Louisiana Transportation Research Center

Final Report 654

Young Driver Crashes in Louisiana: Understanding the Contributing Factors to Decrease the Numbers

by

Elisabeta Mitran
Xiaoduan Sun
M. Ashifur Rahman
Md. Mahmud Hossain
University of Louisiana at Lafayette

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808
(225) 767-9131 | (225) 767-9108 fax | www.ltrc.lsu.edu

TECHNICAL REPORT STANDARD PAGE

1. Title and Subtitle
   Young Driver Crashes in Louisiana: Understanding the Contributing Factors to Decrease the Numbers
2. Author(s)
   Elisabeta Mitran, Xiaoduan Sun, M. Ashifur Rahman, and Md. Mahmud Hossain
3. Performing Organization Name and Address
   Department of Civil Engineering
   University of Louisiana
   Lafayette, LA 70504
4. Sponsoring Agency Name and Address
   Louisiana Department of Transportation and Development
   P.O. Box 94245
   Baton Rouge, LA 70804-9245
5. Report No.
   FHWA/LA.17/654
6. Report Date
   October 2021
7. Performing Organization Code
   LTRC Project Number: 19-5SA
   SIO Number: DOTLT1000296
8. Type of Report and Period Covered
   Final Report
   August 2019 – June 2021
9. No. of Pages
   113

10. Supplementary Notes
    Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration
11. Distribution Statement
    Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.
12. Key Words
    Young Driver; Graduated Driver Licensing; Driving Behavior; Crash Contributing Factor; Louisiana Young Driver Crashes
13. Abstract

Despite the early adoption of Graduated Driver Licensing (GDL) program, teens and young adults in Louisiana continued to experience crashes at higher rates and thereby considered as high-risk drivers. The aim of this study was to analyze young driver crash contributing factors and evaluate the Louisiana's GDL program. Based on a comprehensive literature review, a wide array of crash attributes was identified as potentially influential. A Multinomial Logit (MNL) model was developed to analyze crash contributing factors to indicate their relative crash likelihood among young driver age groups. Several Mann-Kendall (M-K) tests have been performed to detect and quantify the gradual trend of young driver crashes. These crash trends have also been visualized by Innovative Trend Analysis (ITA) method to supplement the M-K test results. To quantitatively assess the impacts of GDL policy changes on young driver crash and consequential casualties, a Seasonal Autoregressive Integrated Moving Average with Explanatory Variables (SARIMAX) method has been applied. In spatial analysis, an analytical approach using ArcGIS to find hotspots of young driver crashes has been performed following the exploration of young driver crashes within Louisiana's nine safety coalitions. The results from the MNL model analysis on selected attributes using 5-year crash data derived several key insights on their potential linkup with crashes with three young driver groups at fault—novice teen (15-16 years), young teen (17-19 years), and young adult (20-24 years). Young driver groups are strongly associated with driving violations, use of electronic devices alongside cellphone, non-use of driver protection system, and nighttime driving. M-K tests and ITA plots on long term crash frequency data, disaggregated by month, showed substantial decrease in crashes and severities related to these young driver age groups and specific characteristics of underage alcohol intoxication, cellphone use, non-usage of restraints. Time series analyses on GDL legislative policies indicated significant reductions in crash and associated casualties due to GDL implementation except for young adult driver groups. Spatial clusters of young driver crashes showed that they are highly concentrated in urban areas. The substantial decline of number of crashes and associated casualties involving young drivers suggests that implementation of the GDL program has been a success in Louisiana. This study provides a foundation to further explore specific crash patterns and trends, develop a statewide GDL curriculum, and evaluate the safety effectiveness of countermeasures for the improvement of young driver safety.

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Administrator
Julius Codjoe
Special Studies Research Administrator

Members
Autumn Goodfellow-Thompson
Betsey Tramonte
Bridget Gardner
Jessica Bedwell
Kenny Martin
Shelly Barrett
Stephanie Baum

Directorate Implementation Sponsor
Christopher P. Knotts, P.E.
DOTD Chief Engineer

Young Driver Crashes in Louisiana: Understanding the Contributing Factors to Decrease the Numbers

By
Elisabeta Mitran
Xiaoduan Sun
M. Ashifur Rahman
Md. Mahmud Hossain

Department of Civil Engineering
University of Louisiana at Lafayette
104 East University Avenue
Lafayette, Louisiana, 70503

LTRC Project No. 19-5SA
SIO No. DOTLT1000296

conducted for
Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

October 2021

Abstract

Despite the early adoption of Graduated Driver Licensing (GDL) program, teens and young adults in Louisiana continued to experience crashes at higher rates and thereby considered as high-risk drivers. The aim of this study was to analyze young driver crash contributing factors and evaluate the Louisiana's GDL program. Based on a comprehensive literature review, a wide array of crash attributes was identified as potentially influential. A Multinomial Logit (MNL) model was developed to analyze crash contributing factors to indicate their relative crash likelihood among young driver age groups. Several Mann-Kendall (M-K) tests have been performed to detect and quantify the gradual trend of young driver crashes. These crash trends have also been visualized by the Innovative Trend Analysis (ITA) method to supplement the M-K test results. To quantitatively assess the impacts of GDL policy changes on young driver crash and consequential casualties, a Seasonal Autoregressive Integrated Moving Average with Explanatory Variables (SARIMAX) method has been applied. In spatial analysis, an analytical approach using ArcGIS to find hotspots of young driver crashes has been performed following the exploration of young driver crashes within Louisiana's nine safety coalitions. The results from the MNL model analysis on selected attributes using 5-year crash data derived several key insights on their potential linkup with crashes with three young driver groups at fault—novice teen (15-16 years), young teen (17-19 years), and young adult (20-24 years). Young driver groups are strongly associated with driving violations, use of electronic devices alongside cellphone, non-use of driver protection system, and nighttime driving. M-K tests and ITA plots on long-term crash frequency data disaggregated by month showed a substantial decrease in crashes and severities related to these young driver age groups and specific characteristics of underage alcohol intoxication, cellphone use, and non-usage of restraints. Time series analyses on GDL legislative policies indicated significant reductions in crash and associated casualties due to GDL implementation except for young adult driver groups. Spatial clusters of young driver crashes showed that they are highly concentrated in urban areas. The substantial decline of the number of crashes and associated casualties involving young drivers suggests that implementation of the GDL program has been a success in Louisiana. This study provides a foundation to further explore specific crash patterns and trends, develop a statewide GDL curriculum, and evaluate the safety effectiveness of countermeasures for the improvement of young driver safety.

Acknowledgments

The research team wants to express their gratitude to the Louisiana Department of Transportation and Development (DOTD) for providing young driver crash data. Special thanks to Office of Motor Vehicles personnel for collecting data on driver population and the timeline of legislative changes regarding the Graduated Driver Licensing program. The suggestions from the project review committee are also appreciated.

Implementation Statement

This study performed a comprehensive analysis to investigate young driver crashes contributing factors and effectiveness of the existing Louisiana GDL program. Findings from crash analysis will provide highway safety stakeholders with a deeper and more comprehensive understanding of factors influencing young drivers' crashes. Based on contributing factors identified from crash data and GDL program evaluation analysis, the study proposed several safety countermeasures. Furthermore, the recommendations of this study will provide DOTD, the Louisiana SHSP team, other highway safety stakeholders, and law enforcement agencies with information to guide the implementation of effective strategies to reduce and prevent young driver crashes. Strategies that cover multiple interventions can be more effective in curtailing young driver crash risks. The results of this project can be used as part of Destination Zero Deaths' efforts to reach the goal of zero fatalities on Louisiana's roadways.

Table of Contents

List of Tables

List of Figures

Introduction

The over-involvement of young drivers in crashes is a long-established problem in the United States. As reported in the latest annual "Traffic Safety Facts" published by the National Highway Traffic Safety Administration (NHTSA), drivers in 16-20- and 21-24-year age groups had the highest fatal crash involvement rates in 2017, 35.6 and 34.5 fatal crashes per 100,000 licensed drivers, respectively *[1]*. Fatal crash involvement rates of these two young driver age groups decreased by 19.5 and 8.5% respectively over the 10 years between 2008 and 2017 *[1], [2]*. However, the most recent data available from the National Center for Health Statistics (NCHS) show that motor vehicle crashes are still a leading cause of death for young people aged 15-24 years *[3]*.

The disproportionately high rate of young driver crashes is also prevalent on Louisiana roadways. Young drivers, defined as 15-24-year olds in Louisiana's Strategic Highway Safety Plan (SHSP), are overrepresented in fatal and severe injury crashes. The annual fatal and severe injury crash frequencies of young drivers were on track (from 2009 to 2016) with the benchmark established by the "Young Driver Emphasis Area" team aiming to reduce fatalities and injuries involving young drivers by 50% by 2030 *[4]*. According to our latest estimate, young drivers were at fault in more than 20% of Louisiana's fatal traffic crashes in 2018, although they constituted 13.6% of all licensed drivers.

The high crash involvement rate of Louisiana's young drivers can evidently be pointed out from the illustrations of Figure 1 and Figure 2. Over 16 years (from 2003 to 2018), estimated "total crash rates" (total crashes per 1,000 licensed drivers) and "fatal and injury crash rates" (fatal and injury crashes per 1,000 licensed drivers) with young drivers at fault are consistently higher than those rates for the rest of the licensed drivers. Although there has been a large decrease in young driver crash rates in recent years (Figure 1), a breakdown of crash rates by age groups in 2018 shows that "total crash rates" and "fatal and injury crash rates" of young drivers are still considerably higher compared to any other age groups (Figure 2).

One widely adopted effective strategy in addressing young driver crashes is deploying a Graduated Driver Licensing (GDL) program, typically a three-stage approach to granting young drivers full license privileges in their earlier years of driving. Three stages are categorized as different levels of driving restrictions are lifted with the progression to the next stage allowing young drivers to safely gain driving experience before obtaining full driving privileges. A typical GDL program includes a learner stage (supervised driving cumulating with a driving test), an intermediate stage (limiting unsupervised driving in high-risk situations), and a full privilege stage. All the states in the U.S. currently have different versions of graduated licensing programs *[5]*.

Figure 1. Crash Rate Comparison between 15-24 and > 24-Year-Old Drivers in Louisiana during 2003-2018

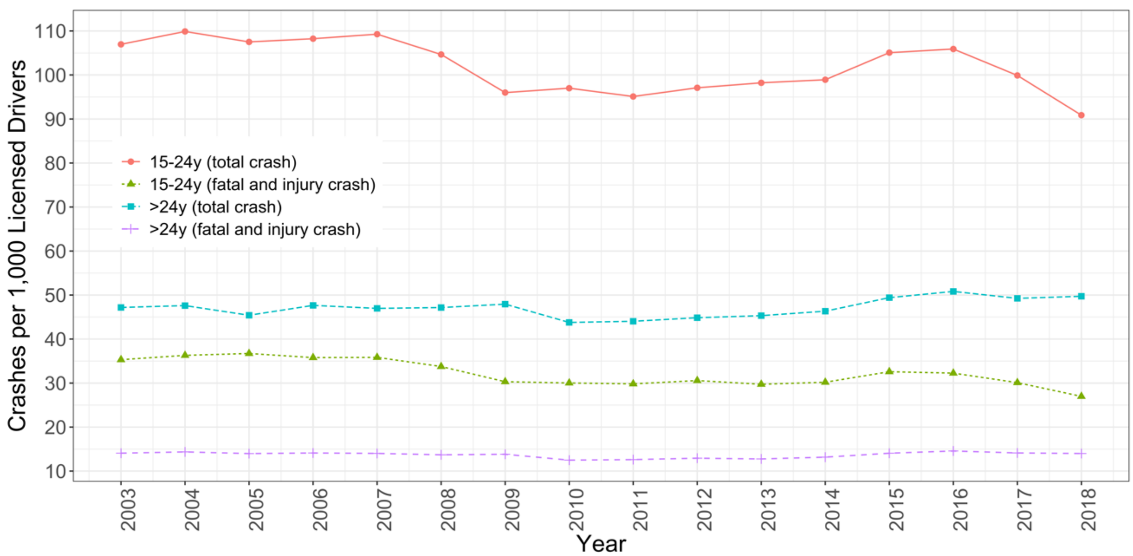
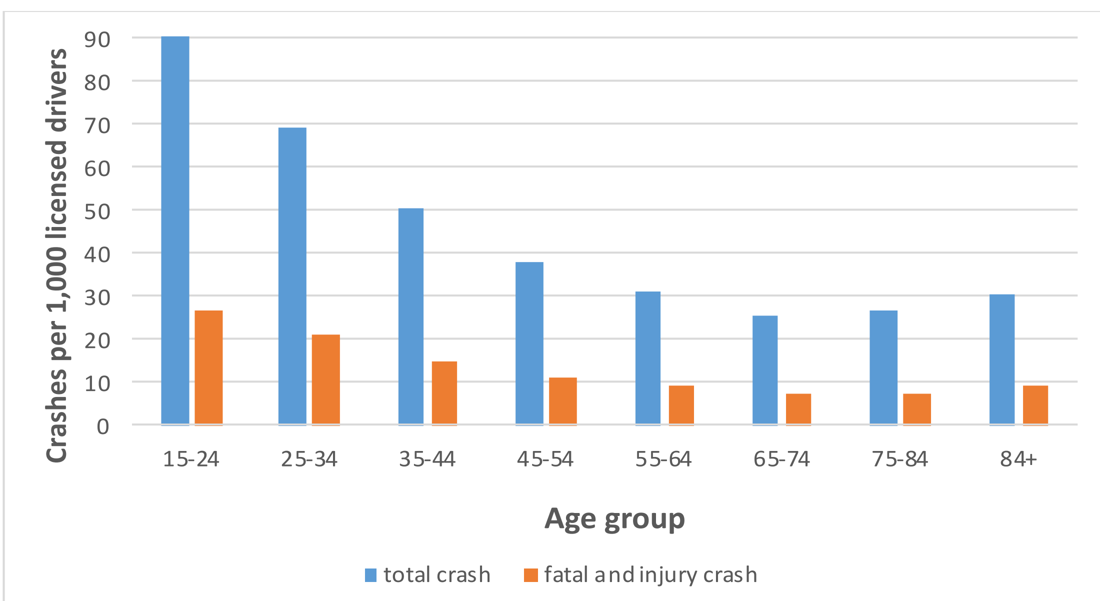


Figure 2. Crash Rate Comparison among Louisiana Drivers of All Age Groups in 2018



After the initiation of the GDL program in Florida in 1996, the state of Louisiana became one of the early adopters of the program. Louisiana implemented the GDL program in the form of the RYAN Act (Reduce Youth Accidents Now) on January 1, 1998, with an initial aim to reduce the number of traffic deaths and injuries in the teenage driver group.

Despite the early adoption of this strategy, teens and young adults in Louisiana continued to experience crashes at higher rates and thereby considered high-risk drivers. The participation of teen drivers in Louisiana's GDL programs is still low. In order to achieve the goal of Louisiana's Destination Zero Deaths, we must find ways to decrease the fatalities and prevent further young driver crashes. Therefore, we need to understand the factors contributing to young driver's crashes, associated GDL policies, and the trend of young driver crashes to recommend effective countermeasures to reduce young driver crashes.

Literature Review

Young driver crashes are an area of wider interest among transportation researchers, planners, and policymakers. The gravity of the issue has been reflected in decades of research effort in understanding the underlying factors of crash-proneness of young drivers and strategic approaches to prevent young driver crashes *[6]–[9]*. It is important to mention that "young drivers" have been identified and defined differently in the literature. The variation in the definition is primarily connected to the state's variation in minimum legal age to obtain a driver's license and also the maximum age when the drivers are considered experienced. However, in line with Louisiana SHSP, this study will recognize 15 to 24-year-old drivers as young drivers; otherwise, the age range will be mentioned. A substantial body of literature identified factors related to teen driver crashes, which is also a key part of this literature review. The age range for the teen driver also varies, typically drivers who are aged 19 years or less and allowed to drive.

The literature review section in this report has been divided into four subsections—"Nationwide and statewide young driver crash statistics," "Major contributing factors to young driver crashes," "Implementation of Graduated Drivers Licensing (GDL) programs in other states," and "Countermeasures."

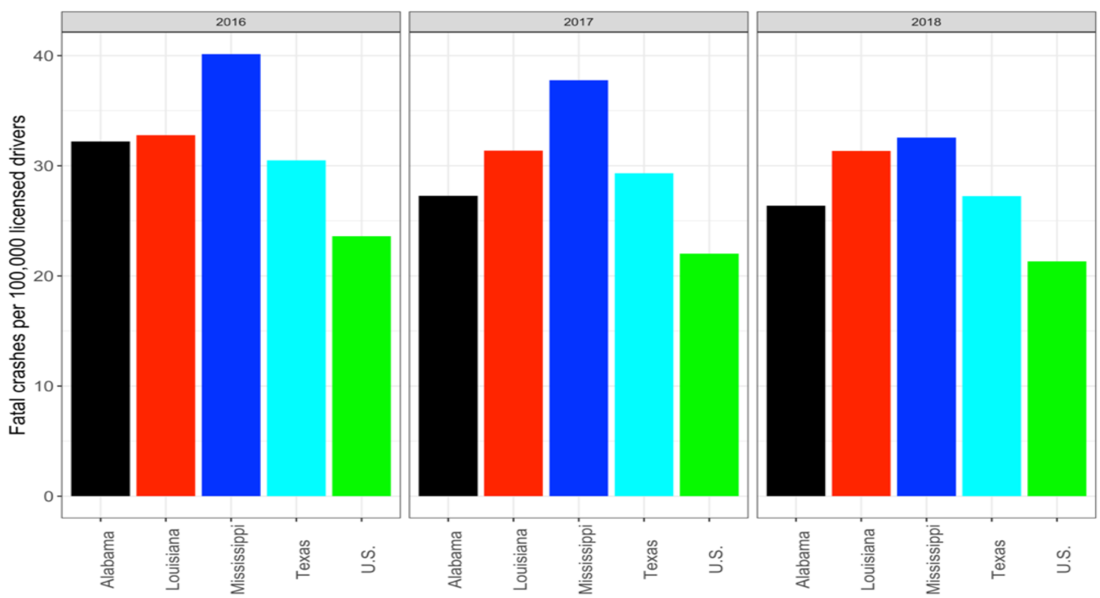
Nationwide and Statewide Young Driver Crash Statistics

Young driver crashes are nationally recognized as a serious issue. According to 2017 census data, 15 to 24-year-olds comprised 13.3% of the total population; whereas, FHWA data estimate that licensed drivers in this age group were 11.8% of total licensed drivers *[1]*. However, this 11.8% of total licensed drivers were involved in 18.3% of all nationwide fatal crashes in 2017.

The NHTSA publishes annual "Traffic Safety Facts of Young Drivers" presenting mainly the trend of nationwide annual frequency of fatal crashes involving 15 to 20-year-olds and commonly known human factors associated with those crashes, e.g. driver gender, use of seatbelts, alcohol involvement, etc. *[10]* The latest statistics show that the percentage of fatalities involving 15 to 20-year-old drivers in all fatal crashes over the last decade (i.e., 2008-2017) is steady, 40% on average and the percentage ranges from 39% to 42%. In 2017, male drivers in this group were about three times more involved than female drivers. A 47% of 15 to 20-year-old drivers who died while driving passenger vehicles (passenger cars, light trucks including pickup trucks, vans, and SUVs) were found unrestrained. A 15% of all 15 to 20-year-old drivers involved in fatal crashes had a blood alcohol concentration (BAC) of 0.08 g/dL or higher.

A comparison of crash rates of young drivers (aged 16-24 years) in Louisiana and its nearby states in 2016, 2017, and 2018 is presented in Figure 3. Drivers aged 15 years were not included in the estimation, due to inconsistent availability of population data of drivers with learner's permits in the FHWA database. Young driver fatal crash rates (estimated as fatal crashes per 100,000 licensed drivers) of all the states showed a decreasing trend in these three years and are higher than national young driver crash rates. Louisiana's young driver crash rates are generally high—consistently over 30 fatal crashes per 100,000 of 16 to 24-year-old drivers—only second to Mississippi's crash rates.

Figure 3. Young driver crash rates in Louisiana and nearby states in 2016, 2017, and 2018



Major Contributing Factors to Young Driver Crashes

This subsection of the report reviews a number of contributing factors that may affect young driver crashes, consolidating a wide range of literature and presenting findings of estimated impacts on the crash risk and severity. Findings on the factors are indicative of prevalent young driver crash characteristics related to operating condition, roadway, vehicle, and driver. Several important findings obtained from the review of international studies are deemed relevant to this context of young drivers. Although a large literature on the psychological factors of young driver crashes exists, the focus of this review is on the crash attributes extractable in the standard crash data collection system. The young driver crash factors presented here should not be contemplated as causal. But rather they should be interpreted as oddities with the perceived normal conditions. A comprehensive review of these factors should enable researchers to draw upon the multitude of issues related to preventive measures of young driver crashes and various components of the GDL program.

Weather and Surface Condition

Inclement weather conditions such as rain, snow, fog/smoke, etc. affect the visibility and pavement surface condition and could present various driving challenges. Dissanayake and Amarsingha attributed teen drivers' (aged 15-19 years) failure in adjustment leading to a higher proportion of crashes on the wet surface compared to experienced drivers (aged 25-55 years) *[11]*. Duddu et al. have estimated that teen drivers are 8%, 18%, 49%, and 40% more likely to be involved in severe injury crashes during wet, icy, snowy, and slushy roads respectively compared to dry road conditions in North Carolina *[12]*. They have deduced that the teen drivers' proneness to severe injury is associated with the inefficiency in braking and with less driving experience in adverse weather conditions that may result in skid, drag, or run off the road. Abdel-Aty et al. estimated the risk of poor visibility crashes involving young drivers due to fog and smoke to be higher than clear visibility crashes. However, they presumed that fog and smoke-related crashes in young drivers tend to be less severe due to their better vision and reaction abilities in hazard perception *[13]*.

Roadway Lighting Condition

Lighting is another important driving condition that may affect a young driver's visibility. The Kansas study showed that young drivers had more crash risk in dark conditions compared to experienced drivers (aged 25-64 years) *[11]*. However, the same study showed that teen drivers (aged 15-19 years) were less likely (odds of 0.83) to be involved in crashes during dark conditions compared to young adult drivers (aged 20 years). On freeways, the likelihood for teen drivers (aged 16 to 19 years) to be associated with injury or fatal crashes gradually becomes higher in the order of darker lighting—

daylight, dawn and dusk, dark and streetlights on, dark and streetlights off, dark and no streetlights. *[14]*

Time of the Day

Rice et al. analyzed pre-GDL crash data of California from January 1993 to June 1998 and found a higher crash risk for drivers aged 16-17 years (both male and female drivers) between 8 pm to 6 am *[15]*. However, lack of driving experience in driving among teen drivers (aged 15-19 years) increases crash risk during the morning (6 am to 9 am) and the evening (3 pm to 6 pm) peak hours of weekdays. One Iowa study performed crash studies on 10- to 18-year-old drivers including students below 14 years with special school permits. The study pointed out that early morning hours (12 am to 6 am) attributed to an increased odd of injury for young teen drivers (up to 18 years old) compared with the time period 6 am to 3 pm *[16]*. An Alabama study on fatal crashes involving young drivers have associated night-time crashes with risky driving behavior like speeding, DUI, or distracted driving *[17]*.

Speed Limit

Speeding is a major factor for young drivers' involvement in road crashes and is considered to be an important determinant of crash risk and crash severity *[18]*. Young drivers, compared to older drivers, have a more positive attitude towards risk-taking, thus involving in risky driving as well as speeding behavior *[19]*. In many cases, young drivers underestimate or overestimate speed limits that possibly result in severe injury crashes. One study in Sweden identified an over-representation of young driver crashes during evenings and nights on roadways with 55 mph or higher speed limit *[20]*. Teen drivers (aged 15-19 years) in posted speed limit under 25 mph, 25-45 mph, and 45-55 mph were 37%, 55%, and 48% less likely to be involved in crashes that lead to injuries respectively, compared to roads with higher posted limit (over 55 mph) *[12]*.

Area Type and Highway Class

Hasselberg and Laflamme conducted a study in Sweden to examine the relationship between country of birth, socioeconomic position, and the risk of being injured as a young car driver (aged 18-26 years). The study found that young drivers having lower socioeconomic opportunities, especially in rural areas, were more likely to be involved in severe crashes *[20]*. Vachal et al. identified a strong correlation between crash rate and measures of rurality using the North Dakota crash database. Teen drivers (aged 14-17 years) were six times more affected by crashes in rural areas compared with crashes in urban areas *[21]*. The Iowa study found that crash rates of older teen drivers (aged 16-18 years) were lower in rural areas compared to the crash rates of younger teen drivers (aged below 16 years) *[16]*. Fatal crash rates were over two times higher among teen drivers aged 10 to 15 years in suburban, rural, and remote rural areas *[16]*. In terms of functional classification, teen drivers (aged 15-19 years) in North Carolina were found to have a higher injury risk on arterial roads, collector roads, and local roads compared to interstates *[12]*.

