0.000
Road Alignment	639,369.4	464.260	8	0.000
Road Profile	640,870.4	1,965.238	12	0.000
Weather Conditions	639,258.8	353.643	28	0.000
Light Conditions	639,671.0	765.864	16	0.000
Road Conditions	641,483.6	2,578.407	16	0.000
Crash On/Off Roadway	643,919.3	5,014.125	4	0.000
Speed Limit	666,963.2	28,058.053	24	0.000

[1] All Other Circumstances include Traffic Control Inoperable/Missing, Improperly Stopped on Roadway, Improper Signal, Improper Backing, Improper Start from Park, Improperly Parked, and Wrong Way.

Factor	**Fatality**	**Sig.**	**Major Injury**	**Sig.**	**Evident Injury**	**Sig.**	**Probable Injury**	**Sig.**
Intercept	-7.569	0.000	-4.548	0.000	-2.759	0.000	-2.795	0.000
Driver's Age								
Age Group 16-19	-0.459	0.000	-0.070	0.000	0.059	0.000	-0.062	0.000
Driver Contributing Circumstance								
Vehicle Defects	-0.581	0.000	-0.049	0.115	0.024	0.210	-0.069	0.000
Speeding	2.433	0.000	1.331	0.000	1.021	0.000	0.548	0.000
Too Fast for Conditions	0.522	0.000	0.672	0.000	0.479	0.000	0.320	0.000

Table 4 continued

Factor	Fatality	Sig.	Major Injury	Sig.	Evident Injury	Sig.	Probable Injury	Sig.
Improper Passing	0.255	0.001	0.162	0.000	-0.203	0.000	-0.383	0.000
Violation Stop Sign / Signal	1.025	0.000	1.076	0.000	0.915	0.000	0.632	0.000
Wrong Side	1.604	0.000	0.989	0.000	0.583	0.000	0.063	0.008
Following Too Close	-1.782	0.000	-0.587	0.000	-0.300	0.000	0.230	0.000
Improper Turn	-0.647	0.000	-0.073	0.021	-0.054	0.002	-0.174	0.000
Improper Lane Usage	0.320	0.000	0.041	0.011	-0.029	0.008	-0.279	0.000
Failed to Yield	0.464	0.000	0.705	0.000	0.575	0.000	0.255	0.000
Alcohol	1.160	0.000	1.028	0.000	0.757	0.000	0.056	0.001
Drugs	0.973	0.000	0.636	0.000	0.425	0.000	0.480	0.000
Physical Impairment	1.035	0.000	1.262	0.000	1.006	0.000	0.873	0.000
Inattention	-0.052	0.099	0.122	0.000	0.107	0.000	0.147	0.000
All Other Circumstances	-0.315	0.001	-0.589	0.000	-0.855	0.000	-0.710	0.000
Environmental Factors								
Number of Occupants	0.087	0.000	0.079	0.000	0.063	0.000	0.052	0.000
Road Surface Unknown	-0.752	0.007	-0.187	0.017	-0.052	0.168	-0.103	0.003
Road Surface Asphalt	0.294	0.000	0.304	0.000	0.160	0.000	0.101	0.000
Road Surface Brick	-0.296	0.768	0.086	0.737	-0.516	0.001	0.011	0.918
Road Surface Gravel	0.025	0.730	0.248	0.000	0.214	0.000	-0.133	0.000
Road Surface Dirt or Sand	0.850	0.001	0.771	0.000	0.456	0.000	0.011	0.922
Road Surface Multi Surface	0.013	0.892	-0.016	0.701	-0.063	0.011	-0.058	0.016
Road Surface Concrete	0		0		0		0	
Road Alignment Unknown	-0.562	0.106	-0.073	0.480	-0.421	0.000	-0.361	0.000
Road Alignment Curve	0.263	0.000	0.184	0.000	0.050	0.000	-0.042	0.000
Road Alignment Straight	0		0		0		0	
Road Profile Unknown	-0.512	0.021	-0.572	0.000	-0.076	0.021	-0.125	0.000
Road Profile Hill/Grade	0.638	0.000	0.332	0.000	0.123	0.000	0.049	0.000
Road Profile Crest	0.478	0.000	0.339	0.000	0.257	0.000	0.056	0.003
Road Profile Level	0		0		0		0	
Weather Conditions Cloudy	0.099	0.001	0.000	0.968	-0.032	0.000	0.053	0.000
Weather Conditions Rain	-0.013	0.859	-0.199	0.000	-0.084	0.000	0.006	0.669
Weather Conditions Snow	-0.265	0.040	-0.291	0.000	-0.159	0.000	-0.067	0.011
Weather Conditions Sleet	-0.502	0.056	-0.095	0.248	-0.239	0.000	-0.041	0.433
Weather Conditions Freezing	0.063	0.703	0.014	0.829	-0.034	0.400	-0.006	0.879
Weather Conditions Fog/Mist	0.319	0.007	-0.083	0.160	0.064	0.081	0.033	0.408
Weather Conditions Indeterminate	0.453	0.030	-0.231	0.018	-0.300	0.000	-0.359	0.000
Weather Conditions Clear	0		0		0		0	
Light Conditions Indeterminate	-0.013	0.926	-0.181	0.001	0.041	0.142	-0.030	0.252
Light Conditions Dark - Streetlights On	0.104	0.013	-0.143	0.000	0.074	0.000	0.058	0.000
Light Conditions Dark - Streetlights Off	0.007	0.970	-0.150	0.045	0.050	0.223	-0.068	0.121