Access Control

The purpose of the application of access control techniques is to improve traffic performance and safety. This access control roadway safety significantly depends on the density of access points, proportion of signalized access points, presence of outside shoulder, two-way left turn lane, and median with no openings between signals *[22]*. One of the major contributing factors of road crashes for teen drivers (aged 10-18 years) is the failure to yield the right-of-way in both urban and rural areas *[16]*. In fully access control roads, sudden variation in speeds at control locations increases teen drivers' (age 15-19 years) injury risk to 16% compared with no access control roads *[12]*.

Gender

An earlier study by Byrnes et al. conducted a meta-analysis of 150 studies to compare risk-taking tendencies among female and male drivers. Findings of the study pointed out male participants' greater risk-taking behavior *[23]*. In general, teenage drivers (aged 16-19 years) crash rates are higher for both males and females compared to any other age group *[24]*.

A study by Shope and Bingham examined historical trends in fatal crash rates by comparing teen drivers (aged 15-19 years) with adult drivers (aged 45-54 years) using the FARS database. The fatal crash rate for male teen drivers was two times higher than female teen drivers *[25]*. Traffic Safety Facts published by NHTSA for 2016 reported that young drivers' (aged 15-24) fatal crashes per 100,000 licensed drivers were 23.28 for females and 51.08 for males in the U.S. *[26]*.

Adanu et al. used Alabama crash data and found male teen drivers (aged 15-18 years) were less likely to be involved in speed and aggressive driving-related fatal crashes than female drivers *[17]*. However, speeding tendency increased with age among young male teen drivers. Alcohol involved driving increased with age for both male and female drivers, especially between 19 and 21 years of age. In the context of severity, female teen drivers (age 15-19) were 35% and 14% less likely to be involved in severe and moderate injury respectively than their male counterparts.

Age

According to the Center for Diseases Control and Prevention (CDC), teen drivers (aged 16-19 years) are almost three times more likely to be involved in fatal crashes than older drivers. More than a decade ago, Mayhew and Simson performed a comprehensive review of the available research to find out the relationship between driver age and experience using crash data from Ontario *[27]*. The results showed that reduction in the crash rate was significantly related to age rather than the years of licensure. McCartt et al. found that age and experience have independent effects on crash risk *[28]*.

Mayhew et al. linked novice drivers' crash rate with their driving experience *[29]*. The study included 40,661 novice drivers who obtained their learner's permits between 1990 and 1993 and had held their full licenses for at least 24 months. The results pointed out that crash rates were the highest in the first month after licensure and rapidly dropped through the 7th month and then gradually declined through the 24th month. Duddu et al. found that teen drivers in North Carolina aged 15-18 years were more vulnerable to severe injuries compared to 19-year-old teen drivers *[12]*. This also indicates that teen drivers' crash severity risk has been reduced with increasing driving experience.

Alcohol/Drug

For teen drivers (aged 14-17 years), alcohol and drug use increase fatal crash risk by 3.3 times *[21]*. As the minimum legal drinking age is 21 in all U.S. states, young adult drivers (aged 20-24 years) are more likely to be involved in severe crashes for alcohol-impaired driving than teen (15-19 years) and experienced (aged 25-64 years) drivers *[11]*. Another earlier study by Mayhew et al. determined the extent to which alcohol has special significance for crashes involving young drivers *[30]*. The results showed that drivers with blood alcohol concentration (BAC) of 0 for ages under 20 and drivers with BAC of 0.05-0.079 g/dl for older age had equivalent crash risk. Young alcohol-impaired drivers (aged 16-19 years) were more vulnerable to crash risk than their older counterparts and showed steeper relative crash risk with elevated BACs *[31]*. Under alcohol influence, teen drivers were less likely to scan an intersection adequately prior to making a left turn, which increases crash risk *[32]*.

According to an earlier study (1996 data), female teen drivers (aged 16-20 years) had a lower crash risk than male teen drivers at all BAC levels *[33]*. Peek-Asa et al. examined teenage driver (10-18 years) crash risk characteristics by rurality using Iowa Department of Transportation crash data from 2002 to 2008 *[16]*. The study explored that urban and rural teens involved in severe crashes are more likely to be tested for alcohol use, and among tested teen drivers, more urban (64.3%) than rural (52.1%) teens were positive.

Vehicle Type

A Colorado study identified that rollover crashes resulting from leaving the roadway are a serious problem for novice drivers driving light trucks and SUVs *[34]*. Using the National Motor Vehicle Crash Causation Study (NMVCCS) data of 2005-2007 for 6,950 crashes involving light passenger vehicles (weighing less than 10,000 pounds), Paleti et al. found that drivers (especially novice drivers between 16 and 17 years of age) driving a pick-up are found to be most likely to behave aggressively and about 100% (or two times) more likely to incur severe injuries in a crash compared to a 16- to 17-year-old driver in a non-pickup vehicle *[35]*.

Seatbelt

Seatbelt use is a critical factor in crash risk reduction across all ages. The seatbelt law is a primary enforcement law in Louisiana applied from July 1, 1986. In Louisiana, the seatbelt usage rate was 87.1% in 2017. Important to notice that limited observational data is available to identify seat belt usage by drivers. The study by Peek-asa et al. found that teen drivers (10-18 years) with unknown seat belt use were less likely to be injured compared to their counterparts *[16]*, which means seatbelt information is less likely to be reported in less severe crashes.

A study conducted by Williams and Shabanova addressed whether belt use is lower in driving situations with higher crash risk using FARS data from 1995 to 1999 considering two age groups (16 to 19 and 20+ years) *[36]*. The results showed that teen drivers were less likely to use seatbelts with passengers in their twenties. For drivers of all ages, belt use was lower in night-time driving and with alcohol present. Vachal et al. considered gender and road type with seatbelt use for teen drivers (aged 14-17 years) in North Dakota *[21]*. Teen drivers, not using seatbelts, had a 1.65 times higher risk of severe injuries. Young female drivers had a higher tendency in wearing seatbelts than young male drivers. Seatbelt usage rate was 15-18% less in rural areas compared to urban areas.

Passengers

Due to high risk-taking behavior, teen drivers (aged 16-19 years) are involved in a higher number of crashes when driving with passengers *[37]*. More than two decades ago, Aldridge et al. conducted a study to identify the relationship between passenger's age and young driver *[38]*. The study found that young drivers (aged 16-20 years) had a higher risk of a crash when they were traveling with peers compared to adults or children (aged 12-24 years). However, the study did not focus on the number of passengers in the vehicle while driving. A study by Chen et al. pointed out the relative risk of death per 10 million trips increased with the increase in the number of passengers and 17-year-old drivers had higher crash rates than 16-year-old drivers in presence of passengers *[39]*.

In Louisiana, Fu and Wilmot conducted a study to identify the effect of passenger age and gender on the young driver (16-20 years) fatal crashes using police-reported crash data collected from 1999 to 2004 *[40]*. In that study, young drivers were grouped into 16, 17, and 18-20 years of age by gender; whereas, passengers were divided into two age groups: 15-17 and 18-20 years by gender. Drivers aged 16- and 17-year-old have similar or higher risk patterns compared to 18-20-year-old drivers. Consistent with the previous finding, the study pointed out that both 16- and 17-year-old drivers had higher crash risk when driving with their same gender and age group passengers. However, a female-to-female driver-passenger combination was found to have a lower crash risk than a male-to-male combination. The number of passengers had little or no impact on young driver's crash risk. However, Duddu et al. showed a lower likelihood of severe and moderate injury as the number of passengers increased for teen drivers aged 15 to 19 years *[12]*. The odds were 9%, 13%, 20%, and 38% less likely in presence of 2, 3, 4, and 5 passengers respectively when compared to driving alone. This could be due to a higher attentiveness and cautious approach adopted by teen drivers learned from GDL passenger restriction laws.

Distraction

In the United States, distraction was included in crash reports in 1995. Driver distraction is known as the diversion of driver attention away from the driving task that increases the crash risk *[41]*. Distraction may originate inside the vehicle or outside the vehicle.

Initially visual (reading a map), auditory (listening to a conversion), biomechanical (tuning radio), and cognitive (lost in thought) were considered as four major categories of distraction on driving *[42]*. Teenage drivers tend to have a higher crash risk when distracted due to less experience and cognitive processing. On the contrary, young experienced drivers sometimes overestimate their ability to multitasking while driving.

Cellphone distraction, a prevalent mode of distraction, includes variables of taking, listening, or dialing a cellphone. Having a conversation on the cellphone while driving has negative impacts on reaction time, lane keeping, car-following ability, and speed control. This multitasking while driving increases the collision risk by 4-5 times *[43]*. A 2018 study examined how distraction activities were related to different crash types for teen drivers (aged 16-19 years) where recorded video, audio, and accelerometer data during a crash or other high g-force events (hard braking, acceleration, or impact) were collected from an inner vehicle camera system during 2007-2015 *[44]*. Observing 400 rear-end collisions, the study concluded that the presence of passengers and using a cellphone were leading causes of rear-end crashes among teen drivers.

Manner of Collision

According to the NHTSA, angular crashes with other vehicles, rear-end collisions, and collision with fixed objects are the most common types of crashes *[45]*. Peek-as et al. found that rear-end and broadside collisions are more frequent in urban crashes; whereas, non-collision and rear-end crashes are more frequent in rural areas considering teen drivers aged 10 to 18 years *[16]*.

Neyens and Boyle examined how distraction types in teen drivers (aged 16 to 19 years) crashes were associated with different factors using data collected from the General Estimates System (GES) *[46]*. Teen drivers were more likely to be involved in fixed object and rear-end collisions under influence of alcohol and exceeding the posted speed limit. Rear-end collision possibility was two times higher among teen drivers. Carney et al. also noted that a significant increase in rear-end collision occurred due to cellphone distraction among teen drivers *[44]*.

Table 1 compiles the contributing factors and key associated findings in the selected peer-reviewed studies that exclusively explored teen or young driver crash contributing factors.

Table 1 Summary of Studies of Young Driver Crash Contributing Factors

Study	Age group	State/Country	Study period	Contributing factor	Findings
[47]	average driver aged 16.48 years (Standard Deviation = 0.33 years)	Virginia, USA	2010-2014	distraction	Teenage drivers had a higher crash likelihood under secondary tasks such as manual cellphone use (e.g., texting, dialing, and browsing the web) and reaching/handling objects in the vehicle.
[48]	16 to 19-year-old drivers compared with 35 to 54-year-old drivers	NHTSA	2005-2007	1) gender, 2) manner of collision, 3) intersection, 4) road geometry, 5) traffic movement	The top five crash scenarios among teen drivers were 1) going straight, other vehicle stopped, rear end; 2) stopped in traffic lanes, turning left at intersections, turning into the path of other vehicles; 3) negotiating curves, off the right edge of the road, right roadside departure; 4) going straight, off the right edge of the road, right roadside departure; and 5) stopped in the lanes, turning left at intersections, turn across the path of other vehicles.
[49]	18 to 20-year-old drivers	Sweden	2003-2004	1) manner of collision, 2) location of the crash, 3) light condition, 4) speed limit, 5) surface condition, 6) crash severity, 7) alcohol, 8) vehicle year	Teen drivers had severe crash risk on rural areas and roads with higher speed limits. Severity level elevates if single-vehicle and front-on collisions occur. Young unlicensed drivers had a higher single-vehicle crash rate under the influence of alcohol during the dark condition.
[50]	18 to 20-year-old drivers	Massachusetts, USA	Survey data	1) number of passengers, 2) distraction, 3) gender, 4) type of friendship, 5) length of friendship, 6) speeding, 7) gender,	Speeding behavior was observed less while driving with close friends. Rather than female drivers, male drivers had a tendency to maintain traffic lanes while driving.

Study	Age group	State/Country	Study period	Contributing factor	Findings
[11]	16 to 24 year-old drivers compared with 25 to 64-year-old drivers	Kansas, USA	2006-2009	1) gender, 2) license compliance, 3) restriction compliance, 4) safety equipment used, 5) airbag, 6) alcohol, 7) lighting conditions, 8) weather, 9) location of the crash, 10) construction or maintenance zone, 11) time of the crash, 12) day of the week, 13) road surface type, 14) road surface condition, 15) road geometry, 16) posted speed limit, 17) vehicle type, 18) vehicle age, 19) number of passengers, 20) teen passenger, 21) driver condition, 22) distraction	Young drivers were overrepresented in intersection-related crashes. Higher crash likelihood had been noticed when driving with an invalid license, without wearing a protection system, at night, on weekends, and in wet road surface condition.
[51]	13 to 15 year-old compared to 16-year-old drivers	FARS	2005-2009	1) driver age, 2) passenger age, 3) gender 4) speeding, 5) crash type, 6) time of the crash, 7) seat-belt use	Fatal crashes involving 13 to 15-year-old drivers depended on licensing age policies. Without adult passenger(s) and license, fatal crash likelihood highly increased for the age group.
[52]	15 to 24-year-old drivers	New Zealand	1999-2006	1) license status, 2) gender	Novice drivers have a higher crash likelihood during the first few months of licensure. Involvement in crashes decreases with increasing holding period before getting a full license.
[34]	16 year-old drivers compared with 25 to 49-year-old drivers	Colorado, USA	1995-2001	1) manner of collision, 2) number of passengers, 3) weather condition, 4) surface condition, 5) vehicle type, 6) time of day, 7) day of the week, 8) lighting condition	At-fault novice driver fatal crashes were associated with speeding, recklessness, single-vehicle and rollover crashes, and traffic law violations. The reason for almost half of fatal crashes of 16-year-old drivers was without using any seatbelts.
[37]	16 to 19-year-old and 20 to 24-year-old drivers	Ontario, Canada	1988	1) gender, 2) severity, 3) number of passengers, 4) time of day, 5) day of week	16 to 19-year-old drivers had higher crash involvement when driving on weekends, at night, and with a passenger. Crash likelihood

Study	Age group	State/Country	Study period	Contributing factor	Findings
	compared with 25 to 59-year-old drivers				increased with the number of passengers in the vehicle.
[36]	16 to 19-year-old drivers	FARS	1995-1999	1) number of passengers, 2) passengers age, 3) alcohol, 4) protection system	Teen drivers had less tendency in wearing seatbelts when driving with an increasing number of passengers especially passengers in their twenties. Seatbelt wearing was most frequent with parents and adult passengers (30 years or older).
[53]	13 to 19-year-old drivers compared with 20+ year-old drivers	FARS	1993	1) driver gender, 2) passenger gender, 3) time of the crash, 4) vehicle type, 5) vehicle model year, 6) passenger age	Both male and female teen drivers had a higher crash rate while driving with teenage passengers compared to older.
[15]	16 to 17-year-old drivers	California, USA	1993-1998	1) time of the crash, 2) day of the crash, 3) alcohol, 4) gender, 5) driver age, 6) number of passengers, 7) severity, 8) passenger age, 9) passenger gender	Higher injury crash rates were observed during night-time hours (10 pm to midnight), absence of adult supervision, and with passengers.
[17]	15 to 24-year-old drivers	Alabama, USA	2009-2016	1) gender, 2) driver race, 3) manner of the crash, 4) primary contributing factor, 5) seatbelt use, 6) season of the crash, 7) day of the crash, 8) location of the crash, 9) highway class, 10) number of traffic lanes, 11) intersection, 12) lighting condition, 13) crash location within 25 mi of driver residence, 14) driver license status, 15) driver ejection status, 16) alcohol	A high percentage of young driver crashes occurred on weekends and close to the driver's home. For male drivers, speeding behavior increased with age and vice-versa. Although, female drivers (15 to 18-year-olds) were highly involved in speeding-related fatal crashes. Crashes under influence of alcohol increased with age especially in 19 to 21-year-olds.

Graduated Driver Licensing (GDL) Program

The Graduated Driver Licensing (GDL) system is designed to minimize inexperienced young drivers' crash risk by acquiring driving experience under low-risk conditions and by gradually increasing exposure to more difficult driving situations. A few states started GDL prior to the mid-1990s and between 1996 and 2006 all other states adapted learner permits with some driving restrictions *[54]*. The first comprehensive study by Baker et al. on nationwide GDL was conducted using 1994-2004 fatal crash data *[55]*. The study analyzed the presence of seven key GDL components in 43 states and identified about 20% reduction in fatal crash involvement rates of 16-year-old drivers, compared to the states without any of the seven GDL components.

A three-state study was conducted using Maryland, Florida, and Michigan crash data *[56]*. Using autoregressive integrated moving average (ARIMA) time-series analysis, the study found that crash rates for drivers aged 16 and 17 years declined in all three states after the implementation or revision of GDL. In Maryland, a 6.9% decrease in possible-injury/PDO crashes was estimated for drivers aged 18 years. A 3.6% increase in possible-injury/PDO crashes was estimated following GDL implementation in Michigan, and no effect of GDL was found in Florida.

An Ohio study performed a cross-sectional analysis of motor vehicle crashes involving drivers aged 16 to 20 years by comparing the pre-GDL (2004-2006) and post-GDL (2008-2010) periods *[57]*. The post-GDL period had lower crash rates for drivers in comparison to the pre-GDL period. The relative crash risks estimated were lower from this comparison were 0.94, 0.9, 0.95, and 0.92 for drivers aged 16, 17, 18, and 16–17 years combined, respectively. However, the crash rate was higher for the post-GDL period for drivers aged 19, 20, 18-20 years with the relative risk being 1.04, 1.09, and 1.02, respectively.

A 10-year citation data comparison of the pre-GDL and post-GDL (5-year each) was performed in Massachusetts (GDL implemented in 2007) using as study group drivers aged 16-17 years and control group drivers aged 25-29 years *[58]*. The rates of licenses per population were compared pre- vs. post-GDL for the study group. In the study group, total, state, and local citations decreased—percentage comparisons of pre- and post-GDL 17.8% vs. 8.1%; 3.7% vs. 2.2%; 14.1% vs. 5.8%, respectively. In the control group, total and state citations did not change—26.7% vs. 23.9, 9.2% vs. 10.2% (p-value is insignificant).

A Michigan study used negative binomial regression controlling for spatial autocorrelation on the crash, census, and organizational data (alcohol outlet, movie theatre, and school locations) and analyzed injury crash rate difference after GDL implementation *[59]*. A substantial reduction in teen crashes after GDL implementation was found (an estimated relative risk of 0.66), with a large effect across gender and the time of the day (light/dark). Concentrations of movie theatres were found to have associations with bigger post-GDL crash rate reductions during darkness.

The study by Baker et al. on nationwide fatal crashes identified that significantly lower fatal crash involvement rates for 16-year-old drivers were associated with GDL programs having five or more components, including age requirements, at least three months waiting period before the intermediate stage, a restriction on nighttime driving, with either 30 or more hours of supervised driving and a restriction on carrying passengers *[55]*.

Steadman et al. conducted an eight-state (representing two of Eastern, Mid-western, Western and Southern states) GDL policy application and scored key eight GDL components for each state on available best practice recommendations *[60]*. The study found states with stronger GDL policies performed better in terms of teen driver crashes and fatalities. The common policies among better-performing states were more required practice hours, banning all teen passengers, and enforcing night driving restrictions for 12+ months. Using driver fatal crash involvements for all U.S. states from 1986 to 2007, Masten et al. found that the largest reductions in 16 to 17-year-old driver fatal crash involvements were associated with two policies—a minimum learner permit holding period of 9-12 months and a passenger restriction allowing only one teen passenger for 6 months or longer *[61]*.

A meta-analysis of GDL research since 2001 (studies on overall 13 different states, 3 nationwide) evaluated the impact of GDL collectively and GDL components individually *[62]*. Results of the meta-analysis showed that GDL programs as a whole were associated with statistically significant reductions in traffic crashes outcomes of 16% for 16-year-olds and 11% for 17-year-olds, but significant associations were not found with changes in crash outcomes for 18- or 19-year-olds. Effect sizes for the unique effects of individual GDL components and calibrations were found to be small for most of the components. The common conclusion from the policy studies is that a stronger GDL policy could reduce crashes for 16 to 17-year-old drivers.

Countermeasures

Developing countermeasures targeted at preventing/lowering young driver crashes is a tall order and often initiated with devising plans and programs by identifying focus areas. Louisiana's SHSP underlines several strategic approaches covering safety programs and enforcement and legislative measures in achieving the goals of reducing young driver crashes *[4]*:

- Maintain and support effective programs aimed at reducing moderate, severe, and fatal crashes among 15- to 17-year-old drivers.
- Identify and create effective programs aimed at reducing moderate, severe, and fatal crashes among 18- to 24-year-old drivers.
- Convene subject matter experts as a resource to review data and promote evidence-based standards to improve young driver safety.
- Expand enforcement of underage drinking laws and regulations.
- Create model legislation that supports young drivers.
- Identify and support data collection for young drivers' distracted driving crashes. Develop effective countermeasures to reduce distracted driving crashes.

General guidelines are available that identify important areas from prevalent young driver crash scenarios. For example, five areas of concern identified by NHTSA in relation to young drivers are—nighttime driving, drinking and driving, passenger interactions, seatbelt use, and cellphone use. With the exception of mandatory minimum legal drinking age of 21 years and blood alcohol concentration (BAC) laws, the GDL program encompasses key safety areas of concern by enforcing additional restrictions for young drivers with the integration of driver education. Several states currently require parent involvement in driver education including a mandatory parent orientation class *[63]*. The GDL programs across various states have evolved through a series of changes in GDL restrictions to facilitate the state's goal to improving young driver safety with measures such as earlier hour nighttime restrictions, increasing the minimum age for full license privilege, various levels of cellphone restrictions *[54]*.

In addition to the changes in GDL restrictions, the benefits of additional measures have also been documented. A small-scale study in New Zealand assessed the effects of high-level training on 16-year-old drivers with video-based hazard perception on a computer, on-road self-evaluation driving exercise, and focus group-based discussions in addition to conventional driving skill training *[64]*. The study found the integration of conventional training with this advanced training could provide significant improvement in visual search and driving performance.

Facilitating enforcement through the identification of young drivers under GDL has also been found beneficial. The state of New Jersey (NJ) implemented the first Graduated Driver Licensing (GDL) with the provision of decal stickers on license plates in the U.S. in May 2010. A study by Curry et al. found the adjusted crash rate for intermediate drivers was 9.5% lower in the 2-year post-decal period than the 4-year pre-decal period *[65]*. Crash rates were also found to have decreased 1.8% per year before the provision and 7.9% per year in the post-decal period.

Objective

The purpose of this study was to fulfill two major objectives:

1. Identifying underlying contributing factors associated with young driver crashes, and
2. Evaluating Louisiana's GDL program.

Scope

The focus of the project was on young driver crashes (15 to 24 years old) on all state-owned and locally owned roadways in Louisiana. As this study heavily relied on crash data, the scope of gathered data narrowed down to the young drivers who were identified and reported as responsible for crashes by the police. The young drivers who were not responsible but were victims of traffic crashes on Louisiana roadways and subsequently amount to young driver casualties were not part of this study. This is partly because the safety countermeasures are designed towards developing safe driving behaviors from the understanding of the crash characteristics of young drivers who have been responsible for the crashes occurred.

Methodology

This study heavily relied on police-reported crash data to fulfill the objective of understanding the effect of crash contributing factors on young drivers. Even with accounting for driving exposure, due to endogenous factors related to experience, behavior, and lifestyle, age-based differences among young driver groups exist and they are indicative of enhanced risk levels for younger drivers. These differences would most likely reflect on the police-reported crash factors identified and derived from the roadway crash data collection system. Furthermore, the current driver data on driver demographic and vehicle data in the crash data collection system don't identify drivers' GDL stage. Therefore, young drivers' age groups were explored for possible associations with crash attributes related to the vehicle, roadway, environment, and human factors available in Louisiana crash data utilizing the thorough review of previous literature. Investigation findings from the comparison of crash factors by age group could uncover linkage to strategic development and application of countermeasures that may be more effective or optimized depending on driver age or level of experience.

To fulfill the broad objective of evaluating the GDL program in Louisiana, several approaches have been undertaken. A trend analysis of the disaggregated time series data estimating the magnitude of crash trends and measuring the increase or decrease of crashes by age group and selected characteristics would indicate the impact of the GDL program over the years. Time series models accounting for the presence of legislative changes around GDL components are likely to evaluate their impact on changes in young driver crash casualties. Spatial analysis was performed for identifying clusters of young driver crashes and presenting the trend of selected crash characteristics across regional safety coalitions in the Louisiana DOTD indicating the possible scope of countermeasure development. Finally, countermeasures were proposed based on the combined understanding of these analyses of crash data and the extensive literature review.

Analyzing Crash Contributing Factors

Besides performing descriptive analysis of young driver crash data, a MNL model was developed to analyze the crash contributing factors to indicate their relative crash likelihood among young driver age groups. The MNL model offered flexibility in the interpretation of the selected crash characteristics. This MNL model development required a comprehensive dataset preparation through data collection and preprocessing, selection, and categorization of the dataset variables before running through data analysis software.

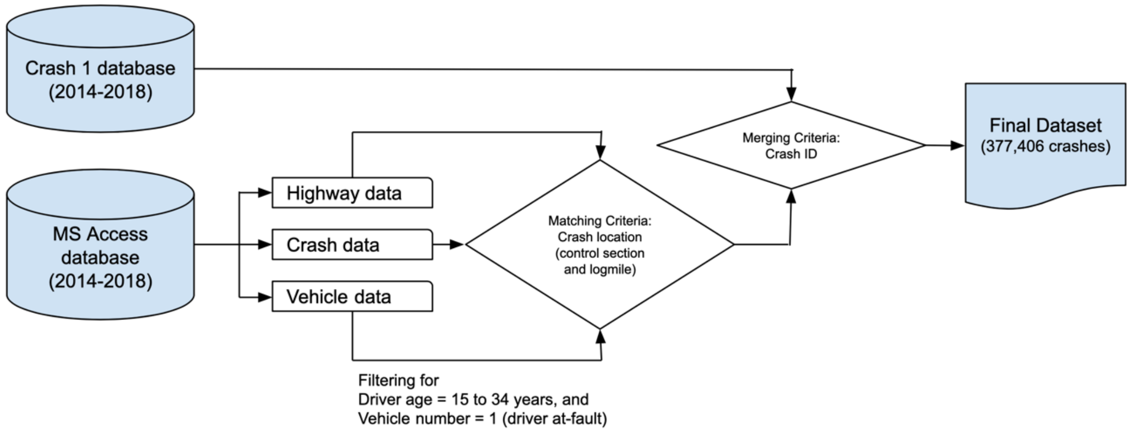
Data Collection and Preprocessing

To reflect on recent young driver crash risks, the research team collected crash data of the last 5 years (2014-2018). Two sources of crash data from the Louisiana Department of Transportation and Development (DOTD) were merged. "Crash 1 Database," a query-based crash database, was used to extract all the crashes with limited available crash variables with more recent years of crash data. Microsoft Access crash databases, developed yearly, were filtered with the criteria of the 15- to 34-year-old age group for more comprehensive crash, highway, and vehicle information. When the latest years of MS files were available, they were merged with the Crash 1 dataset. The crash data of 25-34-year-old drivers were used as a reference group, as this older adult age group is more mature and experienced while possessing a similar intrinsic driving attitude.

The MS Access databases were also filtered only for vehicle 1, especially for multi-vehicle crashes. Crash data extracted for analytic and interpretive purposes in this research feature young drivers and in some cases older experienced drivers who were identified by police as only major liability holders in crashes. Often labeled as the driver of "vehicle 1" in crash databases and associated crash narratives, analyzing this one "at fault" liable driver in each crash appear to be a simplistic yet reasonable approach. Extricating the information regarding the level of liability of other drivers (vehicle 2, 3, etc.) aiming to identify all responsible young drivers involved in multiple-vehicle crashes was found unfeasible.

Data collected by filtering the MS Access files for driver 1 aged 15-34 years were merged with Crash 1 data by matching the unique crash ID. After merging the two databases as presented in Figure 4, and filtering out crashes with multiple unknown information, a final dataset containing a total of 377,406 crashes was prepared.

Figure 4. Dataset Preparation for Young Driver Crash Contributing Factor Analysis



Dataset for Exploring Crash Contributing Factors

The crash dataset contained a large number of crash, roadway, vehicle, and driver-related variables. The selection of appropriate variables suitable for this analysis required a comprehensive understanding of contributing factors from the previous literature, judgment of research team members, and the availability of required variables in DOTD crash databases. The variables in the model were initially selected based on three criteria. First, understanding from previous studies (as presented in the literature review) helps to identify the key variables that could influence young driver crashes. A comprehensive literature review also facilitated the categorization of crash variable classes. For example, crash hour interval has been categorized based on the passenger restriction time of novice young drivers. Second, engineering judgment has also been used while selecting variables. For example, crash severity does not directly serve as a contributing factor, but it has been selected to present the association of young driver groups with crash impact. The third criterion was the data availability in the Louisiana crash database. For example, speeding is known as a key contributing factor of young driver crashes. However, about 85% of operating speed data is either absent or miscoded in the crash database. Hence, in line with previous studies, the operating speed limit was used as an alternate variable. Similarly, the availability of "driver violation" data in the Louisiana crash database lead to its inclusion in the analysis; whereas, "access control" was not included due to unavailability.

Drivers in the final dataset were categorized into four groups. The first three groups represent young drivers aged 15-24 years who were at fault in 199,917 crashes. The four groups are:

- Novice teen (15-16 years): The young driver group holding either a learner's permit or a license with GDL restriction (number of crashes = 11,741).
- Young teen (17-19 years): The rest of the teen drivers who typically do not have any driving restrictions (number of crashes = 70,484).
- Young adult (20-24 years): Young drivers older and more experienced than teen drivers (number of crashes = 117,692).
- Experienced (25-34 years): Older than defined young driver age group (15-24 years). This age group will be used as a reference to estimate the likelihood of crash involvement of other groups (number of crashes = 177,489).

Multinomial Logistic Regression

The MNL model in this study presents a crash profile of each driver age group in reference to the experienced driver group by comparing one or more independent variables (e.g., vehicle type, crash time, etc.). The logit functions are estimated as:

Equation 1: $logit\ (y = novice\ teen) = \log\left(\frac{p(y=novice\ teen)}{1-p(y=novice\ teen)}\right)$

$$= \alpha_0 + \alpha_1 x_{i1} + \alpha_2 x_{i2} + \cdots + \alpha_p x_{in}\ for\ i = 1,2,\ldots\ldots,n \quad (1)$$

Equation 2: $logit\ (y = young\ teen) = \log\left(\frac{p(y=young\ teen)}{1-p(y=young\ teen)}\right)$

$$= \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_p x_{in}\ for\ i = 1,2,\ldots\ldots,n \quad (2)$$

Equation 3: $logit\ (y = young\ adult) = \log\left(\frac{p(y=young\ adult)}{1-p(y=young\ adult)}\right)$

$$= \gamma_0 + \gamma_1 x_{i1} + \gamma_2 x_{i2} + \cdots + \gamma_p x_{in}\ for\ i = 1,2,\ldots\ldots,n \quad (3)$$

Where,

$Reference\ group\ =\ experienced\ driver$

$x =\ variable\ class$

$\alpha, \beta,\ \gamma =\ parameters\ to\ be\ estimated\ in\ the\ model$

Analysis was performed in R statistical software, which also allowed identification of correlated variables through automated multiple estimations of Akaike Information Criterion (AIC). The AIC quantifies and evaluates the relative quality of statistical models utilizing out-of-sample prediction error.

AIC value of the model is expressed as:

$$AIC = 2k - 2\ln(\hat{L}) \quad (4)$$

Where,

$k =\ number\ of\ estimated\ parameters\ in\ the\ model,$

$\hat{L} = maximum\ value\ of\ the\ likelihood\ function\ for\ the\ model.$

GDL Program Evaluation

As part of the main objective of evaluating Louisiana's GDL program, two individual approaches have been undertaken. First, analyses of time series using several methods have been performed. In addition to the descriptive analysis for visually inspecting the presumable trend of young driver crashes and reasonably important crash characteristics, several Mann-Kendall (M-K) tests have been performed to detect and quantify the gradual trend of young driver crashes. These crash trends have also been visualized by the ITA method to supplement the M-K test results. The magnitude and direction of the trends indicate whether the GDL program has been able to lower crashes over the years. To quantitatively assess the impacts of GDL policy changes on young driver crash and consequential casualties, a SARIMAX method has been applied. The signs (positive or negative) of coefficients of this model would possibly indicate their impact on young driver crash casualties.

Second, in spatial analysis, an analytical approach using ArcGIS to find hotspots of young driver crashes that have been performed following the exploration of young driver crashes by Louisiana's nine safety coalitions. Additionally, annual crash trends of selected young driver crash characteristics by safety coalitions have been plotted.

Data for Time Series Analysis

Two types of data were required for the analysis of time trends—crash frequency (both yearly and monthly) and driver population. Crash frequencies by month and year were estimated from the crash dates in previously mentioned data sources—Crash 1 and MS Access files. Fatal crash data of the year 1989 and prior were collected from FARS (Fatality Analysis Reporting System) database, as Crash 1 data were available up to 1990 at the earliest. The FARS reposits data from the nationwide crash events, the vehicles, and drivers, and each person involved, from a census of motor vehicle traffic crashes that result in a fatality to a vehicle occupant or a non-motorist within 30 days of the crash *[66]*.

Driver population data for estimating annual crash rates were collected from the Louisiana Department of Public Safety and Corrections (DOPSC). The annual datasets of 2003-2018 were comprised of driver population segregated by parish, age, and gender.

However, young driver population data by parish were not extractable from the data provided to the researchers.

For seasonal M-K tests, monthly crash frequency data were used in lieu of annual crash data, as M-K tests are more powerful with more data points. A set of seasonal M-K tests was run to statistically quantify the monotonic time trend of the total crash and fatal and injury crash frequencies by age groups and selected specific crash characteristics. However, monthly crash rates could not have been applied in M-K tests as driver population by month was unavailable. Same monthly crash frequency data were used to generate ITA plots.

For the SARIMAX analysis, both aggregate and disaggregate (i.e., yearly and monthly) time series of crash counts were obtained from MS Access files and the Crash 1 database. To explore the impact of the GDL policy changes, a timeline of changes in the GDL and other relevant young driver policies and regulations was provided by one personnel from the Office of Motor Vehicles (OMV).

Seasonal M-K Test and Background

The M-K test is a statistical approach to analyze the presence of a monotonic upward or downward trend of the variable of interest over time *[67]*. In this study, a monotonic upward (or downward) trend indicates that the variable in concern (i.e., crashes of specific age group or crash characteristics) consistently increases (or decreases) through time, irrespective of linear or non-linear trend. A seasonal M-K test was applied from the assumption of a similar crash pattern every 12 months.

Let, $x_1, x_2, \dots, x_n$ are the crash frequencies during the months $1, 2, \dots, n$ respectively in the gth season out of m number of seasons, then, an estimator of trend magnitude is

$$S_g = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_{jg} - x_{ig}), \qquad (1 \le g \le m) \tag{5}$$

S_g simply estimates of the number of positive differences minus the number of negative differences in the gth season. The mean of S_g is $\mu_g = 0$. The variance (including the correction term) can be estimated by

$$\sigma_g^2 = \left[\frac{n(n-1)(2n+5)}{18} - \sum_{u-1}^{v} \frac{t_u(t_u-1)(2t_u+5)}{18}\right], \qquad (1 \le g \le m) \tag{6}$$

Where, v is the number of tied groups and t_u is the number of observations in the uth group.

The seasonal M-K statistic for the entire series can be calculated as

$$\hat{S} = \sum_{g=1}^{m} S_g \text{ and } \hat{\sigma}_g^2 = \sum_{g=1}^{m} \sigma_g^2 \tag{7}$$

Considering S_g is approximately normally distributed, seasonal M-K test statistic Z can be estimated as

$$Z = \begin{cases} \dfrac{\hat{S}-1}{\sqrt{\hat{\sigma}_g^2}}, & if\ \hat{S} > 0 \\ 0, & if\ \hat{S} = 0 \\ \dfrac{\hat{S}+1}{\sqrt{\hat{\sigma}_g^2}}, & if\ \hat{S} < 0 \end{cases} \tag{8}$$

Thus in a two-sided test for trend based on the condition $|Z| \le z_{\alpha/2}$, the null hypothesis H_0 would be accepted indicating the presence of no trend. If the $p - value$ is less than the significance level α (alpha) = 0.05, H_0 would be rejected. If $\hat{S}$ is a positive number, observations obtained later in time would be larger than observations made earlier presenting an upward trend. If $\hat{S}$ is a negative number, then observations made later in time tend to be smaller than earlier observations presenting a downward trend. Seasonal M-K tests were performed in R software.

Background of Innovative Trend Analysis

The ITA method will basically help visualize the monthly trend of crashes by age group and specific characteristics analyzed by M-K tests. The ITA method divides the time series data into two equal halves and plots each time series into a cartesian coordinate system after ranking each series in ascending order. The seasonal effect is not considered in this analysis. The steps in the ITA method are described in the following:

Step 1: Monthly crash frequency data of total n months t_1, t_2, ………t_n, not bound by any season, are divided into two equal halves. Let these two equal half time series are a and b respectively where

$$a = \{t_1, t_2, \dots \dots \dots \dots \dots t_{n/2}\} \tag{9}$$

$$b = \{t_{\frac{n}{2}+1}, t_{\frac{n}{2}+2}, \dots \dots \dots \dots \dots t_n\} \tag{10}$$

Step 2: For each time series (a and b), the data points are ranked into ascending order—lower to higher value. Let R_1 be the ordered version of the time series a, and R_2 be the ordered version of the time series b. They can be expressed as:

$$R_1 = \{\min(t_i) \dots \dots \dots \dots \dots .. \max(t_i)\}\ where\ 1 \le i \le \frac{n}{2} \tag{11}$$

$$R_2 = \{\min(t_i) \dots \dots \dots \dots \dots .. \max(t_i)\}\ where\ \frac{n}{2} + 1 \le i \le n \tag{12}$$

Step 3: Both ordered R_1 and R_2 time-series is plotted in a cartesian coordinate system to obtain a scatter diagram.

Step 4: A diagram line (45^0) is drawn, which divides the whole diagram into two equal (upper and lower) triangles. The scattered data points may lie above or below the diagonal line.

The ITA method provides graphical clarification of the database in addition to the M-K test. If the data points lay on the 1:1 line, there is no trend in the data; data points above the line indicate a positive (increasing) trend, and data points in the bottom triangle reveal a negative (decreasing) trend of the data. A composite trend can be found in the data based on the presence of clusters of low medium and high values above or below the 1:1 line. ITA can be effectively used for trend analysis in terms of assessment of low, medium, and high values of the sample data.

Data Collection for Evaluating the Impact of GDL Components

For evaluating Louisiana's GDL program, the research team first compiled all the specific components of the GDL program through which a safer transition to more risk-exposed driving is expected to be achieved in succeeding stages. Components were basically on limiting the minimum driving age, requiring specific training and tests, and restricting nighttime driving and passengers. Besides these core features, restrictions such as various levels of cellphone use bans can be included under current GDL program features as activities related to cellphone use apply only to teenage drivers and specific stages of GDL *[54]*. The formation of the framework of the GDL program eventually includes a set of characteristics comprising these requirement- and restriction-related legislative components in all three stages as Louisiana's current GDL program framework is presented in Table 2. Almost all the characteristics of the current GDL framework of Louisiana presented are on par with the GDL programs of the majority of the states in the U.S., as can be seen from the distributions of states by key GDL components tabulated in Appendix A.

Table 2. The Current GDL Program Framework of Louisiana

Characteristics	Stage 1	Stage 2	Stage 3
Name of the License	Learner's Permit	Intermediate License	Permanent License
Minimum Age (Years)	15	16	17
Mandatory Pre-licensing Waiting Period (days)	0	180 (with learner's permit)	0
Minimum Hours of Supervised Driving	50 (including 15 hours at night)	0	0
Prerequisite for Issuance	• A successful completion of an approved 38-hour driver education course • A knowledge test • A vision screening	Road skills test	–

Characteristics	Stage 1	Stage 2	Stage 3
Driving Record Requirement	–	• No At-fault Crashes in Stage 1 • No Moving Violations in Stage 1 • No curfew, drug or alcohol law violations in Stage 1	• No At-fault Crashes (12 consecutive months) • No Moving Violations (12 consecutive months) • No curfew, drug or alcohol law violations (12 consecutive months)
Cellphone Restrictions	No cellphone usage including hands-free unless for emergencies	No talk or text (read, write or send) unless hands-free or for emergencies	No talk or text (read, write, or send) unless hands-free or for emergencies (for 17-year-olds)
Nighttime Driving Restriction	–	11 pm to 5 am	–
Passenger Restrictions	A licensed parent, guardian, or adult at least 21 years old, or a licensed sibling at least 18 years old or older.	A licensed parent, guardian, or adult at least 21 years old, or a licensed sibling at least 18 years old or older between 11 pm and 5 am (may not transport more than one passenger during this time)	–
Punishment for Restriction Violations with or without Fine	• Preclusion from advancing to the next license level for 30 to 180 days • Fine of $100 to $500 and up to six months in jail		–

Initially introduced in 1998 with only the core elements, Louisiana's current GDL program went through multiple notable changes. The information on legislative changes associated with GDL including cellphone and texting laws was obtained from historical records and have been summarized in Table 3. For SARIMAX models, these key timelines will be used as an input of intervention variables.

Table 3. The Chronicles of Key GDL Legislations in Louisiana

Time of implementation	Inception of Key GDL Legislations in Louisiana
January 1998	GDL program started (See Table 2 for details) – Learner's permit at 15 years, 90 days holding period, may only drive with adult(s) of aged 21 years or older; – Intermediate stage: minimum age 16 years old, nighttime driving restriction (11 pm to 5 am), not at fault in a crash for 12 months; – Full licensure at 17 years.
June 1999	The learner's permit holder can drive with a licensed sibling of at least 18 years of age in addition to an adult aged 21 years or older (learner's policy change 1)
January 2001	Other immediate family members to ride with a learner's permit holder in addition to adult (learner's policy change 2)
January 2004	Learner's permit holding period increase from 90 days to 180 days.
July 2008	Prohibition of use of a hand-held communication device for minors (17 years or less)
January 2009	Increased the number of behind the wheel driving instruction from 6 hours to 8 hours
January 2011	– Introduced passenger restriction (not more than 1) from 6 pm to 5 am for intermediate stage – Supervised driving increased to 50 hours with 15 hours of night-time driving – Added minimum 8 hours behind the wheel instruction in pre-licensing course 18 or older

Theoretical Background of ARIMAX and SARIMAX Models

A number of legislative changes attributable to the undertaking of young driver safety improvement by the state call for an effective analysis method to measure their impacts on crashes. The Box and Jenkins model, especially the seasonal autoregressive integrated moving average model with explanatory variables (SARIMAX), can be used to estimate the effects of these interventions allowing for seasonality present in time series data. To assess the effects of various regressors and interventions as explanatory variables besides the usual trend and seasonal components, an extension of the model can be expressed as–

$$Y_t = \varpi_0 I_t + \beta X + N_t \tag{13}$$

Here, Y_t is the dependent variable (i.e., crash casualties) for a particular time t. I_t is the intervention component (i.e., legislative changes), which can be coded as a dichotomous variable taking the value 0 during the pre-intervention period and 1 during the post-intervention period. ϖ_0 is its coefficient of the intervention component, the signs (positive or negative) of which will indicate the impact of these legislative changes on crash casualties.

X is the deterministic effects of independent variables also known as control variables. N_t is the stochastic variation or the noise component of the model or noise component which can be represented by the best ARIMAX model denoted as (p, d, q) for a non-seasonal time series and the best SARIMAX model for a seasonal time series denoted as $(p, d, q) \times (P, D, Q)_s$. Here, p is the order of the non-seasonal autoregressive (AR) process, P is the order of the seasonal AR process, d is the order of the non-seasonal difference, D is the order of the seasonal difference, q is the order of the non-seasonal moving average (MA) process, Q is the order of the seasonal MA process, and the subscript s is the length of seasonality (in this study, $s = 12$ for monthly time series data). Including the effect of seasonality on time series data, the ARIMAX noise model can take the following format.

$$N_t = \frac{\theta(B)\Theta(B^s)}{\varphi(B)\Phi(B^s)(1-B)^d(1-B^s)^D} e_t \tag{14}$$

Where, B and B^s are backshift operators, φ and Φ are autoregressive coefficients for regular and seasonal operators, θ and Θ are moving average coefficients for regular and seasonal operators, and e_t is an uncorrelated random error term with zero mean and constant variance (σ^2). Box et al. explains this model in further detail *[68]*.

Method for Spatial Analysis

There are nine safety coalitions in Louisiana each covering a number of parishes. Based on data availability for each safety coalition, the research team limited the investigation by safety coalition area through crash analysis. The crash analysis at the regional level was expected to provide some insights in light of recent statistics of key crash characteristics associated with young drivers.

Based on about 98% of geographic coordinates available and extracted from each young driver crash record, young driver crash hotspots were identified applying hotspot analysis in ArcGIS. The analytic process is similar to the process in Huang et al. *[69]*. The steps are as follows:

- A map is divided into fishnets (small rectangular cells) by creating the fishnet tool in ArcGIS online. In our analysis, the total fishnet was 3,344 with 59,640 valid features. Each fishnet size was 6.55 square miles.
- A new layer named fishnet is created. Then, the crash layer is connected to the fishnet layer; named "fishnet Spatial Join."
- In the layer "fishnet Spatial Join," there is a data field named "Joined Count," which represents the young driver crash frequency in a particular fishnet.
- Finally, a hotspot analysis is done on the layer of "fishnet Spatial Join," according to the "Joined Count" attribute.

Following the hotspot analysis, the research team then looked into the distribution of clusters by safety coalition areas. Besides, this clustering approach, the distribution of crashes by key crash characteristics in the nine safety coalition areas in five years were also plotted.

Discussion of Results

Overview of Young Driver Safety Facts

As part of the initial investigation of the 827,247 crashes that occurred in 2014-2018, the percentage distribution of young driver (15 to 24 years old) crashes by gender, alcohol, driver protection system, and distraction are listed in Table 4. The crash severity is presented for each variable to highlight the discussions on the more serious crashes.

- Young drivers are responsible for 24.2% of 827,247 crashes in 2014-2018.
- Although the crash frequency of young male drivers is higher than that of young female drivers, which is also a general case for all drivers, the percentage of young female drivers involving crashes is higher than that of young male drivers (28.4% vs. 25.4%).
- Even though more than half of the young drivers did not reach the legal age for alcohol consumption, this group of drivers are responsible for more than 25% of the total crashes with driver's BAC between 0 to 0.08 g/dL. They are also responsible for 16.4% of all fatal crashes and 19.5% of all injury crashes with BAC over 0.08 g/dL.
- There are 23.1% of fatal crashes and 31.3% of injury crashes involving responsible drivers without using or improperly using safety protection systems (seatbelt and helmet) belong to young drivers.
- Young drivers distracted by cell phone usage led to 32% of the fatal crashes and 34% of the injury crashes. Additionally, 40.3% of total crashes caused by other electronic device usage occurred to the young drivers.

As Table 5 reveals, the final dataset contains crashes that occurred to 15-34-year-old drivers. Novice teen, young teen, young adult, and experienced drivers shared 3.11%, 18.68%, 31.18%, and 47.03% of crashes, respectively. The percentage distributions of licensure among them, according to the latest 2018 data, are 4.53%, 13.79%, 26.15%, and 55.52% in the same order. The young teen and young adult drivers appear to be over-represented in crashes. Discussions on the percentage distribution have been centered on young driver age groups taking young drivers' driving behaviors and GDL restrictions into consideration.

Table 4. Crash Contributing Factor Analysis of Young Drivers and All Drivers by Severity

Variable	Variable class	Fatal			Injury			PDO			Total		
		15-24y	All Drivers	%	15-24y	All Drivers	%	15-24y	All Drivers	%	15-24y	All Drivers	%
Gender	Male	514	2,512	20.5	32,697	128,523	25.4	76,438	301,006	25.4	109,649	432,041	25.4
	Female	198	852	23.2	27,214	94,716	28.7	62,297	220,634	28.2	89,709	316,202	28.4
	Unknown	0	118	0	118	12,477	0.9	441	66,409	0.7	559	79,004	0.7
Alcohol	0/not tested	534	2,476	21.6	58,678	229,075	25.6	137,655	580,038	23.7	196,867	811,589	24.3
	0-0.08 g/dL	38	153	24.8	202	748	27.0	165	676	24.4	405	1,577	25.7
	0.08+ g/dL	140	853	16.4	1,149	5,893	19.5	1,356	7,335	18.5	2,645	14,081	18.8
Driver Protection System	Properly used	347	1,806	19.2	48,708	179,646	27.1	120,184	440,253	27.3	169,239	621,705	27.2
	Improperly used	4	23	17.4	1,231	5,025	24.5	2,316	9,980	23.2	3,551	15,028	23.6
	None used	277	1,198	23.1	3,313	10,570	31.3	1,497	5,353	28	5,087	17,121	29.7
	Unknown	84	455	18.5	6777	40475	16.7	15179	132463	11.5	22040	173393	12.7
Distraction	Not distracted	236	1,075	22	33,986	128,752	26.4	85,899	326,602	26.3	120,121	456,429	26.3
	Cellphone	8	25	32	1,297	3,815	34	2,484	7,156	34.7	3,789	10,996	34.5
	Other device(s)	1	9	11.1	422	1,026	41.1	848	2,117	40.1	1,271	3,152	40.3
	Inside vehicle	16	62	25.8	3,754	11,863	31.6	7,395	23,098	32	11,165	35,023	31.9
	Outside vehicle	10	43	23.3	2,518	8,891	28.3	5,882	22,096	26.6	8,410	31,030	27.1
	Unknown	441	2,268	19.4	18,052	81,369	22.2	36,668	206,980	17.7	55,161	290,617	19
Total Crashes		**712**	**3,482**	**20.4**	**60,029**	**235,716**	**25.5**	**139,176**	**588,049**	**23.7**	**199,917**	**827,247**	**24.2**

Descriptive Statistics of Crash Contributing Factors

Table 5 presents the frequency and percentage distribution of crash characteristics of the driver groups from the final dataset. The percentage distribution of each variable in the final dataset of 377,406 crashes that occurred during 2014-2018 presents the relative magnitude of specific groups across various crash characteristics in predefined young driver age groups and the experienced group. The difference of many characteristics between driver groups may appear to be small, as they possess similar distribution in the majority of the variables. Due to intricacies and randomness associated with crashes, the difference of all crash characteristics between driver groups may not be meaningful. While this percentage distribution also serves as a base to the analytic model, a thorough discussion presents the salient features of crash characteristics involving young driver age groups.