Table 4 continued

Factor	Fatality	Sig.	Major Injury	Sig.	Evident Injury	Sig.	Probable Injury	Sig.
Light Conditions Dark - No Streetlights	0.512	0.000	0.191	0.000	0.147	0.000	0.013	0.292
Light Conditions Daylight	0		0		0		0	
Road Conditions Other/ Unknown	-0.447	0.003	-0.352	0.000	-0.188	0.000	-0.010	0.756
Road Conditions Wet	-0.696	0.000	-0.493	0.000	-0.262	0.000	-0.075	0.000
Road Conditions Snow	-1.330	0.000	-1.040	0.000	-0.759	0.000	-0.346	0.000
Road Conditions Ice	-1.250	0.000	-0.937	0.000	-0.532	0.000	-0.190	0.000
Road Conditions Dry	0		0		0		0	
Crash On Roadway	-0.125	0.000	-0.386	0.000	-0.435	0.000	0.294	0.000
Crash Off Roadway	0		0				0	
Speed Limit 15-20 mph	-0.142	0.524	-0.242	0.000	-0.074	0.013	-0.136	0.000
Speed Limit 25-30 mph	0.436	0.008	0.240	0.000	0.323	0.000	0.256	0.000
Speed Limit 35-40 mph	1.238	0.000	0.781	0.000	0.716	0.000	0.599	0.000
Speed Limit 45-50 mph	1.909	0.000	1.244	0.000	0.883	0.000	0.546	0.000
Speed Limit 55-60 mph	2.731	0.000	1.841	0.000	1.168	0.000	0.690	0.000
Speed Limit 65-70 mph	2.875	0.000	1.742	0.000	0.917	0.000	0.390	0.000
Speed Limit Unknown	0		0		0		0	

Table 5: Probability of Crash Severity for 16- to 19-Year-Olds under Selected Scenarios

		Scenario				
Crash Severity	**Base**	**1**	**2**	**3**	**4**	**5**
P(Fatal)	0.0002	0.0137	0.0286	0.0362	0.0452	0.1807
P(Injury Disabling)	0.0051	0.0838	0.0902	0.0897	0.1977	0.2258
P(Injury Evident)	0.0384	0.1791	0.2152	0.1839	0.3198	0.3250
P(Injury Probable)	0.0633	0.1204	0.1457	0.1186	0.0658	0.0489
P(Property Damage)	0.8930	0.6030	0.5204	0.5716	0.3715	0.2196

The probabilities in Table 5 are computed employing equation (1) by first summing the product of the estimated coefficients for each severity outcome (the baseline category is normalized to sum to zero) and the values of the associated factors for each scenario, then computing the exponential of each of the five severity outcome summed products, and finally dividing each exponential by the sum of the five exponentials. For example, considering the base scenario, when a teenage driver is involved in a crash in a 15 mph or 20 mph speed limit zone, but does not contribute to the crash in any way and is driving under favorable conditions (straight, level, dry concrete road with clear weather conditions during daylight, and the crash occurs on the roadway), the probability of a fatal outcome is only 0.0002.

This probability is calculated by first computing the summed product of the scenario factors (e.g., teenager driving in a 15-20 mph zone) and associated estimated coefficients for each severity outcome. In the base case, the summed products of the outcome intercept + Age Group 16-19 outcome coefficient*1 + Number of Occupants outcome coefficient*1 + Crash on Roadway outcome coefficient*1 + Speed Limit 15-20 mph outcome coefficient*1 for each level of injury severity relative to the baseline of property damage only are:

Fatal = -7.569 + -0.459 + 0.087 + -0.125 + -0.142 = -8.208;
Injury Disabling = -4.548 + -0.07 + 0.079 + -0.386 + -0.242 = -5.167;
Injury Evident = -2.759 + 0.059 + 0.063 + -0.435 + -0.074 = -3.146;
Injury Probable = -2.795 + -0.062 + 0.052 + 0.294 + -0.136 = -2.647; and
Property Damage Only = 0.