Table 5. Distribution of Selected Variables in the Final Dataset

	Whole dataset (100%)		Novice teen (3.11%)		Young teen (18.68%)		Young adult (31.18%)		Experienced (47.03%)	
	frequency	%	frequency	%	frequency	%	frequency	%	frequency	%
Vehicle with driver at fault										
Gender										
male	210,991	55.91	6,109	52.03	38,080	54.03	65,459	55.62	101,343	57.1
female	165,362	43.82	5,603	47.72	32,183	45.66	51,923	44.12	75,653	42.62
unknown	1,053	0.28	29	0.25	221	0.31	310	0.26	493	0.28
Alcohol (BAC)										
<0.02 g/dL	369,803	97.99	11,715	99.78	69,981	99.29	115,206	97.89	172,901	97.42
0.02-0.08 g/dL	788	0.21	9	0.08	87	0.12	274	0.23	418	0.24
≥0.08 g/dL	6,815	1.81	17	0.14	416	0.59	2,212	1.88	4,170	2.35
Distraction										
cellphone	7,001	1.86	188	1.60	1,411	2.00	2,190	1.86	3,212	1.81
other device(s)	2,153	0.57	89	0.76	465	0.66	717	0.61	882	0.5
inside vehicle	20,775	5.50	635	5.41	4,136	5.87	6,394	5.43	9,610	5.41
outside vehicle	15,439	4.09	566	4.82	3,026	4.29	4,818	4.09	7,029	3.96
not distracted	226,926	60.13	6,972	59.38	42,131	59.77	71,018	60.34	106,805	60.18
unknown	105,112	27.85	3,291	28.03	19,315	27.40	32,555	27.66	49,951	28.14
Passenger										
no passenger	280,628	74.36	7,339	62.51	50,622	71.82	89,217	75.81	133,450	75.19
single passenger	62,653	16.60	2,956	25.18	13,610	19.31	19,319	16.41	26,768	15.08
multiple passengers	34,125	9.04	1,446	12.32	6,252	8.87	9,156	7.78	17,271	9.73
Vehicle type										
car	209,173	55.42	5,650	48.12	41,904	59.45	72,953	61.99	88,666	49.96
van and SUV	76,338	20.23	2,816	23.98	12,358	17.53	19,443	16.52	41,721	23.51
pickup truck	75,671	20.05	2,998	25.53	15,199	21.56	21,415	18.20	36,059	20.32
motorcycle	2,309	0.61	23	0.20	200	0.28	722	0.61	1,364	0.77

	Whole dataset (100%)		Novice teen (3.11%)		Young teen (18.68%)		Young adult (31.18%)		Experienced (47.03%)	
	frequency	%	frequency	%	frequency	%	frequency	%	frequency	%
others	13,915	3.69	254	2.16	823	1.17	3,159	2.68	9,679	5.45
Protection system										
properly used	316,910	83.97	9,895	84.28	60,255	85.49	99,089	84.19	147,671	83.2
improperly used	7,320	1.94	179	1.52	1,113	1.58	2,259	1.92	3,769	2.12
none used	9,782	2.59	382	3.25	1,626	2.31	3,079	2.62	4,695	2.65
unknown	43,394	11.50	1,285	10.94	7,490	10.63	13,265	11.27	21,354	12.03
Violation										
no violation	27,346	7.25	542	4.62	3,880	5.50	8,109	6.89	14,815	8.35
careless operation	122,739	32.52	3,966	33.78	24,239	34.39	38,856	33.01	55,678	31.37
failure to yield	61,404	16.27	2,673	22.77	13,065	18.54	19,313	16.41	26,353	14.85
following too closely	68,044	18.03	1,926	16.40	13,255	18.81	21,753	18.48	31,110	17.53
other improper actions	97,873	25.93	2,634	22.43	16,045	22.76	29,661	25.20	49,533	27.91
Crash environment										
Crash hour										
5 am to 12 pm	88,544	23.46	2,266	19.30	14,037	19.92	26,611	22.61	45,630	25.71
12 pm to 6 pm	153,706	40.73	5,255	44.76	30,980	43.95	47,940	40.73	69,531	39.17
6 pm to 11 pm	98,443	26.08	3,493	29.75	19,320	27.41	30,706	26.09	44,924	25.31
11 pm to 5 am	36,713	9.73	727	6.19	6,147	8.72	12,435	10.57	17,404	9.81
Day of the week										
weekday	268,968	71.27	8,355	71.16	50,153	71.16	83,272	70.75	127,188	71.66
weekend	108,438	28.73	3,386	28.84	20,331	28.84	34,420	29.25	50,301	28.34
Lighting condition										
daylight	269,629	71.44	8,753	74.55	51,489	73.05	82,832	70.38	126,555	71.3
dark with no streetlight	34,161	9.05	951	8.10	6,077	8.62	10,964	9.32	16,169	9.11

	Whole dataset (100%)		Novice teen (3.11%)		Young teen (18.68%)		Young adult (31.18%)		Experienced (47.03%)	
	frequency	%	frequency	%	frequency	%	frequency	%	frequency	%
dark with streetlight	62,726	16.62	1,664	14.17	11,035	15.66	20,453	17.38	29,574	16.66
dusk dawn	9,383	2.49	335	2.85	1,637	2.32	2,950	2.51	4,461	2.51
others	1,507	0.40	38	0.32	246	0.35	493	0.42	730	0.41
Weather										
clear	267,304	70.83	8,294	70.64	49,038	69.57	82,686	70.26	127,286	71.71
cloudy	60,272	15.97	1,875	15.97	11,370	16.13	18,818	15.99	28,209	15.89
rain	45,121	11.96	1,458	12.42	9,341	13.25	14,742	12.53	19,580	11.03
snow/sleet/hail	1,211	0.32	13	0.11	145	0.21	391	0.33	662	0.37
others	3,498	0.93	101	0.86	590	0.84	1,055	0.90	1,752	0.99
Surface condition										
dry	309,666	82.05	9,593	81.71	56,774	80.55	95,718	81.33	147,581	83.15
wet	64,948	17.21	2,107	17.95	13,361	18.96	21,090	17.92	28,390	16
snow/slush/ice	1,971	0.52	19	0.16	225	0.32	621	0.53	1,106	0.62
others	821	0.22	22	0.19	124	0.18	263	0.22	412	0.23
Road characteristic										
Highway class										
local	130,451	34.57	4,347	37.02	23,438	33.25	39,872	33.88	62,794	35.38
ramp-exit	1,741	0.46	26	0.22	257	0.36	565	0.48	893	0.5
rural interstate	7,514	1.99	59	0.50	1,015	1.44	2,582	2.19	3,858	2.17
rural multilane divided	3,782	1.00	86	0.73	660	0.94	1,171	0.99	1,865	1.05
rural multilane undivided	741	0.20	31	0.26	136	0.19	235	0.20	339	0.19
rural two-lane	27,274	7.23	1,161	9.89	5,811	8.24	8,161	6.93	12,141	6.84
service frontage road	880	0.23	19	0.16	154	0.22	285	0.24	422	0.24
urban interstate freeways	45,498	12.06	667	5.68	6,897	9.79	15,271	12.98	22,663	12.77

	Whole dataset (100%)		Novice teen (3.11%)		Young teen (18.68%)		Young adult (31.18%)		Experienced (47.03%)	
	frequency	%	frequency	%	frequency	%	frequency	%	frequency	%
urban multilane divided	47,567	12.60	1,250	10.65	8,820	12.51	14,922	12.68	22,575	12.72
urban multilane undivided	61,328	16.25	1,844	15.71	12,039	17.08	19,584	16.64	27,861	15.7
urban two-lane	50,630	13.42	2,251	19.17	11,257	15.97	15,044	12.78	22,078	12.44
Posted speed limit										
<=25 mph	55,188	14.62	2,029	17.28	9,906	14.05	16,411	13.94	26,842	15.12
30 to 35 mph	89,751	23.78	2,700	23.00	16,463	23.36	27,864	23.68	42,724	24.07
40 to 45 mph	109,819	29.10	3,697	31.49	22,183	31.47	34,236	29.09	49,703	28
50 to 55 mph	61,112	16.19	2,114	18.01	12,083	17.14	18,907	16.06	28,008	15.78
>=60 mph	45,335	12.01	623	5.31	6,914	9.81	15,389	13.08	22,409	12.63
unknown	16,201	4.29	578	4.92	2,935	4.16	4,885	4.15	7,803	4.4
Road geometry										
straight segment	216,569	57.38	6,398	54.49	40,464	57.41	67,993	57.77	101,714	57.31
curve segment	24,278	6.43	856	7.29	4,890	6.94	7,476	6.35	11,056	6.23
intersection	127,453	33.77	4,200	35.77	23,552	33.41	39,455	33.52	60,246	33.94
intersection on curve	7,843	2.08	240	2.04	1,406	1.99	2,361	2.01	3,836	2.16
others	1,263	0.33	47	0.40	172	0.24	407	0.35	637	0.36
Crash characteristic										
Manner of collision										
rear end	150,915	39.99	4,323	36.82	29,099	41.28	47,791	40.61	69,702	39.27
head on	5,439	1.44	152	1.29	933	1.32	1,630	1.38	2,724	1.53
non collision	60,961	16.15	1,763	15.02	10,982	15.58	19,158	16.28	29,058	16.37
left turn	29,715	7.87	1,188	10.12	6,133	8.70	9,240	7.85	13,154	7.41
right angle	49,737	13.18	1,924	16.39	9,625	13.66	15,451	13.13	22,737	12.81
right turn	7,479	1.98	349	2.97	1,608	2.28	2,259	1.92	3,263	1.84

	Whole dataset (100%)		Novice teen (3.11%)		Young teen (18.68%)		Young adult (31.18%)		Experienced (47.03%)	
	frequency	%	frequency	%	frequency	%	frequency	%	frequency	%
sideswipe opposite	5,386	1.43	155	1.32	741	1.05	1,508	1.28	2,982	1.68
sideswipe same	36,357	9.63	957	8.15	6,158	8.74	11,311	9.61	17,931	10.1
others	31,417	8.32	930	7.92	5,205	7.38	9,344	7.94	15,938	8.98
Severity										
fatal	1,537	0.41	35	0.30	198	0.28	479	0.41	825	0.46
severe	2,656	0.70	75	0.64	385	0.55	867	0.74	1,329	0.75
moderate	22,615	5.99	698	5.94	3,898	5.53	6,960	5.91	11,059	6.23
complaint	89,743	23.78	2,664	22.69	16,628	23.59	27,854	23.67	42,597	24
PDO	260,855	69.12	8,269	70.43	49,375	70.05	81,532	69.28	121,679	68.56
Total	377,406	100	11,741	100	70,484	100	117,692	100	177,489	100

The discussions of descriptive statistics by crash characteristics are as follows:

- *Gender:* Male drivers are more at fault in crashes across all young driver age groups, 4.31%, 8.37%, and 11.5% higher than female novice teen, young teen, and young adult drivers, respectively. The disproportionate prevalence of young male drivers in crashes has often been attributed to their excessively optimistic judgments of driving competency and crash risk *[70]*. Besides the fact that male drivers generally drive up to 1.5 times more than female drivers *[71]*, the share of licensure between male and female young drivers as of 2018 is similar, 49.5% and 50.5%, respectively. The estimates of male and female young driver crash rates in the same year, 94.4 and 77.5 per 1,000 licensed drivers respectively, also support young male drivers' higher prevalence of crashes.
- *Alcohol:* In Louisiana, the legal blood alcohol concentration (BAC) limit for drivers of 21 years or older is 0.08 g/dL; whereas, it is 0.02 g/dL for drivers under 21 years. The percentages of alcohol-related crashes (both "0.02-0.08 g/dL" and "≥ 0.08 g/dL") in young driver age groups are lower than or equal to the percentages in experienced drivers, which is expected considering the alcohol ban for drivers aged 21 years or less. A slightly increasing trend can be seen of reported alcohol involvement along with the increasing age group—both low intoxication ("0.02-0.08 g/dL") with 0.08%, 0.12%, and 0.23%, and high intoxication ("≥0.08 g/dL") with 0.14%, 0.59%, and 1.88% for novice teen, young teen, and young adult drivers respectively. Although the frequency and percentage of crashes with alcohol intoxication in young drivers including underage drunk driving may appear to be small, it requires serious attention.
- *Distraction:* There are two issues that need to be taken into account prior to discussions regarding distraction-related crash data in the final dataset. First, cellphone usage is largely underreported *[72]*, *[73]*, which explains large percentages of unknowns in the category. Second, cellphone usage while driving is heavily restricted for a fraction of young drivers especially for less than 17-year-olds or holders of either learner's permit or intermediate license. The percentage of crashes with reported cellphone distraction among young teen drivers is slightly higher than other groups, which may well be even higher given the large underreporting is considered.
- *Passenger:* The percentages of crashes with single passengers are substantially high for novice teen and young teen driver age groups, in comparison with experienced drivers. It should be noted that drivers in stages 1 and 2 of the GDL

program, typically novice teen—15- and 16-year-olds have all time and nighttime (11 pm to 5 am) passenger restrictions, respectively. An exploration of crash data with 15-year-old drivers at fault indicates that a very high 47% (483 out of 1,029 crashes) had no passengers present, which may draw attention considering that the GDL law requires these drivers to have adult passenger present while driving. A further investigation reveals that 59% of total crashes (426 out of 727) with 15 to 16-year-old drivers at fault during the hours of 11 pm to 5 am also had no passengers, which was also prohibited by the GDL law.

- *Vehicle type:* Passenger car is associated with an overwhelming majority of crashes across all driver age groups, understandably so in part because of higher ownership of passenger cars in general. Compared to other age groups, a higher percentage of crashes involving novice teen drivers driving relatively large vehicles—pick-up trucks, and vans and SUVs —is noticeable.
- *Driver protection system:* 11.5% of crashes in the final dataset lack information regarding the status of drivers' protection system (seatbelt or helmet use) during crashes. Out of 11,741 crashes with novice teen drivers at fault, 4.8% had no or improper use of protection system during driving, higher than any other young driver group. This percentage could be even higher, had the protection system use status of 10.9% crashes in this age group been known.
- *Violation:* In the final dataset, crashes due to "careless operation" and "failure to yield" are among the top three driving violations recorded by police. "Careless operation" indicates unwilful but dangerous driving, which encompasses an extensive number of examples—illegal lane changes, hitting another vehicle at rear-end, failure to brake, etc. Crashes due to "failure to yield" to oncoming and turning vehicles commonly occur at stop or yield signs and left turn on yield signals. Crash percentages due to these two violations are apparently higher in all three young driver age groups compared to experienced drivers.
- *Driving hour:* Crashes during the afternoon (12 pm to 6 pm) are the highest in percentage regardless of age groups in comparison to other time intervals; however, the magnitude is even higher for novice teen and young teen drivers when compared to other driver groups. Crashes during the hours of 11 pm to 5 am involving novice teen drivers and young teen drivers are smaller in percentage compared to other driver groups. This can be attributed to nighttime driving restrictions of passengers for these two groups resulting in less amount of driving.
- *Day of the week:* To properly represent the weekend crash condition, the actual data of the day of the week was imputed. From Friday 6 pm to Sunday 6 pm was

considered as a weekend and the rest of the time during the week was considered as weekdays. However, although the data still shows a large number of crashes for 5-day weekdays, there is no discernible difference between driver age groups.

- *Lighting condition:* The majority of the crashes occur during daylight for all age groups, followed by crashes in the presence of streetlight and absence of streetlight. Among the young drivers, the percentage of crashes in darkness (both in the presence and absence of streetlight) increases with older age groups.
- *Weather condition:* Percentage of crashes during different weather conditions follow the pattern of the most persistent conditions—clear weather followed by cloudy and rainy weather. There is no distinguishable difference between age groups, with young teen drivers showing a very slightly high percentage of crashes during cloudy and rainy weather.
- *Surface condition:* More than 80% of crashes occur on dry surface conditions, as it presents the normal condition without any impact from the inclement weather. Wet surfaces share a relatively high percentage of crashes for young driver age groups compared to experienced driver groups.
- *Highway class:* Local roads are not state-controlled highways, but they constitute the largest portion of the highway network and eventually the largest percentage of crashes across all age groups. Novice teen and young teen drivers have a noticeably larger percentage of crashes than young adult drivers on urban two-lane highways, 19.17% and 15.97% against 12.78%, respectively.
- *Speed limit:* For all driver groups, a higher percentage of crashes occurred on roads with speed limits of 40-45 mph. On roadways with the speed limit range of 40-55 mph, novice teen and young teen drivers had a higher percentage of crashes than other age groups. Novice teen drivers also had a higher percentage on roads with speed limits of $\leq$ 25 mph. For roads with high speed limits of $\geq$ 60 mph, the percentage of crashes increased with age among young driver groups.
- *Road geometry:* The majority of the crashes occurred on straight segments, followed by intersections, curve segments, and intersections on curves. Between young driver groups, novice teen drivers have a slightly higher percentage of crashes at intersections, while young teen and young adults have a slightly higher percentage of crashes on straight segments.
- *Manner of collision:* In general, rear-end crashes continue to be the highest in percentage followed by non-collision (single vehicle) and right-angle crashes across all age groups. Compared to other driver groups, novice teen drivers seem to have a higher proportion of right angle and turning crashes (left turn, right turn)

and crashes that typically occur at intersections.

- *Severity:* More than 90% of crashes for all age groups are less severe, either PDO or complaint crashes. Crashes with fatal, severe, and moderate injury possess small percentages but they require more attention. Fatal and severe injury are more random, small percentage difference exists across the driver age groups. The percentage of crashes with moderate severity is slightly higher for novice teen drivers and experienced drivers.

Multinomial Logit Model Results

Results from the MNL logit model are presented in Table 6. Using the cut off p-value of 0.05, insignificant results have been presented in italics. As shown in Equations 1, 2, and 3, this model presents crash profiles of novice teen, young teen, and young adult drivers through the incorporation of coefficients of significant variable classes in those equations. In Table 6, standard errors and p-values of the coefficients have also been presented. In addition to coefficients, the model results can also be presented using an adjusted odds ratio (estimated as exponentiating the coefficients, $e^{coefficient}$) to describe the likelihood of crashes of the young driver age group. Positive coefficients or greater than 1 odds ratio indicated significantly higher association compared to the reference group, given p-value is less than 0.05. It should be noted that the odds ratios are estimated based on the reference class predefined for each variable in Table 6 while fitting in the model (equation 1, 2, 3). The reference class was selected through the compromise between the variable class that represented the safest crash scenario and the variable class with the highest frequency.

Although the initial variable selection was performed based on literature review, engineering judgment, and data availability, the final selection was performed through an automated selection process in R software by eliminating multicollinearity. Both backward and forward stepwise selection was performed in the R software algorithm for identifying the best model through minimizing AIC value. In the process of selection of the best model, the variable “weather condition” got excluded. Surface condition is often causally linked to the weather condition, which consequently presents a similar crash scenario. The AIC value of the final model was estimated as 842,017.7, with an associated log-likelihood of -420,813.9.

Table 6. Results of Multinomial Logit Model

	Novice Teen (15-16y)				Young Teen (17-19y)				Young Adult (20-24y)			
	co-efficient	std. error	p-value	Odds Ratio	co-efficient	std. error	p-value	Odds Ratio	co-efficient	std. error	p-value	Odds Ratio
(Intercept)	-3.78	0.06	0.00	0.02	-1.48	0.03	0.00	0.23	-0.56	0.02	0.00	0.57
Vehicle with driver at fault												
Gender (Ref: male)												
female	0.19	0.02	0	1.21	0.06	0.01	0	1.06	*-0.01*	*0.01*	*0.36*	*0.99*
unknown	*0.14*	*0.19*	*0.48*	1.15	0.29	0.08	0	1.34	*0*	*0.07*	*0.97*	*1.00*
Alcohol (Ref: BAC<0.02)												
BAC:0.02-0.08	-1.16	0.34	0	0.31	-0.69	0.12	0	0.50	*-0.07*	*0.08*	*0.37*	*0.93*
BAC≥0.08	-2.71	0.24	0	0.07	-1.40	0.05	0	0.25	-0.28	0.03	0	0.76
Distraction (Ref: not distracted)												
cellphone	*-0.07*	*0.08*	*0.34*	*0.93*	0.08	0.03	0.01	1.09	*0*	*0.03*	*0.90*	*1.00*
other device(s)	0.48	0.11	0	1.61	0.28	0.06	0	1.32	0.19	0.05	0	1.21
inside vehicle	-0.10	0.04	0.02	0.90	*0.01*	*0.02*	*0.46*	*1.02*	*-0.01*	*0.02*	*0.62*	*0.99*
outside vehicle	0.20	0.05	0	1.22	0.07	0.02	0	1.07	*0.03*	*0.02*	*0.19*	*1.03*
unknown	*0.01*	*0.02*	*0.60*	*1.01*	*-0.01*	*0.01*	*0.41*	*0.99*	-0.02	0.01	0.01	0.98
Passenger (Ref: no passenger)												
single passenger	0.67	0.02	0	1.95	0.27	0.01	0	1.31	0.06	0.01	0	1.06

	Novice Teen (15-16y)				Young Teen (17-19y)				Young Adult (20-24y)			
	co-efficient	**std. error**	**p-value**	**Odds Ratio**	**co-efficient**	**std. error**	**p-value**	**Odds Ratio**	**co-efficient**	**std. error**	**p-value**	**Odds Ratio**
multiple passengers	0.37	0.03	0	1.44	-0.07	0.02	0	0.93	-0.24	0.01	0	0.79
Vehicle type (Ref: passenger car)												
van and SUV	*0.03*	*0.02*	*0.15*	*1.04*	-0.47	0.01	0	0.63	-0.56	0.01	0	0.57
pickup truck	0.35	0.03	0	1.41	-0.10	0.01	0	0.91	-0.33	0.01	0	0.72
motorcycle	-1.12	0.21	0	0.33	-1.07	0.08	0	0.34	-0.43	0.05	0	0.65
others	-0.77	0.07	0	0.46	-1.62	0.04	0	0.20	-0.89	0.02	0	0.41
Protection system (Ref: properly used)												
improperly used	-0.20	0.08	0.01	0.82	-0.21	0.04	0	0.81	-0.07	0.03	0.01	0.93
none used	0.40	0.06	0	1.49	0.08	0.03	0.01	1.08	0.10	0.02	0	1.11
unknown	*-0.05*	*0.03*	*0.10*	*0.95*	-0.09	0.02	0	0.91	-0.05	0.01	0	0.96
Violation (Ref: no violation)												
careless operation	0.68	0.05	0	1.97	0.47	0.02	0	1.61	0.24	0.02	0	1.27
failure to yield	0.83	0.05	0	2.30	0.56	0.02	0	1.75	0.29	0.02	0	1.33
following too closely	0.63	0.06	0	1.88	0.47	0.02	0	1.60	0.24	0.02	0	1.28
other improper actions	0.41	0.05	0	1.50	0.29	0.02	0	1.34	0.14	0.02	0	1.15
Crash environment												
Crash hour (Ref: 6 am to 12 pm)												
11 pm to 5 am	*0.01*	*0.05*	*0.85*	*1.01*	0.28	0.02	0	1.32	0.20	0.02	0	1.22
12 pm to 6 pm	0.35	0.03	0	1.41	0.33	0.01	0	1.39	0.17	0.01	0	1.18