The probability of each level of severity is then found by applying equation (1) as follows:

$$P(\text{Fatal}) = \frac{e^{-8.208}}{1+ e^{-8.208}+e^{-5.167}+ e^{-3.146}+ e^{-2.647}} = 0.0002;$$

$$P(\text{Injury Disabling}) = \frac{e^{-5.167}}{1+ e^{-8.208}+e^{-5.167}+ e^{-3.146}+ e^{-2.647}} = 0.0051;$$

$$P(\text{Injury Evident}) = \frac{e^{-3.146}}{1+ e^{-8.208}+e^{-5.167}+ e^{-3.146}+ e^{-2.647}} = 0.0384;$$

$$P(\text{Injury Probable}) = \frac{e^{-2.647}}{1+ e^{-8.208}+e^{-5.167}+ e^{-3.146}+ e^{-2.647}} = 0.0633; \text{ and}$$

$$P(\text{Property Damage Only}) = \frac{1}{1+ e^{-8.208}+e^{-5.167}+ e^{-3.146}+ e^{-2.647}} = 0.8930.$$

As expected, when adding contributory circumstances and/or unfavorable conditions, the probability of a fatal outcome dramatically increases. In Scenario 1, when a teenage driver is involved in a crash resulting from inattentive behaviors that are accompanied by driving on the wrong side of the road (e.g., swerving, which has been found to commonly accompany texting and driving [Drews et al. 2009]) during favorable conditions with a single occupant and assuming zero values for all other variables, the probability of a fatal outcome rises to 0.0137.

Additionally, when considering teenagers involved in a crash where speeding in a speed limit zone of 55 or 60 mph occurred during favorable conditions, with a single occupant and assuming zero values for other variables as in Scenario 2, the probability that a fatal outcome will result in a crash increases further to 0.0286. When adding improper passing with speeding (both of which have been linked to head-on collisions (Gårder 2006), and increasing the speed limit zone to 65 mph or 75 mph, (Scenario 3), the probability that a teenage driver will be involved in a fatal crash (given a crash occurs) increases to 0.0362.

Lastly, when a teenage driver involved crash resulting from driving too fast in relatively poor conditions (curvy/hilly dirt road, dark lighting conditions, and foggy/misting weather conditions) in a speed limit zone of 55 mph or 60 mph, with a single occupant and the crash occurs off the roadway, assuming zero values for all other variables (Scenario 4), the probability of a fatality increases to 0.0452. However, when speeding rather than driving too fast for conditions (Scenario 5), while other factors remain unchanged, the likelihood of a fatal outcome drastically increases to 0.1807.

CONCLUSIONS

Prior national studies have found that GDL programs can significantly decrease the fatal crash rate of teenage drivers when additional restrictions are present (National Highway Traffic Safety Administration n.d.). Therefore, given the combination of prevalence among teenage drivers to be involved in crashes and the large impact on fatalities, legislation and education that further discourages the contributing circumstances of inattention and accompanying behaviors, speeding,

improper passing, driving too fast for conditions, and driving under the influence of alcohol and drugs should be considered for GDL policy to better protect and prepare Missouri teenage drivers.

Speeding, Driving Too Fast for Conditions, and Improper Passing

The current GDL requirements for Missouri teenage drivers, as detailed in Appendix A, include that during the instruction and intermediate phases, the driver may not have any traffic convictions in the last six months, and to graduate to an under-21 full driver's license the driver may not have any traffic convictions in the last 12 months. However, the consideration of a more stringent requirement for speed related traffic convictions could improve the efficacy of GDL policy. For example, if a conviction occurs, increasing the time required between the conviction and graduation from a GDL phase would increase the length of restricted driving time, allow inexperienced drivers additional time to gain experience in a controlled environment, and further encourage compliance with driving laws. Additionally, better preparation of properly obeying speed limits, recognizing unfavorable conditions that require speed reduction, and proper passing techniques should be considered. Since drivers who participate in the GDL program most likely lack experience, increased education on identified problem areas could encourage all teenagers to improve their driving behaviors.

Inattention and Accompanying Behaviors

Missouri Revised Statute Section 304.820 makes it illegal for 21-year-old and under drivers to text while driving (Joint Committee on Legislative Research 2012). In 2014, six additional distracted driver bills were brought before the Missouri Legislature. Contents of the bills include prohibition of handheld wireless communications devices by all drivers (House Bill 1106 and Senate Bill 840), addition of points against a driver's license for texting while driving, prohibiting the wearing of a head-mounted display while operating vehicles and increment of penalties for distracted driving law (House Bill 1123), prohibition of texting and driving by all drivers unless hands-free technology is used (House Bill 1256), and prohibition of text messaging by all drivers (House Bill 1282 and House Bill 1316) (Able 2014). The results of this study support the goals of these bills, and further indicate that the inclusion of additional cell-phone restrictions should be considered for improving the impact of the GDL program.