	Novice Teen (15-16y)				**Young Teen (17-19y)**				**Young Adult (20-24y)**			
	co-efficient	**std. error**	**p-value**	**Odds Ratio**	**co-efficient**	**std. error**	**p-value**	**Odds Ratio**	**co-efficient**	**std. error**	**p-value**	**Odds Ratio**
6 pm to 11 pm	0.44	0.03	0	1.55	0.34	0.01	0	1.40	0.14	0.01	0	1.15
Day of the week (Ref: weekday)												
weekend	*0.04*	*0.02*	*0.09*	*1.04*	0.03	0.01	0	1.03	0.03	0.01	0	1.03
Lighting condition (Ref: daylight)												
dark with no streetlight	*-0.08*	*0.04*	*0.06*	*0.92*	-0.07	0.02	0	0.93	*0.02*	*0.02*	*0.30*	*1.02*
dark with streetlight	-0.13	0.03	0	0.88	-0.07	0.02	0	0.93	*0.03*	*0.01*	*0.06*	*1.03*
dusk dawn	*0.09*	*0.06*	*0.11*	*1.10*	-0.07	0.03	0.02	0.93	*0.04*	*0.02*	*0.15*	*1.04*
others	*-0.16*	*0.17*	*0.34*	*0.85*	*-0.05*	*0.08*	*0.49*	*0.95*	*0.07*	*0.06*	*0.23*	*1.08*
Surface condition (Ref: dry)												
wet	0.14	0.03	0	1.14	0.18	0.01	0	1.2	0.12	0.01	0	1.13
snow/slush/ice	-1.07	0.23	0	0.34	-0.46	0.07	0	0.63	*-0.06*	*0.05*	*0.25*	*0.94*
others	*-0.01*	*0.22*	*0.96*	*0.99*	*-0.01*	*0.11*	*0.9*	*0.99*	*0.06*	*0.08*	*0.43*	*1.07*
Road characteristic												
Highway class (Ref: local)												
rural interstate	-1.29	0.15	0	0.27	-0.40	0.04	0	0.67	*-0.05*	*0.03*	*0.12*	*0.95*
rural multilane divided	-0.30	0.12	0.01	0.74	*-0.06*	*0.05*	*0.26*	*0.95*	*-0.06*	*0.04*	*0.14*	*0.94*
rural multilane undivided	*0.28*	*0.19*	*0.14*	*1.32*	*0.12*	*0.10*	*0.26*	*1.12*	*0.12*	*0.09*	*0.17*	*1.12*
rural two-lane	0.34	0.04	0	1.40	0.26	0.02	0	1.29	0.05	0.02	0.01	1.05
urban interstate freeways	-0.69	0.06	0	0.50	-0.26	0.02	0	0.77	-0.04	0.02	0.04	0.96

	Novice Teen (15-16y)				Young Teen (17-19y)				Young Adult (20-24y)			
	co-efficient	std. error	p-value	Odds Ratio	co-efficient	std. error	p-value	Odds Ratio	co-efficient	std. error	p-value	Odds Ratio
urban multilane divided	-0.28	0.04	0	0.76	-0.04	0.02	0.01	0.96	*-0.02*	*0.01*	*0.14*	*0.98*
urban multilane undivided	-0.14	0.03	0	0.87	0.03	0.01	0.02	1.03	0.04	0.01	0	1.04
urban two-lane	0.30	0.03	0	1.35	0.21	0.02	0	1.24	*0.02*	*0.01*	*0.22*	*1.02*
service/frontage road	*-0.42*	*0.24*	*0.07*	*0.65*	*-0.06*	*0.10*	*0.53*	*0.94*	*0.03*	*0.08*	*0.69*	*1.03*
ramp-exit	-0.87	0.20	0	0.42	-0.37	0.07	0	0.69	*-0.07*	*0.06*	*0.20*	*0.93*
Posted speed limit (Ref: <=25 mph)												
30 to 35 mph	-0.15	0.03	0	0.86	*0*	*0.02*	*0.79*	*1.00*	0.04	0.01	0.01	1.04
40 to 45 mph	*-0.02*	*0.03*	*0.46*	*0.98*	0.07	0.02	0	1.07	0.06	0.01	0	1.06
50 to 55 mph	*-0.06*	*0.04*	*0.11*	*0.94*	*0.03*	*0.02*	*0.16*	*1.03*	0.07	0.02	0	1.07
>=60 mph	-0.23	0.07	0	0.80	0.06	0.03	0.03	1.06	0.13	0.02	0	1.14
unknown	*-0.03*	*0.05*	*0.60*	*0.97*	*-0.01*	*0.03*	*0.81*	*0.99*	*0.01*	*0.02*	*0.50*	*1.01*
Road geometry (Ref: straight segment)												
curve segment	0.18	0.04	0	1.19	0.12	0.02	0	1.12	*0.02*	*0.02*	*0.31*	*1.02*
intersection	*-0.02*	*0.02*	*0.43*	*0.98*	-0.06	0.01	0	0.95	-0.02	0.01	0.01	0.98
intersection on curve	*0.04*	*0.07*	*0.54*	*1.04*	*-0.04*	*0.03*	*0.20*	*0.96*	-0.07	0.03	0.01	0.93
others	0.35	0.15	0.02	1.42	-0.21	0.09	0.02	0.81	*0.02*	*0.07*	*0.74*	*1.02*
Crash characteristic												
Manner of collision (Ref: rear-end)												
head on	*-0.08*	*0.09*	*0.34*	*0.92*	*-0.08*	*0.04*	*0.06*	*0.93*	-0.07	0.03	0.03	0.93
non collision	0.11	0.04	0	1.12	0.04	0.02	0.02	1.04	*0*	*0.01*	*0.91*	*1.00*

	Novice Teen (15-16y)				Young Teen (17-19y)				Young Adult (20-24y)			
	co-efficient	**std. error**	**p-value**	**Odds Ratio**	**co-efficient**	**std. error**	**p-value**	**Odds Ratio**	**co-efficient**	**std. error**	**p-value**	**Odds Ratio**
left turn	0.20	0.04	0	1.22	0.09	0.02	0	1.09	0.04	0.02	0.03	1.04
right angle	0.16	0.04	0	1.18	*0.03*	*0.02*	*0.07*	*1.04*	*0.03*	*0.02*	*0.07*	*1.03*
right turn	0.41	0.06	0	1.51	0.19	0.03	0	1.21	*0.05*	*0.03*	*0.08*	*1.05*
sideswipe opposite	-0.18	0.09	0.03	0.83	-0.36	0.04	0	0.70	-0.17	0.03	0	0.85
sideswipe same	*0.03*	*0.04*	*0.51*	*1.03*	*-0.03*	*0.02*	*0.10*	*0.97*	*-0.01*	*0.02*	*0.43*	*0.99*
others	*0.04*	*0.04*	*0.30*	*1.05*	-0.06	0.02	0	0.94	-0.06	0.02	0	0.95
Severity (Ref: PDO)												
fatal	*-0.25*	*0.18*	*0.16*	*0.78*	-0.22	0.08	0.01	0.80	*-0.06*	*0.06*	*0.29*	*0.94*
severe	*-0.09*	*0.12*	*0.44*	*0.91*	-0.16	0.06	0.01	0.85	*0.04*	*0.04*	*0.39*	*1.04*
moderate	-0.15	0.04	0	0.86	-0.12	0.02	0	0.89	-0.05	0.02	0	0.95
complaint	-0.16	0.02	0	0.85	-0.07	0.01	0	0.93	-0.04	0.01	0	0.96

Findings from the MNL model are discussed from the perspective of the crash likelihood that young driver groups present in terms of the estimated odds ratios for variable classes. The following discussions presented by variables provide useful insights that may not be discoverable from the age distribution.

- Although the frequency of male drivers in crashes is higher than female drivers across all young driver groups, crashes were 1.21 and 1.06 times more likely to be associated with female drivers with respect to male drivers in cases of novice teen and young teen drivers.
- All young driver groups are less likely to be associated with crashes due to driving under influence of alcohol, with the exception of young adult drivers' insignificantly less association of crashes with a BAC limit of 0.02-0.08 g/dL. The other significant associations corroborate with the alcohol ban with a BAC limit of 0.02 g/dL for drivers under 21 years.
- The young teen group showed 9% more likelihood (i.e., odds ratio = 1.09) to crashes due to cellphone distractions; whereas, the other two young driver groups showed insignificant association to cellphone distraction-related crashes. In reference to the "no distraction" scenario, the crash propensities due to known cellphone use of novice teen and young adult driver groups are not distinguishable. Novice teen drivers were 1.61 times likely to be at fault in crashes while using electronic devices. All three driver groups are also highly likely to be at fault in crashes by distractions due to external sources.
- Drivers in all three young driver age groups are likely to be at fault in crashes if one passenger is present, as the odds are 1.95, 1.31, and 1.06 for novice teen, young teen, and young adult groups, respectively. Only novice teen drivers can be at fault even if more than one passenger is present with the odds being 1.44. Although crashes with no passengers are most frequent across all age groups, young drivers are still more crash-prone when a passenger is present.
- Only the pickup truck among the vehicle types was found to be more associated with novice teen drivers, with 1.41 times than crashes with passenger cars. A higher risk of crashes for a 16-year-old driver driving a pickup truck was also identified in the study by Paleti et al. *[35]*
- All young driver groups are more prone to crashes when protection systems (seatbelt, helmet, etc.) are not used. Novice teen, young teen, and young adult drivers are estimated to be 1.49, 1.08, and 1.11 times more likely to be at fault in crashes while driving without a protection system than with a protection system in

use.

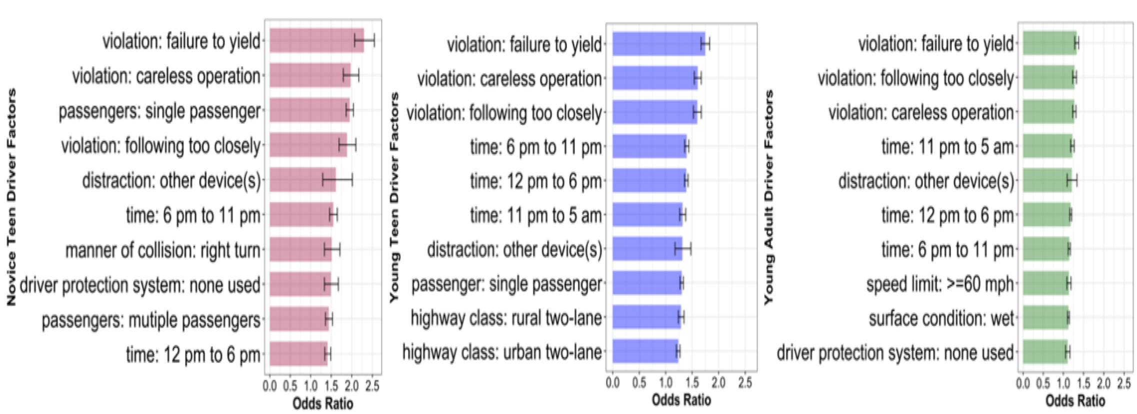
- All young driver groups were found to be heavily associated with crashes due to driving violations in reference to the 'no violation' scenario. 'Failure to yield' turns out to be linked with a higher likelihood of young driver crashes than other driving violations.
- Driving during the hours of 11 pm to 5 am comes with passenger restriction for novice teen drivers in the GDL program. Interestingly, an insignificant association of novice teen drivers exists with crashes during this time; whereas, young teen and young adult drivers showed 1.32 times and 1.22 times higher likelihood of crashes during this time, respectively, in comparison to morning hour crashes (6 am to 12 pm). However, the novice teen group shows 1.55 times higher likelihood of crashes during 6 pm to 11 pm compared to morning time (6 am to 12 pm) crashes, indicating a high risk of crashes may still exist for inexperienced young drivers during the nighttime hours when passenger restriction is not enforced. For all young drivers, crash likelihood is also higher during the hours of 12 pm to 6 pm.
- Weekend crashes were found to be associated with young teen and young adult drivers, as estimated odds ratios showed both groups have 3% higher likelihood of crashes than weekday crashes.
- The novice teen driver group does not appear to be significantly affected by the absence of streetlights; however, they are less prone to crashes in presence of streetlights. Young teen drivers, on the other hand, are not negatively affected by the absence of daylight.
- Novice teen, young teen, and young adult drivers are 1.14, 1.2, and 1.13 times more likely to be associated with crashes on wet pavement surfaces than dry surfaces.
- In comparison to crashes on local roadways, all young driver groups showed a strong association with crashes on rural two-lane highways with odds ratios of 1.4, 1.29, and 1.05 for novice teen, young teen, and young adult groups, respectively. In terms of urban roadways, novice teen and young teen driver crashes were also found to be strongly associated with urban two-lane highways with odds ratios of 1.35 and 1.24, respectively. Both young teen and young adult drivers tend to be associated with crashes on urban multilane undivided highways with odds ratios of 1.03 and 1.04, respectively.
- Odds ratio estimates indicate that novice teen drivers are less prone to crashes on roadways with speed limits of both 30-35 mph and 60 mph or greater in

comparison to roadways with a speed limit of 25 mph or less. On the other hand, young teen drivers show 7% and 6% higher likelihood to crashes on roadways with speed limits of 40 to 45 mph and 60 mph or greater, respectively. With reference to the speed limit of 25 mph or less, young adult drivers show a gradually higher likelihood of crashes with the increase of speed limit.

- Novice teen and young teen drivers showed 19% and 12% higher likelihood to be associated with crashes on curves than crashes on straight segments, respectively.
- In reference to crashes due to the most frequent "rear-end" collision type, novice teen drivers are more prone to crashes due to right turn, left turn, right angle, and single-vehicle collisions, with the odds ratio being 1.51, 1.22, 1.18, and 1.12 respectively. For young teen drivers, crashes are more likely due to right turn, left turn, and single-vehicle collisions; whereas, young adults are only more prone to crashes due to left turn collisions. Only cross-centerline/median crashes due to sideswipe opposite direction collisions are less likely to occur to all young age groups, and head-on crashes were less likely to happen to young adult drivers.
- Property damage only (PDO) crashes overwhelmingly outweigh the likelihood of crashes resulted in other severity types—fatal, severe, moderate, and complaint.

As the estimated odds ratios listed in Table 6 present high likelihood (odds ratio > 1) of a number of characteristics with statistical significance in comparison to perceived normal and most frequent scenarios, the predominant contributing factors were identified by ordered descending odds ratios for each young driver age group with discarding factors that are "unknown" and "other." Figure 5 displays the results of the top 10 contributing factors, illustrating the ordered odds ratios and associated 95% confidence intervals in error bars. The 95% confidence intervals were estimated as $e^{(coefficient \pm 1.96 * std.error)}$.

Figure 5. Adjusted Odds Ratios of Top Ten Factors of Young Driver Groups



The error bar plots are presented in Figure 5 with average odds ratios of top 10 factors for novice teen, young teen, and young adults of 1.71, 1.42, and 1.2, respectively, indicating higher crash-proneness of inexperienced young drivers in high-risk crash scenarios. Crash variables such as violation, distraction, passenger presence, time of the crash, driver protection system are featured in multiple young driver groups in Figure 5. Three driving violation-related factors —"failure to yield," "careless operation," and "following too closely"—appear in all three young driver groups with the highest odds. Being at fault in crashes due to distraction from electronic devices other than cellphones is also common for all three groups with relatively high variability, i.e., bigger confidence interval. All three young drivers appear to be at fault in crashes with higher than 1 odds while driving during midday to 11 pm (categorized in two intervals—6 pm to 11 pm and 12 pm to 6 pm).

Several predominant factors are present in two driver age groups. Both young teen and novice teen drivers have high odds to be at fault in crashes when they drive with a single passenger. Driving during the hours of 11 pm to 5 am is associated with both young teen and young adult drivers. Among the top 10 factors, both novice teen and young adult drivers have been associated with non-use of driver protection system.

Time Series Analyses

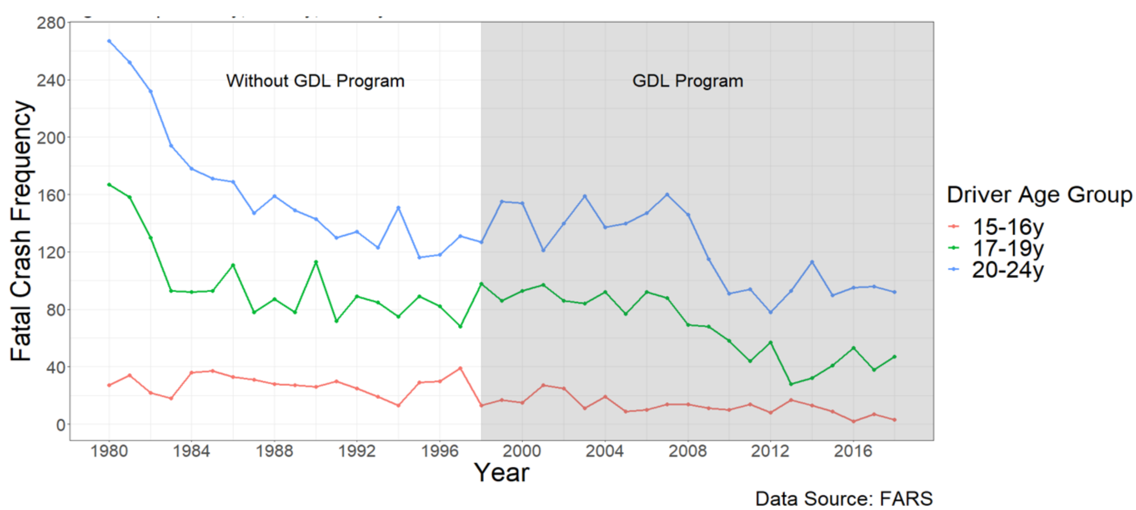
With an overarching goal of evaluating the GDL program, several approaches have been undertaken to analyze the sequence of young driver crash frequency data. In addition to describing the line charts of the annual crash data of age group and specific characteristics and driver cohorts of different generations, seasonal Mann-Kendall (M-K) tests and Innovative Trend Analysis (ITA) were applied to detect the trend by statistically analyzing and visualizing the disaggregate monthly data, respectively. Finally, relative effects of legislative changes due to intervention associated with GDL policies on the time series data of young driver crashes and casualties were examined with the seasonal autoregressive integrated moving average with explanatory variable, also known as the SARIMAX model.

Descriptive Analysis of Young Driver Crash Trends

The aim of the descriptive analysis of crash trends is to track the crash frequency or rates involving young driver groups and associated important attributes over the years. Besides, it provides an initial impression of future crash trajectories emphasizing the initial guidance of countermeasure development. Aggregate or yearly data have been used to preliminarily describe the young driver crash trend, as the transportation agencies such as DOTD commonly use annual frequency data to set safety plans for countermeasure implementation.

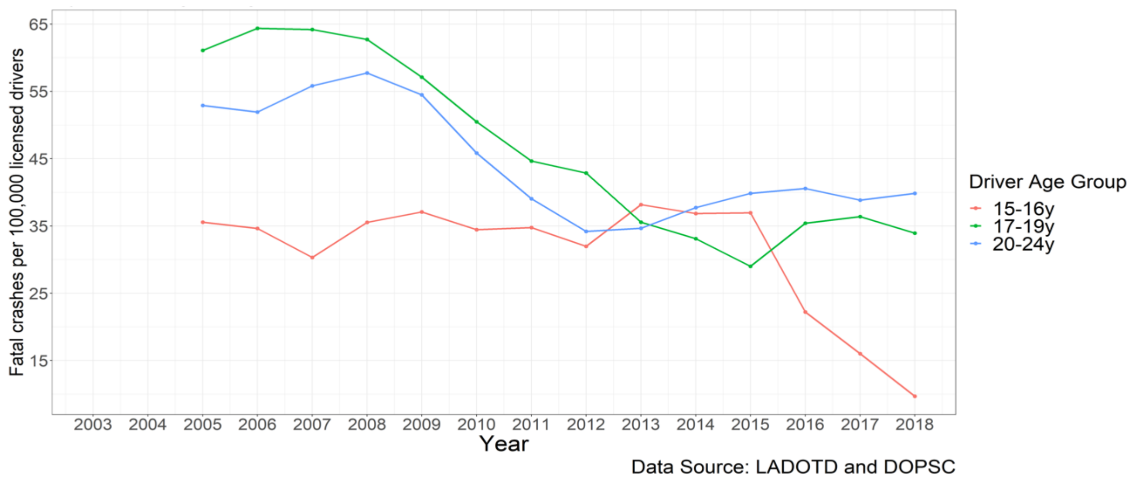
The Trend of Age Group and Gender: In annual fatal crash frequency comparison of the previously defined three young drivers presented in Figure 6, all three groups—novice teen (15-16 years), young teen (17-19 years), and young adult (20-24 years) drivers—appear to have a decreasing trend in at fault crashes in general. The line charts representing 39-year-long (1980-2018) data show many fluctuations possibly associated with the randomness of fatal crashes but clearly indicate visible large reductions in crashes both overall (i.e., from the 1980s to 2010s) and during the post-GDL period (1998 and after). Interestingly, fatal crash frequency initially increased following the inception of the GDL program in 1998 to up to 2007/2008 for young teen and young adult drivers. The difference in frequencies among the three groups is most possibly associated with their population of drivers, as Table 5 also presented disproportionate total crash frequencies among young driver age groups.

Figure 6. Annual Trend of Fatal Crash Frequency with Young Drivers at Fault (1980-2018)



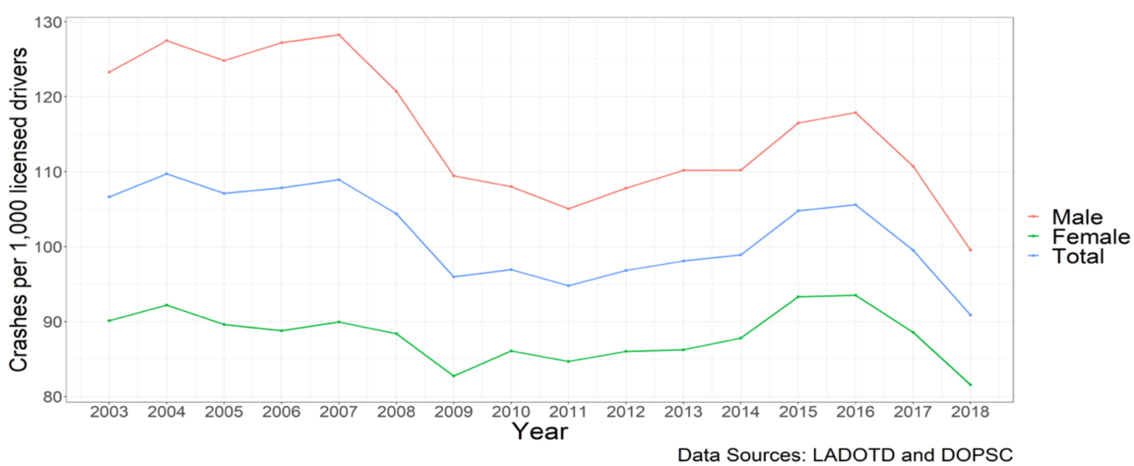
Due to the absence of the annual driver population data distributed by age for 2002 and prior years, fatal crash frequencies could be normalized by respective young driver population only for 2003 and the following years. The three-line chart presented in Figure 7 displayed a three-year moving average of fatal crash rates for the same three driver age groups. A decreasing trend can be seen in general and especially for novice teens in recent years; however, fatal crash rates of the young adult group (20-24 years) showed an increase after 2012 and appeared to become higher than the crash rates of the young teen group (17-19 years) in 2014 and onwards.

Figure 7. Three-Year Moving Average of Fatal Crash Rates of Young Drivers (2005-2018)



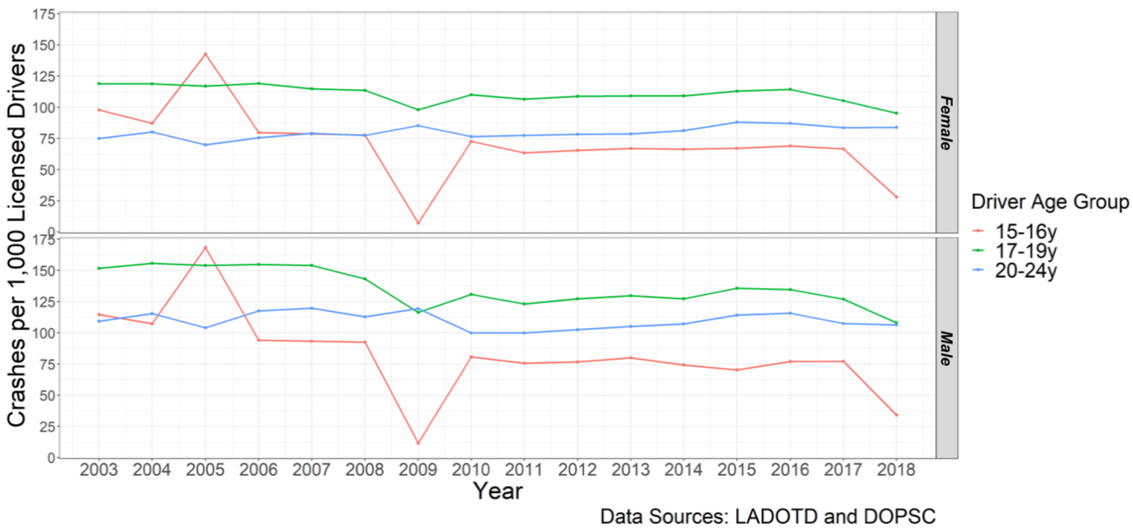
When moving average is not considered between 2003 and 2018, total young driver crash rates showed a decreasing trend in general and in recent years; however, an increase can be seen during 2012-2015 (Figure 8). Despite having an almost equal share of the driving population over the years, female young drivers have been continuously less at fault in terms of fatal crash rates compared to male drivers, which may be partly attributed to their fewer driving hours as discussed earlier. However, both these groups showed trends visibly very similar to all young drivers—a decline overall and in recent years.