Intoxication

In order to graduate to an under-21 full driver's license, the intermediate driver may not have had any alcohol related offenses within the last 12 months. However, the consideration of more stringent requirements for alcohol and drug related convictions seem likely to increase the effectiveness of the existing GDL policy. Not only would harsher requirements reduce the number of full-licensed teenage drivers that exhibit poor driving judgment, but the increased delay of full driving privileges could also encourage teenagers who have not been convicted of such charges to better consider their behaviors before driving while intoxicated. Likewise, since older drivers are more likely to be involved in a fatal crash when alcohol is a contributing factor, given a crash occurs, harsher policies should also be considered for this population to increase overall traffic safety.

LIMITATIONS/FUTURE RESEARCH

It is important to note that this study assumes all drivers aged 16 to 19 years old have a GDL license with no special exemptions; however, some drivers may be permitted hours-related exemptions for employment or religious reasons. It is also important to recognize that the presence of the contributing circumstances are based on the investigator's judgment; therefore, while training

attempts to minimize variation among investigators, systematic discrepancies among investigator's judgment may occur.

The analysis of the data inferred that the group of Missouri driver's aged 20 to 24 years old have a large number of fatalities resulting from not only contributing circumstances, but also road types and surfaces, road conditions, and weather conditions. Future research may choose to focus on the factors leading to fatal crashes in this age group in order to provide information pertinent to future GDL revisions (i.e., extending GDL restrictions past 19 years old).

Future research may focus on changes in influence of contributing circumstances when temporary GDL restrictions are in place (i.e., restricted night driving) versus when GDL restrictions are lifted. The comparison of all drivers in the GDL program to all drivers not in the GDL program (independent of age) would also provide a better understanding of the experiential learning and restrictions being employed.

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APPENDIX A

Current GDL Requirements for Missouri Teenage Drivers
(Missouri Department of Revenue 2014)

Instruction Permit:

Eligible Age: 15
Valid for: 0-12 Months

- You must pass the vision, road sign, and written tests.
- A qualified person must accompany you to the license office to sign a permission statement.
- Under age 16, you may drive only when accompanied in the front seat by a licensed driver who is a qualified person, grandparent, or qualified driving instructor.
- At age 16 or older, you may drive when accompanied in the front seat by a licensed driver who is at least 21 years old and has a valid driver license.
- Seat belts must be worn by the driver and all passengers.
- Your test paper alone is not legal for driving. Be sure to carry your permit with you.
- You may renew your instruction permit.
- You must have an instruction permit for a minimum of 182 days (beginning the day after issuance).
- You may not have any alcohol-related convictions in the last 12 months and no traffic convictions within the last six months.
- You must have received 40 hours of driving instruction, including a minimum of 10 hours of nighttime driving instruction between sunset and sunrise, with a qualified person, grandparent, or qualified driving instructor.

Intermediate License:

Eligible Age: 16 to 18
Valid for: 0-2 Years

- You must hold the instruction permit for at least 182 days (beginning the day after issuance).
- You may not have any alcohol-related offenses in the last 12 months and no traffic convictions in the last six months.
- A qualified person or grandparent must accompany you to the license office to verify you have received 40 hours of driving instruction, including a minimum of 10 hours of nighttime driving instruction between sunset and sunrise.
- You must pass the vision, road sign, and written tests if previous results are more than one year old.
- You must pass the driving test.
- Your test paper alone is not legal for driving. Be sure to carry your intermediate license with you.
- Seat belts must be worn by the driver and all passengers.
- Passenger restrictions outlined below may not be applicable to an intermediate license holder who is operating in agricultural work-related activities.
- During the first six months, you may not operate a motor vehicle with more than one passenger who is under 19 years old and who is not a member of your immediate family.
- After the first six months, you may not operate a motor vehicle with more than three passengers who are under 19 years old and who are not members of your immediate family.
- You may not drive alone between 1:00 a.m. - 5:00 a.m. except to and from a school activity, job, or for an emergency, unless accompanied by a licensed driver 21 years old or older.

To Graduate to an Under-21 Full Driver License:

Eligible Age: 18
Valid for: 0-3 Years

- You must satisfy the requirements for an Intermediate License, including having no alcohol-related offenses or traffic convictions in the last 12 months.
- You must have a valid intermediate license. Your driving privilege cannot be suspended, revoked, or denied when you apply for a full license.
- You must pass the vision and road sign recognition tests. (You are not required to pass the written and driving tests if already completed.)

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