Figure 8. Annual Trend of Crash Rates of Young Drivers (15-24 Years) by Gender



When separated by the age groups, young drivers of both genders show a quite similar crash pattern over 2003-2018, as displayed in Figure 9. The young teen group had higher crash rates than two other age groups in general for both male and female drivers. Both the male and female novice teen group crash rates leaned towards an overall decrease albeit exhibiting positive and negative peaks in 2005 and 2009, respectively. Female young adult drivers showed an increase overall.

Figure 9. Annual Trend of Crash Rates of Male and Female Young Drivers by Age Group



Overall, noticeably large reductions in crash frequency and rate with novice teen drivers at fault can be observed from the comparison of statistics from the earliest to the latest years in the analysis as presented in Table 7. Crashes with young teen drivers also declined; however, the recent increase in crashes with young teen drivers at fault can be identified from the previous plots (Figures 6-9). Relatively smaller reductions in young adult driver crash rates and an increase in crash rates of their female groups are notable.

Annual average crash reductions also showed a similar picture for young teen drivers—reduction in crashes for all statistics presented. However, despite an overall decline in male novice teen, male young adult, and female novice teen driver crashes, an annual average increase in crashes for those driver groups presents inconsistencies in crash reductions.

Table 7. Crash Reduction by Age Group in comparison to Licensed Driver and by Gender

Reduction Type	Statistics of Young Driver	Years	Age Group			Additional Information
			Novice Teen	Young Teen	Young Adult	
Overall Reduction	Licensed Drivers	2003-2018	0.84%	-0.84%	-1.04%	
	Fatal Crash Frequency	1980-2018	88.89%	66.47%	59.92%	
	3-Year Moving Average of Fatal Crash Rates	2005-2018	72.75%	44.47%	24.67%	
	Male Crash Rates	2003-2018	70.24%	28.82%	2.70%	All young Drivers: 19.72%, Male young drivers: 19.26%, Female Young Drivers: 9.50%
	Female Crash Rates	2003-2018	71.36%	19.96%	-11.87%	
Average Annual Reduction	Licensed Drivers	2003-2018	0.12%	-0.12%	-0.15%	
	Fatal Crash Frequency	1980-2018	-8.45%	0.74%	1.94%	
	3-Year Moving Average of Fatal Crash Rates	2005-2018	7.6%	3.97%	1.82%	
	Male Crash Rates	2003-2018	-30.74%	1.94%	-0.08%	All young Drivers: 1% Male Young Drivers: 1.31%, Female Young Drivers: 0.59%
	Female Crash Rates	2003-2018	-51.03%	1.3%	-0.96%	

Note: "-" implies increase and no sign implies reduction

The Trend of Young Driver Crash Rates by Cohorts: Aiming to evaluate the combined effect of GDL programs and associated young driver safety programs, the safety of the age groups in terms of annual rates of crashes can be tracked for the same cohort from year 1 (15-year-old) to year 10 (24-year-old). Based on the available driver population data by age group, the two comparable cohorts of young drivers parted by longest time are both from the post-GDL period—relatively older generation of young driver group aged 15 in 2003 and the younger driver group aged 15 years in 2009.

From the comparison of the two driver age groups (Figure 10), it appears that drivers of six-year-older cohorts had higher crash rates during their teenage driving years, somewhat equal rates during ages 20-21 years, and relatively lower crash rates in the ages of 22-24 years. This could be indicative of progression towards safety improvement due to the implementation of GDL and other associated safety programs specifically during early driving and teen years. However, crash rates of younger cohorts during their age of 22-24 years compared to older cohorts are higher. The breadth of the data, however, is relatively small considering the younger cohorts did not include the GDL inception stage (i.e., 2003). A longer-term trend would have provided a more solid and conclusive indication on whether the impact of the combination of the GDL program and other associated young driver safety programs over the years had been effective.

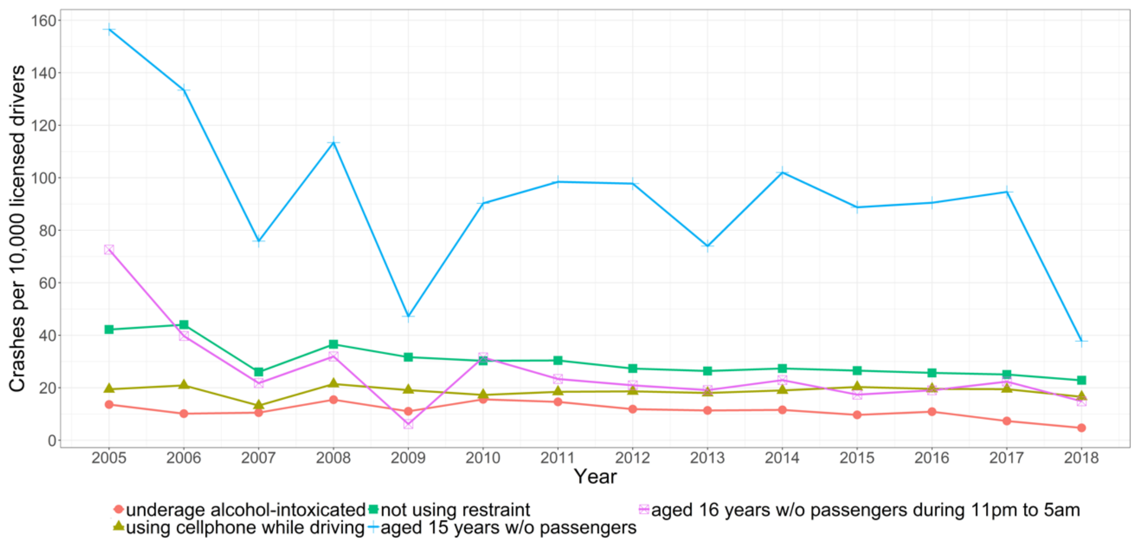
Figure 10. Trend of Crash Rates of Two Young Driver Population Cohorts

The Trend of Key Selected Crash Characteristics: Facilitated by the understanding of the detailed literature review from white papers and other gray literature regarding young driver crash characteristics and GDL program, the research team prioritized to descriptively analyze (in addition to the crash rates segregated by age group) the time trends of rates of crashes involving young drivers at fault who were:

- underage and alcohol-intoxicated,
- reported to have used cellphone,
- not using restraint,
- aged 15 years and driving without passengers, and
- aged 16 years and driving without passengers during the hours of 11 pm to 5 am

Analysis of the time trend of the first three characteristics is aimed towards understanding the safe driving behaviors of young drivers; whereas, the trend exploration of the last two crash conditions would hint at the GDL enforcement of unfavorable driving condition exposure of specific young driver age groups. Figure 11 is illustrating trends of crash characteristics in order with related descriptions. Crash rates presented in the figure have been estimated in 10,000 licensed drivers.

Figure 11.Trend of Young Driver Crash Rates of Selected Characteristics



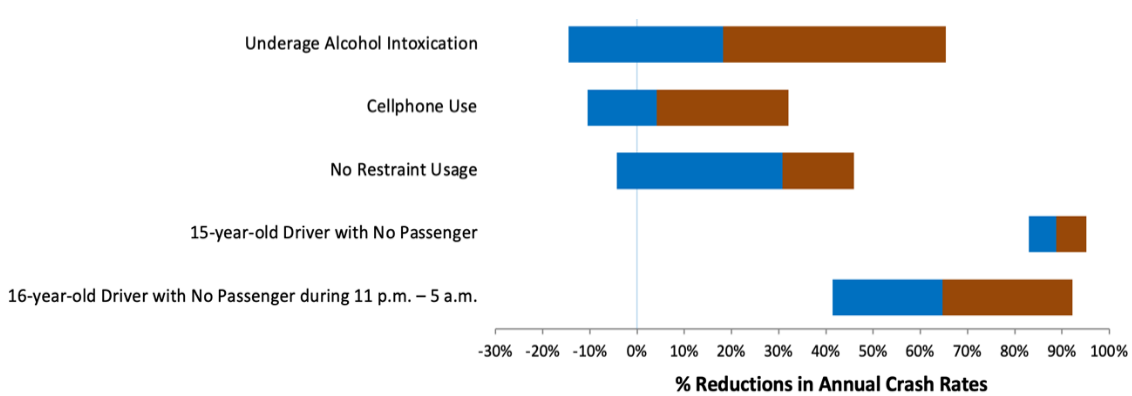
Alcohol-impaired driving has been prioritized as one of the key addressable areas in Louisiana's strategic transportation safety development plan, as fatalities and severe injuries resulted from this unsafe driving behavior have not declined in recent years *[4]*. The percentage of alcohol-related annual fatalities in Louisiana has exceeded to consistently stay over the national average for more than a decade. Underage (drivers aged 20 years or less) alcohol driving is specifically a more serious concern. The trend of crash rates due to underage (15-20 years) alcohol intoxication (BAC ≥ 0.02 g/dl) presented in Figure 11 however shows a decline in general in recent years (2017-18), relatively high but fluctuating crash rates during 2005-10. Louisiana's underage alcohol-impaired driving fatalities per 100,000 population was 1.7, till almost 55% higher than the national average in 2018.

Although underreported, it is important to track cellphone-related young driver crashes, partly because the widespread cellphone use has been a critical distracting element for at least more than a decade and has often been associated with high risk for young drivers. As presented in Figure 11, the estimated crash rates annually from reported cellphone use by young drivers at fault have generally shown a decreasing trend since 2015, with fluctuating rates between 2005 and 2010.

Along with alcohol intoxication and cellphone use while driving, non-usage of restraint is another important issue that has often been linked with young drivers. Figure 11 shows a general decline in “no restraint” crashes with young drivers, especially from 2008 to 2018. This result is somewhat reflective of increasing weighted rates of seatbelt use estimated from sampled observation of Louisiana drivers—a 9.8% increase estimated from the annual data extracted from the 2019 statewide report of seatbelt use survey *[74]*. Here it was assumed that increasing seatbelt use by young drivers should at least be consistent with the seatbelt use weighted for the total driving population, as the educational and enforcement measures for seatbelt use are targeted more at teen and young drivers.

Under the GDL program in Louisiana, drivers aged 15 years are not allowed to drive without an adult passenger aged 21 years. From 2005, the annual crash rate trend of 15-year-old drivers appear to decrease in general with visible fluctuations in the years in between (Figure 11). The multiple ups and downs in crash rates are not entirely unexpected considering the relatively small frequency of crashes involving a small driver demographic. Drivers who are in the intermediate license stage (i.e., stage 2) of the GDL program, typically 16-year-olds are not allowed to drive during nighttime, specifically during the hours of 11 pm to 5 am. Crash rates for this specific driver population subgroups during this time interval are also in decline (Figure 11).

Figure 12. Average and Range in Annual Crash Rate Reductions Involving Key Young Driver Issues



Note: “-” implies increase and no sign implies reduction

M-K Test Results and ITA Plots for Trend Detection

As descriptive analyses provided an overview of changes in crashes and crash rates related to young drivers based on aggregated crash count data, disaggregated crash data were used to statistically quantify the gradual changes in those crash characteristics. The trend detected with monthly crash rates normalized by driver population would have provided a more accurate picture; however, analyzing monthly crash frequency data for trend detection is considerably important. Based on the data availability, seasonal M-K tests were run on monthly total and additionally for FI (fatal and injury) crash frequency for young driver age groups for the period of 1990/1991-2018 and also separately for pre-GDL and post-GDL timelines and on the monthly crash frequency of selected young driver characteristics for the period of 2005-2018.

According to the value and sign of trend magnitude ($\hat{S}$) and p-values estimated from the two-tailed test on the z-statistics (Appendix B), both total as well as FI crashes showed decreasing trends during the combined pre- and post-GDL period for novice teen and young teen drivers. Total crashes involving young adult drivers at fault showed an increasing trend, but their FI crashes showed an insignificant decreasing trend magnitude. During the pre-GDL period, total as well as fatal and injury crashes increased significantly for all young driver age groups. During the post-GDL period, FI crashes declined significantly; whereas, results showed a significant decreasing trend except for total crashes involving young adult drivers at fault.

Detailed results of M-K tests by age group are presented in Appendix B and summarized results are in Table 8 in which positive and negative signs indicate monotonic increase and decrease, respectively. Coinciding with the results of average crash reductions from aggregated crash counts of selected characteristics (Figure 12), seasonal M-K tests also showed a significant monotonic decrease in total crashes regarding every crash characteristic investigated. Additionally, fatal and injury crashes involved with those characteristics also showed a monotonic decrease.

Table 8. M-K Test Results Summary

Crash Type	Time period	Total Crashes	Fatal & Injury Crashes
Novice Teen (15-16 Years)	Pre-GDL (1990[a]/91[b]-1997)	(+)[s]	(+)[s]
Novice Teen (15-16 Years)	Post-GDL (1998-2018)	(-)[s]	(-)[s]

Crash Type	Time period	Total Crashes	Fatal & Injury Crashes
Novice Teen (15-16 Years)	Overall (1990[a]/91[b]-2018)	(-)[s]	(-)[s]
Young Teen (17-19 Years)	Pre-GDL (1990[a]/91[b]-1997)	(+)[s]	(+)[s]
Young Teen (17-19 Years)	Post-GDL (1998-2018)	(-)[s]	(-)[s]
Young Teen (17-19 Years)	Overall (1990[a]/91[b]-2018)	(-)[s]	(-)[s]
Young Adult (20-24 Years)	Pre-GDL (1990[a]/91[b]-1997)	(+)[s]	(+)[s]
Young Adult (20-24 Years)	Post-GDL (1998-2018)	(-)	(-)[s]
Young Adult (20-24 Years)	Overall (1990[a]/91[b]-2018)	(+)[s]	(-)
All Young Drivers (15-24 Years)	Pre-GDL (1990[a]/91[b]-1997)	(+)[s]	(+)[s]
All Young Drivers (15-24 Years)	Post-GDL (1998-2018)	(-)[s]	(-)[s]
All Young Drivers (15-24 Years)	Overall (1990[a]/91[b]-2018)	(-)	(-)[s]
Underage (15-20 Years) Alcohol Driving	2005-2018	(-)[s]	(-)[s]
Cellphone Use for Young Drivers (15-24 Years)	2005-2018	(-)[s]	(-)[s]
No Restraints for Young Drivers (15-24 Years)	2005-2018	(-)[s]	(-)[s]
15-Year-Old-Drivers with No Passenger	2005-2018	(-)[s]	(-)[s]
16-Year-Old-Drivers with No Passengers during 11 pm - 5 am	2005-2018	(-)[s]	(-)[s]

[a] Time period for total crashes

[b] Time period for fatal & injury crashes

[s] Statistically significant

In addition to supplementing and comparing with the results M-K tests, the ITA plots were aimed to visualize the monthly crash data in a simplified manner without considering the seasonal effects. From the ITA plots generated from the ordered monthly crash frequencies for total crashes and FI crashes, the following observations can be made:

- *Pre-GDL:* During the pre-GDL period, all three age groups showed a consistent increase in total crashes (Table 9) and FI crashes (Table 10) coinciding with the results of seasonal M-K tests.

- *Post-GDL:* During the post-GDL period, novice teen and young teen drivers showed a decrease both in total and FI crashes. However, for young adults the scenario is slightly different, especially total crashes involving them showed a small cluster of increase in low values in contrast with the overwhelming majority of the rest of the points. The seasonal M-K test found this post-GDL decrease insignificant.
- *Overall:* When the combined period (1990/91-2018) is considered for analysis, except for a few points in high values, novice teens showed an increase unlike the rest of the points in that graph. The same plot for young adults also implies a somewhat increasing trend as the large portions of the low and medium values are more in the second half than the first half, and the seasonal M-K test also implied a significant increase. A cluster of high values for young adults in ITA plots can be seen as unchanged; whereas, the rest of the points showed an increase. The seasonal M-K test found the increase significant. In the case of FI crashes with young adults at fault, the seasonal M-K test found the decrease insignificant although the ITA plots only showed the lowest value above the 1:1 line. For all young drivers' total crashes, a composite trend is indicated with high values closely below the 1:1 line and the seasonal M-K test implied this decrease insignificant. In the plots of FI crashes of all drivers, the majority of the medium and high values posit further below the 1:1 line compared to the plot of their plot of total crashes, and the seasonal M-K test estimated this as a significant decrease.

With some mixed results for the overall combined period, the ITA plots present considerably similar results considering the fact that the seasonal effect has not been taken into account in this method.

Table 9. ITA plots of Total Crashes by Age Group

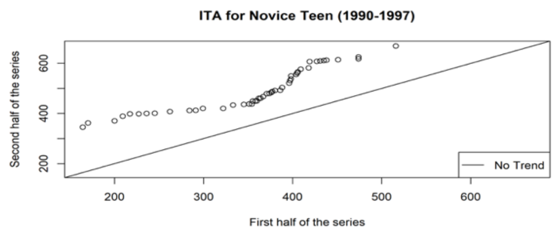
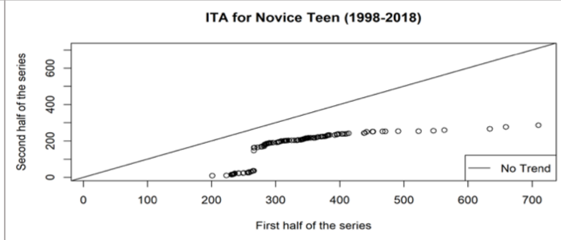
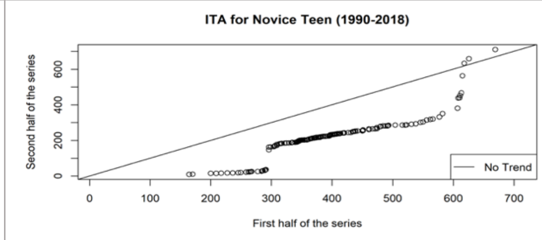
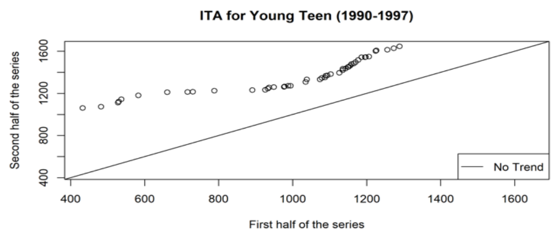
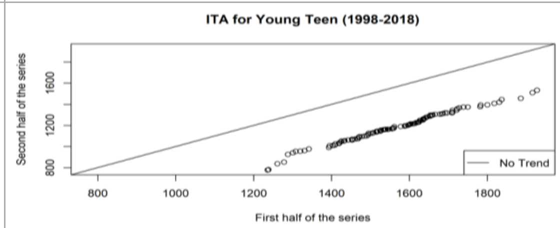
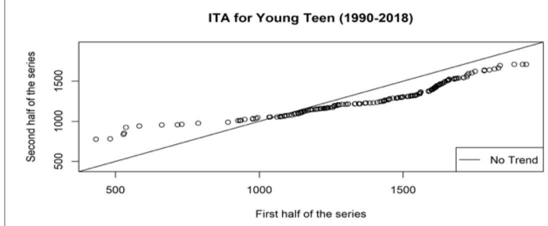
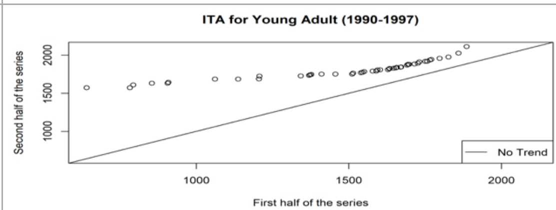
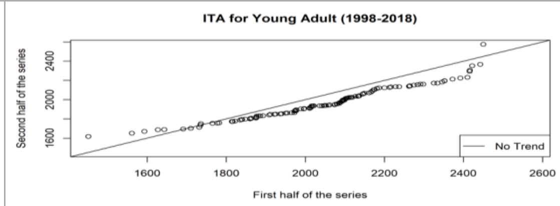
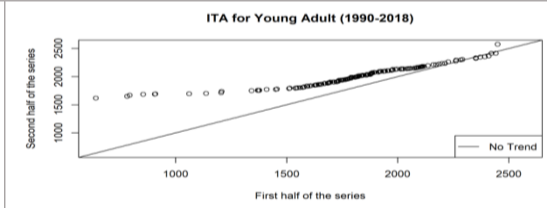
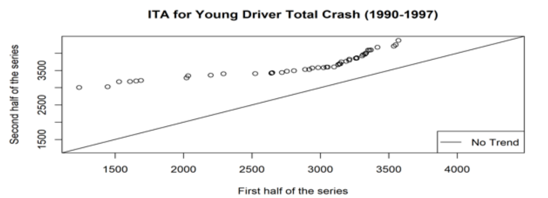
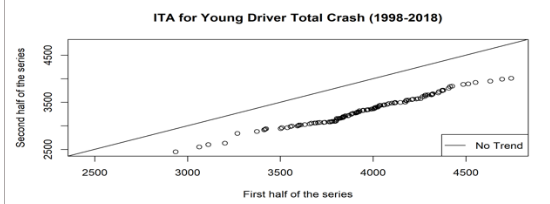
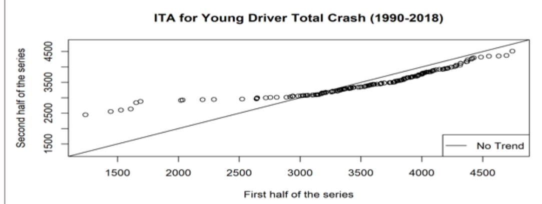
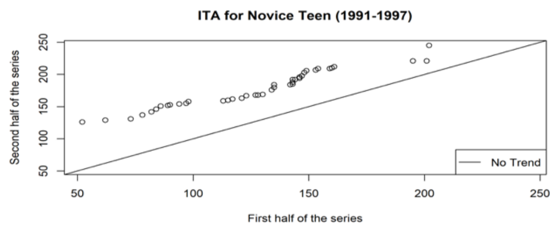
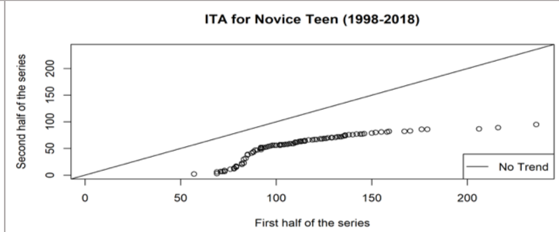
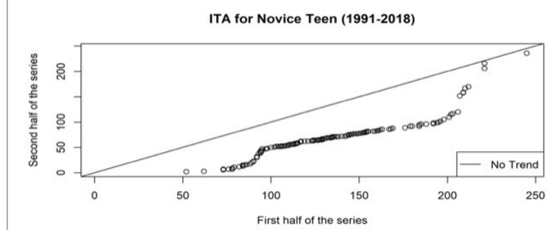
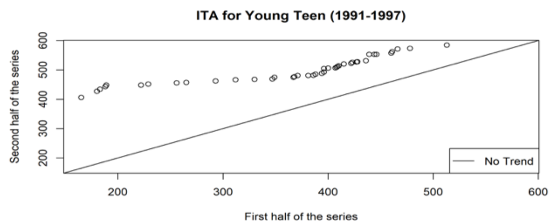
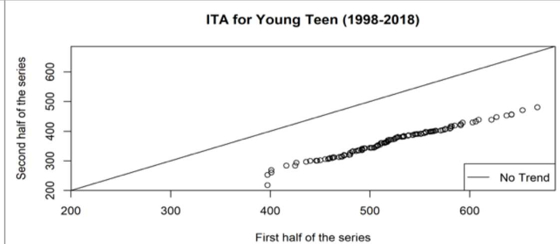
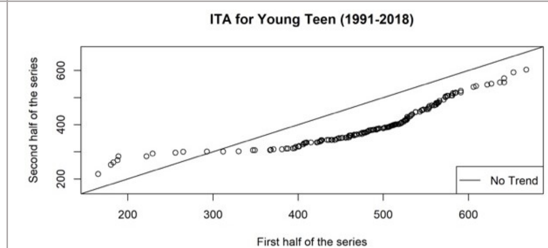
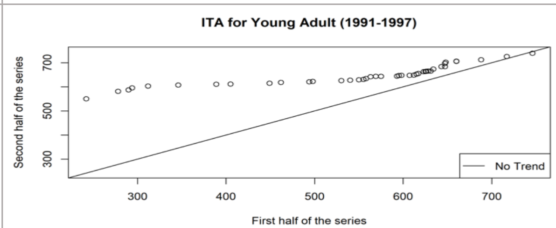
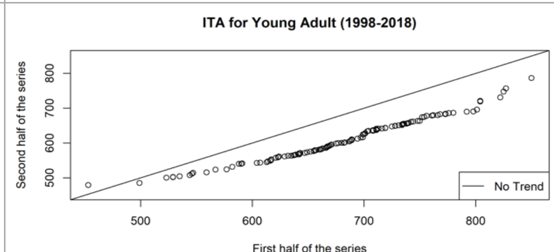
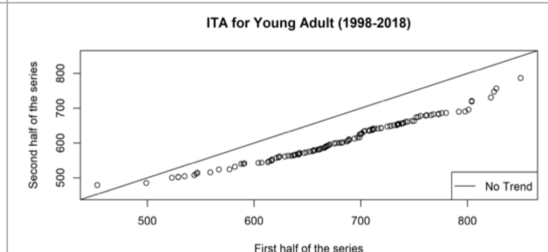
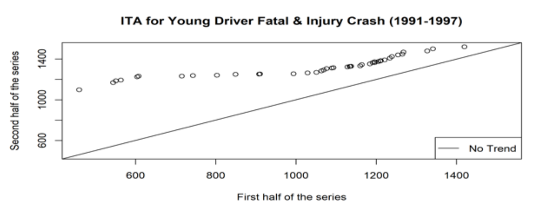
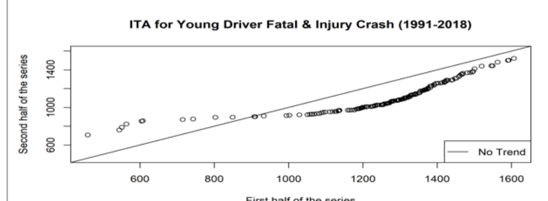
	Pre-GDL period (1990-1997)	Post-GDL period (1998-2018)	Overall (1990-2018)
Novice Teen (15-16 Years)			
Young Teen (17-19 Years)			
Young Adult (20-24 Years)			
All (15-24 Years)			

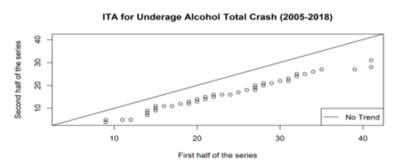
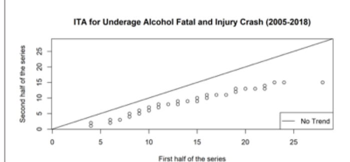
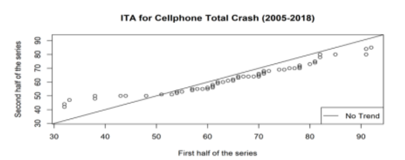
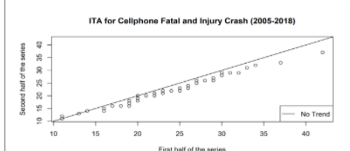
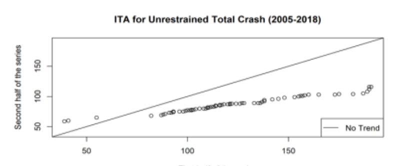
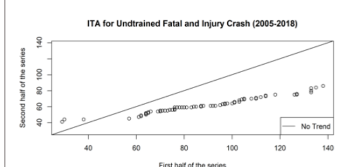
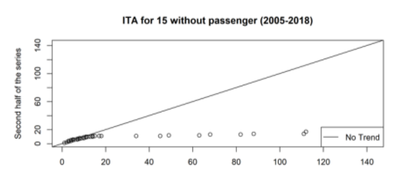
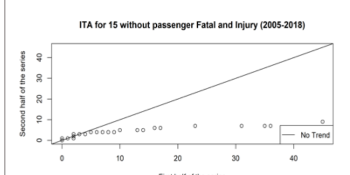
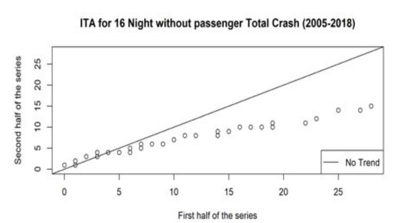
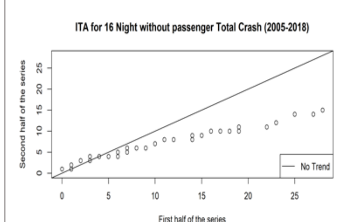
Table 10. ITA plots of Fatal and Injury Crashes by Age Group

	Pre-GDL period (1991-1997)	Post-GDL period (1998-2018)	Overall (1991-2018)
Novice Teen (15-16 Years)			
Young Teen (17-19 Years)			
Young Adult (20-24 Years)			
All (15-24 Years)			

Analyses with selected characteristics were only performed based on the available data; therefore, data before and after the GDL could not be compared for these characteristics. All characteristics selected for analyzing the time trend have shown a declining trend in the seasonal M-K trend test. ITA plots showed similar results; however, some low values showed increases.

Matching with the visible yearly trend, seasonal M-K tests and ITA plots on monthly crash frequency data also showed declines. Additionally, when only FI crashes on those specific characteristics are considered in seasonal M-K tests and ITA plots on monthly data, a substantial decrease can also be identified for all cases (Table 11).

Table 11. ITA plots of Total and FI Crashes of Young Drivers' Selected Characteristics

Characteristics	Total Crashes	Fatal & Injury Crashes
Underage Alcohol Driving		
Cellphone Use		
No Restraints		
15 Years with No Passengers		
16 Years with No Passengers during 11 pm - 5 am		

Time Series Model Results

In time series models, seven intervention variables and one control variable have been used as the explanatory variables. The intervention variables are legislative changes regarding GDL programs presented in Table 3—all of which have been assumed as individual step functions. The control variable is the total annual and monthly young driver crashes (with conditions specified by age group or time). The response variables in the time series models are annual and monthly fatalities and injuries with young drivers at fault for ARIMAX and SARIMAX models, respectively. The effect of interventions has been assessed through several models for all young drivers and young drivers by previously defined three age groups. Assessments have also been performed through models of nighttime (11 pm - 5 am) crashes for all young drivers and drivers aged 15-17 years.

The analytic model results from crash data of 1991-2018 have not been used for a predictive purpose. They have rather been utilized for interpretation of specific GDL law changes in Louisiana based on the coefficients with p-value < 0.05. It should also be noted that the crash reductions identified to be connected with legislative changes but may not be definitively resulted from them. To some extent, the changes in crashes as interpreted from the coefficients in the models may also have been impacted by continuous young driver safety improvement measures (e.g., educational safety campaigns), and other external factors such as recession or changes in gasoline price, etc.

The interpretations of results have more been directed from SARIMAX models performed with disaggregated data, as the timeline (Table 3) reflects more accurately from monthly data. The SARIMAX model results are presented in Table 12 and the ARIMAX model results have been presented in Appendix C. The results are summarized below:

- The best SARIMAX model of casualties of crashes with young drivers is $(2,1,3) \times (2,0,0)_{12}$. It implies that the best model has two non-seasonal autoregressive (ar) components, three non-seasonal moving average (ma) components, and two seasonal autoregressive (sar) components. It has first order non-seasonal difference, but no seasonal moving average components considering a seasonality of 12 months. The best ARIMAX model is (0,1,0), with only first order of non-seasonal difference and no autoregressive components, and no non-seasonal moving average components.

- Apart from one significant moving average parameter and one significant seasonal moving average parameter in the SARIMAX model, both models generated the same qualitative results—the control variable (annual and monthly crash counts respectively) and one intervention variable (GDL implementation) have been found significant. In both cases, GDL implementation with its core components in 1998 appears to have contributed to a reduction of casualties of crashes (a negative sign of coefficient) with young drivers at fault.
- In SARIMAX models (Table 12), GDL implementation can be seen to have contributed to a reduction in casualties associated with crashes with novice teen and young teen driver at fault; whereas, the result is not significant for young adult. If only results of one control variable and all the intervention variables are compared between ARIMAX and SARIMAX models of all three young driver groups without considering crashes during a particular driving hour, the results are qualitatively not similar. Reduction in casualties occurred in crashes with young adult drivers at fault is not significant. Model results from both aggregated and disaggregated time series data indicate the legislative change of cellphone use in 2008 was found to have a positive impact on young teen drivers.
- Young drivers' (both all young drivers and minors) nighttime crash casualties specifically have been effectively reduced in connection to GDL implementation as per the SARIMAX results. The legislative changes in 2008 may have contributed to the reduction of these monthly nighttime casualties as well.
- Implementation of GDL may not be directly linked to the reduction in nighttime (11 pm - 5 am) monthly casualty reduction due to crashes with novice teen at fault. However, these reductions have been found to be connected to law changes with statistical significance in 2008 (cellphone ban).
- The combination of extension of instructional hours (both on-road and in-class) in the GDL program and minor change in passenger restriction (possibly for novice teen drivers) could not be linked to crash casualties of nighttime driving. However, they may have been reflected to be effective in overall young teen drivers' crash casualty reductions. And individual effects of these changes are difficult to measure.

Table 12. SARIMAX Models on Disaggregated Time Series Data (1991-2018)

Driver Age	Young Drivers (15-24 Years)		Novice Teen (15-16 Years)		Young Teen (17-19 Years)		Young Adult (20-24 Years)		Drivers aged 15-17 Years at 11pm-5am		Young Drivers (15-24 Years) at 11pm-5am	
Best Model	$(2,1,3) \times (2,0,0)_{12}$		$(0,1,1) \times (0,0,0)_{12}$		$(4,1,2) \times (2,0,0)_{12}$		$(4,1,2) \times (2,0,0)_{12}$		$(1,1,3) \times (0,0,0)_{12}$		$(2,1,2) \times (1,0,0)_{12}$	
	Coeff.	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**
ar1	0.496	0.207	–	–	-0.442	0.121	*0.811*	*<0.001*	-0.266	0.256	-0.39	0.193
ar2	-0.124	0.613	–	–	*0.376*	*<0.001*	0.121	0.111	–	–	*0.156*	*0.018*
ar3	–	–	–	–	0.017	0.844	*-0.177*	*0.024*	–	–	–	–
ar4	–	–	–	–	-0.041	0.601	-0.083	0.208	–	–	–	–
ma1	*-1.169*	*0.002*	*-0.999*	*<0.001*	-0.308	0.271	*-1.596*	*<0.001*	*-0.72*	*0.002*	-0.437	0.144
ma2	0.477	0.299	–	–	*-0.691*	*0.013*	*0.635*	*<0.001*	-0.12	0.611	-0.524	0.067
ma3	-0.249	0.08	–	–	–	–	–	–	*-0.159*	*0.005*	–	–
sar1	*0.219*	*<0.001*	–	–	0.099	0.088	*0.174*	*0.008*	–	–	*0.189*	*0.002*
sar2	*0.165*	*0.005*	–	–	0.087	0.149	*0.124*	*0.04*	–	–	–	–
ln(Monthly Crash Count)	*1.008*	*<0.001*	*0.96*	*<0.001*	*0.955*	*<0.001*	*1.042*	*<0.001*	*0.937*	*<0.001*	*0.921*	*<0.001*
GDL Implementation	-0.051	0.064	*-0.121*	*0.003*	*-0.101*	*<0.001*	-0.039	0.169	*-0.189*	*0.008*	-0.059	0.196

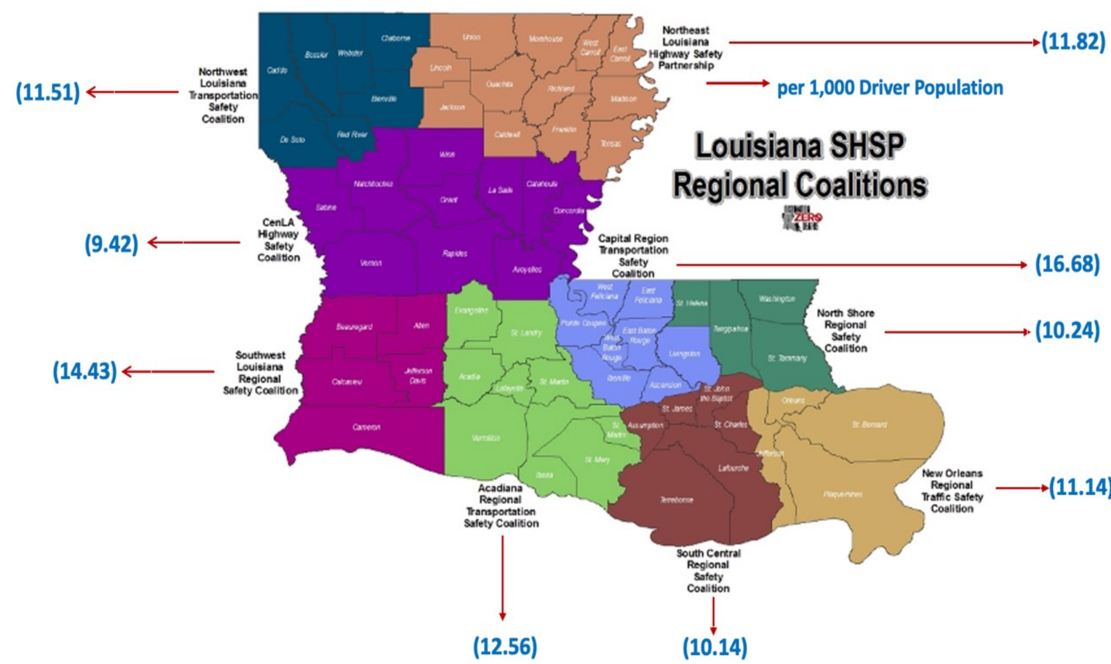
Driver Age	**Young Drivers (15-24 Years)**		**Novice Teen (15-16 Years)**		**Young Teen (17-19 Years)**		**Young Adult (20-24 Years)**		**Drivers aged 15-17 Years at 11pm-5am**		**Young Drivers (15-24 Years) at 11pm-5am**	
Learners Policy Change 1	0.028	0.288	0.039	0.458	0.029	0.347	0.019	0.498	0.051	0.579	-0.012	0.796
Learners Policy Change 2	-0.01	0.703	0.009	0.838	0.006	0.806	-0.015	0.591	0.067	0.396	0.008	0.834
Holding Period Extension	0.001	0.953	-0.006	0.856	-0.037	0.094	0.016	0.568	-0.087	0.147	-0.027	0.459
Cellphone Ban	-0.012	0.662	-0.064	0.112	*-0.062*	*0.009*	0.007	0.819	*-0.147*	*0.032*	*-0.087*	*0.024*
Passenger Restriction + Increase of On-Road Instruction Hours + Supervised Hours Extension	0.011	0.691	*0.104*	*0.002*	*-0.061*	*0.004*	0.04	0.197	-0.005	0.931	-0.025	0.509
Log-likelihood	572.32		136.93		456.66		506.50		-7.49		307.58	

Note: ar: Autoregressive parameter values; ma: Moving-average parameter values; sar: Seasonal autoregressive parameter values.

Results of Spatial Analysis

Prior to the crash analysis at the regional level, the driver population distribution is presented. The results of the distribution of driver population by nine road safety coalitions can be seen in Figure 13. New Orleans Regional Traffic Safety Coalition apparently has the highest share of the total driver population but possesses the lowest amount of lane miles. Capital Region Transportation Safety Coalition has the second highest total driver population.

Figure 13. Crash Rate of Young Drivers (2018) in SHSP Regional Traffic Safety Coalitions



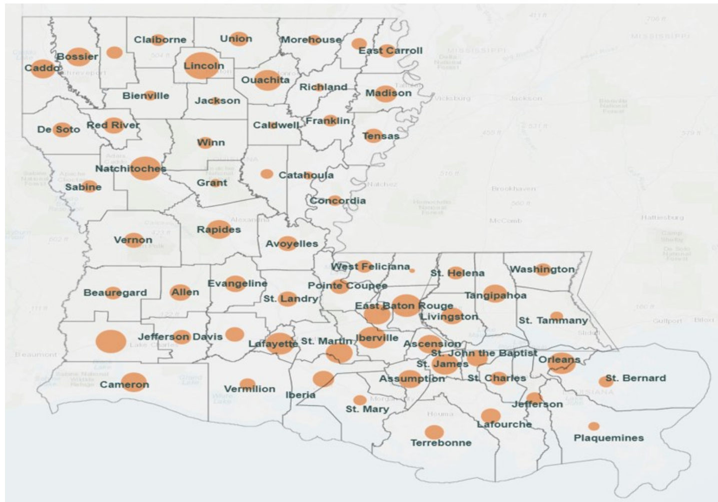
Young driver population and population density could be linked to young driver crashes; however, total driver population data have been considered as an alternate as the young driver population by parish cannot be extracted from known data sources. Although New Orleans Regional Traffic Safety Coalition apparently has the highest share of total driver population, when crash counts are normalized by the coalition's total driver population, Southwest LA and Capital Regional Traffic Safety Coalitions had the highest rates, as presented in Table 13.

Table 13. Fatal and Injury Young Driver Crash by Age Group in Safety Coalitions

Safety Coalitions	Fatal and injury crash count by age				Young driver crashes per 1,000 overall driver population
	Novice Teen	Young Teen	Young Adult	All Young Driver	
Acadiana Regional Transportation Safety Coalition	63	582	1,009	1,654	3.79
Capital Region Transportation Safety Coalition	59	733	1,463	2,255	4.42
Central LA Highway Safety Coalition	37	303	439	779	3.39
New Orleans Regional Traffic Safety Coalition	31	499	1,224	1,754	3.34
Northeast LA Highway Safety Partnership	33	305	480	818	3.74
North Shore Regional Safety Coalition	39	287	426	752	2.46
Northwest LA Transportation Safety Coalition	36	402	689	1,127	3.8
South Central Regional Safety Coalition	17	284	440	741	3.2
Southwest LA Regional Safety Coalition	28	320	580	928	4.58

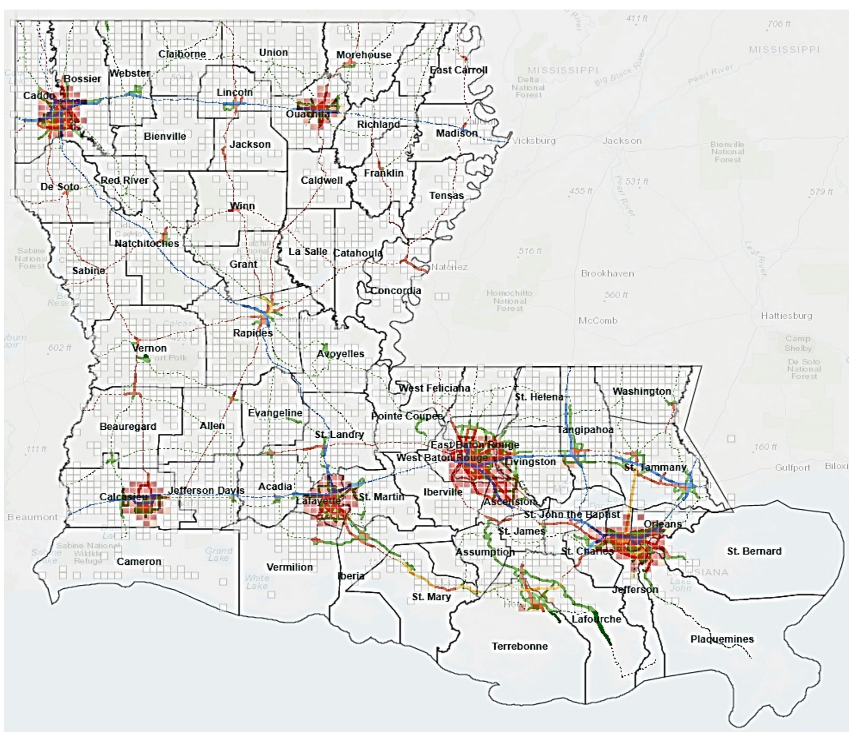
The research team also plotted the crash rates by parish to visualize the young driver crash rates estimated in 1,000 driver population on a more disaggregate level. The top 10 parishes with the highest young driver crash rates in descending order are – Lincoln, Natchitoches, Calcasieu, East Baton Rouge, Lafayette, Iberville, Orleans, Ouachita, St. James, and St. Martin. Crash rates by parish can be visualized in Figure 14.

Figure 14. Visualization of Young Driver Crash Rates by Parish



Young driver crash hotspots have been identified and presented in the Louisiana map (Figure 15) extracted from ArcGIS. The clusters with a high concentration of young driver crashes can be seen around known large cities, where the young driver population is also more concentrated.

Figure 15. Young Driver Crash Hotspots



Using the ArcTool map, six large clusters can be found from young driver crash coordinates, which are also visible in Figure 15. Table 14 presents the area of those clusters and their locations by parish. The largest cluster (cluster 5) is in and around the Capital Region Transportation Safety Coalition area (600.8 square miles). The second and third largest clusters are in New Orleans Regional Traffic Safety Coalition (cluster 6, 418.1 square miles) and in the Acadiana Regional Transportation Safety Coalition area (cluster 4, 334.3 square miles).

Table 14. Clusters of Young Driver Crashes Spread by Parish

Cluster No	Parishes	Area in square mile
1	Caddo, Bossier	259.2
2	Ouachita	176.5
3	Calcasieu	226.5
4	Lafayette, Vermilion, St. Martin	334.3
5	East Baton Rouge, West Baton Rouge, Iberville, Ascension, Livingston	600.8
6	Orleans, Jefferson, St. Charles, Plaquemines	418.1

Two main takeaways were identified from the spatial analysis. First, the identification of hot spots reveals that urban areas more specifically neighboring areas of urban interstates are the areas with higher young driver crash frequency. These crash clusters of young drivers are centering around the highly populated areas coincided with the large population of drivers. Second, Capital and New Orleans Transportation Safety Coalition possess the highest concentration of young driver crashes and can be critical for young driver safety implementation.

Countermeasures

Louisiana's current safety programs, as presented in Appendix F, are extensive enforcement programs and school-centric safety awareness campaigns against underage alcohol intoxication, distracted driving, other educational programs on educating young drivers on traffic laws (such as restraint usage), and risky driving maneuvers *[75]*. The continuation of these programs could consistently contribute to the overall reduction (as presented in Figure 11) of these specific characteristics. Devising programs targeted at specific parishes would be benefitted from the estimated rate of crash characteristics by the safety coalition (Appendix D). The initial indication of coalition-based safety countermeasures from the trend of selected key characteristics can be available from the 5-year crash trend by safety coalition from those plots.

Proposed countermeasures for Louisiana GDL programs will be targeted according to the possible contributing factors identified from crash data and GDL program evaluation analysis. Implementation of specific countermeasures may require further feasibility evaluation and support from similar case studies in other states.

Countermeasures from the Perspective of Age Group

Young driver age groups pose a different likelihood of crashes in terms of crash contributing factors despite having some similarities such as a higher number of crashes due to driving violations, nighttime driving, and using electronic device(s) while driving. According to the disaggregated time series intervention model, the impact of the GDL program and other associated policy changes also impact different groups differently. The common countermeasures especially related to enforcements against cellphone usage, alcohol intoxication, and driving violations would encapsulate all drivers including young driver groups as well.

According to the latest SHSP, the Louisiana DOTD recommends identification and developing separate safety programs targeted at the minor drivers (17 years or younger) and also the 18 to 24-year-old drivers. Logically, these two young driver subpopulations may require different safety treatments as one of them is under the GDL program and another is not. A sudden increase in exposure to high-risk driving conditions *[76]* during the early post-GDL phase (e.g., for drivers aged 18-19 years) could be among the important factors to consider for safety programs raising safety awareness.

Young adult (20-24 years) drivers had a higher moving average fatal crash rates (Figure 7), a less reduction in crash rates (Table 7), and a higher crash rates in younger cohorts during the later stages of driving (Figure 10). The combination of these findings of young adult drivers from this study corroborates the strategy mentioned in Louisiana SHSP about devising programs targeting this age group. Their high likelihood of crashes involving non-usage of restraints, nighttime driving, electronic device use, etc. (Figure 5) could narrow down the specific areas of countermeasures. Regardless of countermeasure development, it is still important to monitor crash characteristics segregated by age groups including the young teen and young adult drivers.

Countermeasure by Analysis Findings

Based on the findings procured in this study through multiple methods of analysis, countermeasures associated with the issues identified are described as follows:

- **Alcohol:** The continuation of ongoing education programs on raising awareness of young drivers against alcohol intoxication targeted at high schools and universities as well as ongoing enforcement training programs for better prevention of both young adult and underage drinking are strongly recommended. Despite the reduction of underage alcohol crashes over the years and less association with underage young driver groups (21 years or less), the continuation of educational awareness campaigns and enforcement programs targeted at this young driver demographic is substantially important since the combination of underage drinking during early years of driving could greatly increase risks and far-reaching negative effects. Special focus can be given on enforcement during the weekend and nighttime targeting teen drivers.
- **Nighttime and Weekend Crashes:** Considering the strong linkage of nighttime crashes with all young driver groups, nighttime driving for both novice teen and post-GDL drivers could still pose unsafe driving conditions. In addition to enforcement in general for preventing unsafe or aggressive driving behavior at nighttime especially during weekends that could be further compounded by alcohol or drug intoxication, strong enforcement of passenger restriction for novice teen drivers who are only allowed to drive with adult passengers could further improve safety as a higher propensity of crashes with novice teen drivers without passengers during nighttime has been identified.
- **Distraction:** Distraction due to the use of cellphone and electronic devices currently is and will continue to be an important issue in the near future. Therefore, effective enforcement of cellphone and electronic device use laws segregated by GDL stages is important to combat the growing distracted driving issues of young drivers.
- **Restraint Usage:** While restraint usage in Louisiana is on the rise, novice teen drivers still pose a higher likelihood of crashes due to its non-usage. Besides educational instructions regarding seatbelt use in the GDL program, safety campaigns encouraging the use of driver and occupant protection systems will continue benefitting the safe driving behavior of restraint usage and reducing the risk of severe crashes of young drivers.
- **Large Vehicle Maneuver:** The higher propensity of novice teen drivers'

involvement in crashes with large vehicles especially pickup trucks calls for possible inclusion of maneuvering large vehicles in the behind-the-wheel instructions for driving skill development.

Safety Programs within the Current GDL Framework

Enhanced Education Program: Both behind-the-wheel and in-class instructions within GDL can be annually updated to include the young driver safety issues identified from continuous tracking of crash characteristics. Besides the conventional defensive driving educational courses, the instructions in the classroom as part of the current GDL program can take advantage of teaching the impact of distracted driving, not wearing seatbelts, alcohol and drug intoxication, etc. One strategic approach is updating the curriculum by including the knowledge of attitude patterns linked with teen driver crashes and by also accounting for case studies of enhanced education improvement in other states or nations. The large odds of novice teen drivers (who typically are in the GDL program) in driving violation related factors (Table 6)—“failure to yield,” “careless operation,” and “following too closely”—imply there is a continuous need for improvement in road instructions within the GDL program. In addition to the customizable standardized curriculum, the inclusion of updated visual and video materials as in-class instruction supplements and in-depth training for driving instructors in the local area have been suggested.

Parental Involvement Program: Considering the high likelihood of driving violation-related crashes, parental involvement can be identified as a critical element for initial driving behavior development. Parental involvement during the provisional phase has the potential to encourage compliance with GDL restrictions and the roadway rules (cellphone use, curfew, etc.) more broadly. Parental involvement in driver education including a mandatory parent orientation class *[63]* and parental intervention program integrated with active engagement of parents have already shown success in reducing risky driving behavior *[77]*. Therefore, devising a plan to integrate parental involvement within GDL frameworks is expected to be highly beneficial. The involvement of parents during the orientation of GDL could provide novice drivers information about driver education and GDL requirements in the very early driving phase. Their continuous engagement to ensure their children’s safe driving behavior development could further be benefitted by software programs to track and notify about their driving behaviors or by comprehensive informational websites with specific pages for parents.

Conclusions

Although young driver crashes in Louisiana recently manifest a decreasing trend, their crash rate is still considerably higher than the rest of the driver population. Aimed to analyze the safety of young drivers under the Louisiana Graduated Driver Licensing (GDL) program that started in 1998 and to investigate the safety problems of young drivers for potential solutions, this project carried out a comprehensive study to investigate the unique contributing factors of young driver crashes and effectiveness of the existing Louisiana GDL program.

A group of factors has been identified as potential key contributing factors to young driver crashes based on the initial descriptive crash characteristics analysis. Further analyses with the MNL model on the three young driver age groups reveal several key associations as presented below:

- All three young driver groups are strongly associated with driving violations—"failure to yield," "careless operation," and "following too closely."
- The number of crashes caused by using cellphones and other electronic devices is significant in all young driver groups despite the rigorous restrictions on the usage of electronic devices while driving for young drivers aged 15-17 years.
- Not using a driver protection system (seatbelt, helmet, etc.) is a serious problem in too many young driver crashes.
- Young drivers are more likely to have turning-related crashes, especially left turn crashes.
- The high-speed highways are crash-prone locations for young teen and young adult drivers.
- The highest young driver crash frequency occur between noon and midnight.
- The relatively inexperienced driver groups (novice teen and young teen groups) tend to have a higher propensity for crashes on curve alignment.
- The top crash contributing factors of the young driver groups are violation, distraction, passenger presence, time of crash, and driver protection system.

Statistical Mann-Kendall tests and supplementary Innovative Trend Analysis (ITA) on monthly crash data in addition to the descriptive analysis of visual trends of annual crash data were undertaken to detect the trend of crashes associated with young driver groups and their selected characteristics. Implementation of the GDL program has been a success in Louisiana, as the number of crashes and associated casualties involving young drivers declined significantly over the years. The young driver crashes caused by drinking, cellphone usage, no safety restraints, nighttime single novice teen driver (without passengers), and associated fatal and injury crashes were generally showing a decreasing trend even these crashes are still substantial among all young drivers.

The results from disaggregated time series data analysis performed with SARIMAX method also indicate that the GDL program appears to have reduced casualties with young driver crash overall, particularly for novice teen (aged 15-16 years) and young teen (aged 17-19 years) drivers. It is worthwhile to point out that a somewhat increasing trend has been observed for young adult drivers (aged 20-24 years) in recent years even with a crash decreasing trend from young drivers. Not 100% of first-time drivers going through the GDL programs (Appendix E) could be a critical factor for a few key crash types by young adult drivers, such as no safety restraints, nighttime driving, and electronic device usage.

Spatial analysis was undertaken to segregate the five-year trend of selected young driver crash types in nine safety coalition areas. The research team identified the top 10 parishes with the highest young driver crash rates. Using the ArcMAP tool on the geographic coordinates of young driver crashes, the distribution of clusters with a high frequency of young driver crashes was also identified by safety coalition areas. The six clusters with a high concentration of young driver crashes identified are correlated with highly populated areas.

The study developed crash profiles of three young driver age groups through the incorporation of a number of crash variables using 2014 to 2018 crash data. This study also documented the current GDL program framework describing its components in Louisiana and other states. The timeline of legislative changes associated with GDL programs in Louisiana since its inception in 1998 has also been documented. The trend of young driver crashes by safety coalition area on specific characteristics—underage alcohol intoxication, cellphone usage, restraint non-usage, and nighttime crashes—could be an important resource for area-based countermeasure development. Additionally, several crash patterns and trends identified in this study can be further explored.

Without knowing the scope of the GDL program participation, it is impossible for us to investigate the crash pattern by GDL stages. Lack of the historical Louisiana driver age distribution data has limited the project analysis capacity on the effectiveness of GDL program evaluation. A lack of driver database extractable by both driver age and parish made also limited the scope of the spatial analysis. A comprehensive digital resource of citation data would be helpful in understanding the driving behaviors of cellphone use and restraint non-use while driving.

Recommendations

The key recommendations from the analysis findings on crash factors and evaluation of GDL programs, supported by literature review and issues identified by researchers are:

- Based on the understanding of crash contributing factors and trends of young driver crashes, the research team recommends considering developing a plan that promotes parent or guardian involvement within the framework of the GDL program to increase GDL program participation, which can promote safety behavior in the early years of driving.
- This study strongly recommends continually supporting strategic measures of educating young drivers about GDL and driving laws, real-life impact of risk-taking behavior, awareness campaigns at the local level targeting prevention of underage drinking, cellphone use, non-usage of restraints while driving, etc. as the analysis conducted on the crash trend suggests substantial reductions of crashes associated with those specific characteristics.
- It is recommended to consider standardizing the state GDL program's curriculum for consistent driver education and easy program evaluation. The standardized curriculum can be updated by including the knowledge of attitude patterns linked with teen and young driver crashes and by also accounting for case studies of enhanced education improvement in other states or nations.
- The research team identified the lack of a comprehensive driver database as a hindrance in analyzing the crash trend and specific areas of the GDL program. Enhancement of the data flow system between enforcement agencies and the state motor vehicle office is recommended, which can make the up-to-date young driver record available for their performance evaluation at their license upgrading time.
- This study recommends strong enforcement of current passenger restrictions. However, no specific recommendations for changes in the GDL program are being made in this study. Increased minimum ages of GDL stages, earlier passenger restriction hours, limited teen passengers, and enforcement of color-coded decal during nighttime have been proven successful in terms of safety benefits in other states. Separate feasibility analyses with comprehensive driver data are required to assess whether such changes in the GDL program would ensure young driver safety improvements in Louisiana.

Acronyms, Abbreviations, and Symbols

Term	Description
AASHTO	American Association of State Highway and Transportation Officials
ARIMAX	Autoregressive Integrated Moving Average with Explanatory Variables
BAC	Blood Alcohol Concentration
CDC	Center for Diseases Control and Prevention
DOPSC	Department of Public Safety and Corrections
DOTD	Department of Transportation and Development
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GDL	Graduated Licensing Program
ITA	Innovative Trend Analysis
LADOTD	Louisiana Department of Transportation and Development Louisiana
LTRC	Transportation Research Center
M-K	Mann-Kendal
MNL	Multinomial Logit
mph	miles per hour
NHTSA	National Highway Traffic Safety Administration
NCHS	National Center for Health Statistics
OMV	Office of Motor Vehicles
PDO	Property Damage Only
RYAN	Reduce Youth Accidents Now
SHSP	Strategic Highway Safety Plan
SARIMAX	Seasonal Autoregressive Integrated Moving Average with Explanatory Variables

References

[1] NHTSA, “Traffic Safety Facts 2017: A Compilation of Motor Vehicle Crash Data,” Washington DC, 2019. [Online]. Available: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812806.

[2] NHTSA, “Traffic Safety Facts 2008: A Compilation of Motor Vehicle Crash Data,” Washington DC, 2010.

[3] Centers for Disease Control and Prevention’s Fatal Injury Queries, “Leading Causes of Death Reports, National and Regional, 1999-2015.” https://webappa.cdc.gov/sasweb/ncipc/leadcaus10_us.html (accessed Mar. 01, 2020).

[4] LADOTD, “Destination Zero Deaths: Louisiana Strategic Highway Safety Plan,” Baton Rouge, 2018. [Online]. Available: http://www.destinationzerodeaths.com/Images/Site Images/ActionPlans/SHSP.pdf.

[5] GHSA, “State Laws by Issue: Teen and Novice Drivers,” *Governors Highway Safety Association*, 2020. https://www.ghsa.org/state-laws/issues/teen and novice drivers (accessed Apr. 12, 2020).

[6] WHO, “Youth and Road Safety,” 2010. doi: 10.1080/15389581003754593.

[7] OECD, “Young Drivers: The Road to Safety,” Paris, France, 2006. doi: 10.1017/CBO9781107415324.004.

[8] A. Crettenden and A. Drummond, “The Youing Driver Problem versus The Young Problem Driver - A Review and Crash Data Analysis,” Canberra, Australia, 1994.

[9] D. Shinar, *Traffic Safety and Human Behavior*. Bingley, UK: Emerald Publishing, 2017.

[10] NHTSA, “Traffic Safety Facts 2017 Data: Young Drivers,” Washington DC, 2019. doi: http://dx.doi.org/10.1016/j.annemergmed.2013.12.004.

[11] S. Dissanayake and N. Amarasingha, “Safety experience of young drivers in comparison to experienced drivers,” *T and DI Congress 2014: Planes, Trains, and Automobiles - Proceedings of the 2nd Transportation and Development Institute Congress*, pp. 344–355, 2014, doi: 10.1061/9780784413586.033.

[12] V. R. Duddu, V. M. Kukkapalli, and S. S. Pulugurtha, “Crash risk factors associated with injury severity of teen drivers,” *IATSS Research*, vol. 43, no. 1, pp. 37–43, 2019, doi: 10.1016/j.iatssr.2018.08.003.

[13] M. Abdel-Aty, A. A. Ekram, H. Huang, and K. Choi, “A study on crashes related

to visibility obstruction due to fog and smoke," *Accident Analysis and Prevention*, vol. 43, no. 5, pp. 1730–1737, 2011, doi: 10.1016/j.aap.2011.04.003.

[14] J. Wang and G. Zhang, "Modeling and examining the teenage and adult freeway crash risks and injury severities in Washington state," *Journal of Transportation Safety and Security*, vol. 3, no. 3, pp. 207–221, 2011, doi: 10.1080/19439962.2011.591518.

[15] T. M. Rice, C. Peek-Asa, and J. F. Kraus, "Nighttime driving, passenger transport, and injury crash rates of young drivers," *Injury Prevention*, vol. 9, no. 3, pp. 245–250, 2003, doi: 10.1136/ip.9.3.245.

[16] C. Peek-Asa, C. Britton, T. Young, M. Pawlovich, and S. Falb, "Teenage driver crash incidence and factors influencing crash injury by rurality," *Journal of Safety Research*, vol. 41, no. 6, pp. 487–492, 2010, doi: 10.1016/j.jsr.2010.10.002.

[17] E. K. Adanu, P. Penmetsa, S. Jones, and R. Smith, "Gendered analysis of fatal crashes among young drivers in Alabama, USA," *Safety*, vol. 4, no. 3, pp. 8–13, 2018, doi: 10.3390/safety4030029.

[18] H. C. Joksch, "Velocity change and fatality risk in a crash-A rule of thumb," *Accident Analysis and Prevention*, vol. 25, no. 1, pp. 103–104, 1993, doi: 10.1016/0001-4575(93)90102-3.

[19] J. Hatfield and R. Fernandes, "The role of risk-propensity in the risky driving of younger drivers," *Accident Analysis and Prevention*, vol. 41, no. 1, pp. 25–35, 2009, doi: 10.1016/j.aap.2008.08.023.

[20] M. Hasselberg and L. Laflamme, "How do car crashes happen among young drivers aged 18-20 years? Typical circumstances in relation to license status, alcohol impairment and injury consequences," *Accident Analysis and Prevention*, vol. 41, no. 4, pp. 734–738, 2009, doi: 10.1016/j.aap.2009.03.012.

[21] K. Vachal, R. Faculty, and D. Malchose, "What can we learn about North Dakota's youngest drivers from their crashes?," *Accident Analysis and Prevention*, vol. 41, no. 3, pp. 617–623, 2009, doi: 10.1016/j.aap.2009.02.014.

[22] H. C. Brown and A. P. Tarko, "Effects of access control on safety on urban arterial streets," *Transportation Research Record*, no. 1665, pp. 68–74, 1999, doi: 10.3141/1665-10.

[23] J. P. Byrnes, D. C. Miller, and W. D. Schafer, "Gender differences in risk taking: A meta-analysis," *Psychological Bulletin*, vol. 125, no. 3, pp. 367–383, 1999, doi: 10.1037/0033-2909.125.3.367.

[24] A. F. Williams and V. I. Shabanova, "Responsibility of drivers, by age and gender, for motor-vehicle crash deaths," *Journal of Safety Research*, vol. 34, no. 5, pp.

527–531, 2003, doi: 10.1016/j.jsr.2003.03.001.

[25] J. T. Shope and C. R. Bingham, “Teen Driving. Motor-Vehicle Crashes and Factors That Contribute,” *American Journal of Preventive Medicine*, vol. 35, no. 3 SUPPL., 2008, doi: 10.1016/j.amepre.2008.06.022.

[26] NHTSA, “Traffic safety facts 2016 (DOT HS 812 554),” 2018.

[27] D. R. Mayhew and H. M. Simpson, “New To the Road. Young Drivers and Novice Drivers: Similar Problems and Solutions?,” 1990.

[28] A. T. McCartt, D. R. Mayhew, K. A. Braitman, S. A. Ferguson, and H. M. Simpson, “Effects of age and experience on young driver crashes: Review of recent literature,” *Traffic Injury Prevention*, vol. 10, no. 3, pp. 209–219, 2009, doi: 10.1080/15389580802677807.

[29] D. R. Mayhew, H. M. Simpson, and A. Pak, “Changes in collision rates among novice drivers during the first months of driving,” *Accident Analysis and Prevention*, vol. 35, no. 5, pp. 683–691, 2003, doi: 10.1016/S0001-4575(02)00047-7.

[30] D. R. Mayhew, A. C. Donelson, D. J. Beirness, and H. M. Simpson, “Youth, alcohol and relative risk of crash involvement,” *Accident Analysis and Prevention*, vol. 18, no. 4, pp. 273–287, 1986, doi: 10.1016/0001-4575(86)90042-4.

[31] R. D. Blomberg, R. C. Peck, H. Moskowitz, M. Burns, and D. Fiorentino, “Crash Risk of Alcohol Involved Driving: A Case Control Study,” 2005.

[32] A. J. McKnight and A. S. McKnight, “Young novice drivers: Careless or clueless?,” *Accident Analysis and Preventio*, vol. 35, no. 6, pp. 921–925, 2003, doi: 10.1016/S0001-4575(02)00100-8.

[33] P. L. Zador, “Alcohol-related relative risk of fatal driver injuries in relation to driver age and sex,” *Journal of Studies on Alcohol*, vol. 52, no. 4, pp. 302–310, 1991, doi: 10.15288/jsa.1991.52.302.

[34] M. M. Gonzales, L. M. Dickinson, C. DiGuiseppi, and S. R. Lowenstein, “Student drivers: A study of fatal motor vehicle crashes involving 16-year-old drivers,” *Annals of Emergency Medicine*, vol. 45, no. 2, pp. 140–146, 2005, doi: 10.1016/j.annemergmed.2004.08.039.

[35] R. Paleti, N. Eluru, and C. R. Bhat, “Examining the influence of aggressive driving behavior on driver injury severity in traffic crashes,” *Accident Analysis and Prevention*, vol. 42, no. 6, pp. 1839–1854, 2010, doi: 10.1016/j.aap.2010.05.005.

[36] A. F. Williams and V. I. Shabanova, “Situational factors in seat belt use by teenage drivers and passengers,” *Traffic Injury Prevention*, vol. 3, no. 3, pp. 201–204,

2002, doi: 10.1080/15389580213650.

[37] S. T. Doherty, J. C. Andrey, and C. MacGregor, “The situational risks of young drivers: The influence of passengers, time of day and day of week on accident rates,” *Traffic Injury Prevention*, vol. 30, no. 1, pp. 45–52, 1998, doi: 10.1016/S0001-4575(97)00060-2.

[38] B. Aldridge, M. Himmler, L. Aultman-Hall, and N. Stamatiadis, “Impact of passengers on young driver safety,” *Transportation Research Record* no. 1693, pp. 25–30, 1999, doi: 10.3141/1693-05.

[39] L. H. Chen, S. P. Baker, E. R. Braver, and G. Li, “Carrying passengers as a risk factor for crashes fatal to 16- and 17- year-old drivers,” *Journal of the American Medical Association*, vol. 283, no. 12, pp. 1578–1582, 2000, doi: 10.1001/jama.283.12.1578.

[40] H. Fu and C. G. Wilmot, “Effect of passenger age and gender on fatal crash risks of young drivers,” *Transportation Research Record*, no. 2078, pp. 33–40, 2008, doi: 10.3141/2078-05.

[41] T. B. Sheridan, “Driver distraction from a control theory perspective,” *Human Factors*, vol. 46, no. 4, pp. 587–599, 2004, doi: 10.1518/hfes.46.4.587.56807.

[42] T. Ranney, E. Mazzae, R. Garrott, and M. Goodman, “NHTSA driver distraction research: Past, present, and future,” *USDOT, National Highway Traffic Safety Administration*, pp. 1–11, 2000, [Online]. Available: http://www-nrd.nhtsa.dot.gov/departments/Human Factors/driver-distraction/PDF/233.PDF.

[43] D. L. Strayer and F. A. Drews, “Profiles in driver distraction: Effects of cell phone conversations on younger and older drivers,” *Human Factors*, vol. 46, no. 4, pp. 640–649, 2004, doi: 10.1518/hfes.46.4.640.56806.

[44] C. Carney, K. K. Harland, and D. V. McGehee, “Examining teen driver crashes and the prevalence of distraction: Recent trends, 2007–2015,” *Journal of Safety Research*, vol. 64, pp. 21–27, 2018, doi: 10.1016/j.jsr.2017.12.014.

[45] NHTSA, “General Estimates System (GES),” 2014.

[46] D. M. Neyens and L. N. Boyle, “The effect of distractions on the crash types of teenage drivers,” *Accident Analysis and Prevention*, vol. 39, no. 1, pp. 206–212, 2007, doi: 10.1016/j.aap.2006.07.004.

[47] P. Gershon *et al.*, “Distracted Driving, Visual Inattention, and Crash Risk Among Teenage Drivers,” *American Journal of Preventive Medicine*, vol. 56, no. 4, pp. 494–500, 2019, doi: 10.1016/j.amepre.2018.11.024.

[48] C. C. McDonald, A. E. Curry, V. Kandadai, M. S. Sommers, and F. K. Winston,

"Comparison of teen and adult driver crash scenarios in a nationally representative sample of serious crashes," *Accident Analysis and Prevention*, vol. 72, pp. 302–308, 2014, doi: 10.1016/j.aap.2014.07.016.

[49] M. Hasselberg and L. Laflamme, "How do car crashes happen among young drivers aged 18-20 years? Typical circumstances in relation to license status, alcohol impairment and injury consequences," *Accident Analysis and Prevention*, vol. 41, no. 4, pp. 734–738, 2009.

[50] F. Zhang, S. Mehrotra, and S. C. Roberts, "Driving distracted with friends: Effect of passengers and driver distraction on young drivers' behavior," *Accident Analysis and Prevention*, vol. 132, no. June, p. 105246, 2019, doi: 10.1016/j.aap.2019.07.022.

[51] A. F. Williams and J. Tison, "Motor vehicle fatal crash profiles of 13-15-year-olds," *Journal of Safety Research*, vol. 43, no. 2, pp. 145–149, 2012, doi: 10.1016/j.jsr.2012.03.002.

[52] B. Lewis-Evans, "Crash involvement during the different phases of the New Zealand Graduated Driver Licensing System (GDLS)," *Journal of Safety Research*, vol. 41, no. 4, pp. 359–365, 2010, doi: 10.1016/j.jsr.2010.03.006.

[53] A. F. Williams and J. A. K. Wells, "Deaths of teenagers as motor-vehicle passengers," *Journal of Safety Research*, vol. 26, no. 3, pp. 161–167, 1995, doi: 10.1016/0022-4375(95)00012-F.

[54] A. F. Williams, A. T. McCartt, and L. B. Sims, "History and current status of state graduated driver licensing (GDL) laws in the United States," *Journal of Safety Research*, vol. 56, pp. 9–15, 2016, doi: 10.1016/j.jsr.2015.11.006.

[55] S. P. Baker, L.-H. Chen, and G. Li, "National Evaluation of Graduated Driver Licensing Programs," Washington DC, 2006. doi: 10.1017/CBO9781107415324.004.

[56] J. P. Ehsani, C. Raymond Bingham, and J. T. Shope, "Graduated driver licensing for new drivers effects of three states' policies on crash rates among teenagers," *Journal of Preventive Medicine*, vol. 45, no. 1, pp. 9–18, 2013, doi: 10.1016/j.amepre.2013.03.005.

[57] K. A. Conner and G. A. Smith, "An evaluation of the effect of Ohio's graduated driver licensing law on motor vehicle crashes and crash outcomes involving drivers 16 to 20 years of age," *Traffic Injury Prevention*, vol. 18, no. 4, pp. 344–350, 2017, doi: 10.1080/15389588.2016.1209493.

[58] C. DePesa *et al.*, "The impact of the 2007 graduated driver licensing law in Massachusetts on the rate of citations and licensing in teenage drivers," *Journal of Safety Research*, vol. 61, pp. 199–204, 2017, doi: 10.1016/j.jsr.2017.02.012.

[59] J. E. Goldstick, P. M. Carter, F. Almani, S. J. Brines, and J. T. Shope, "Spatial variation in teens' crash rate reduction following the implementation of a graduated driver licensing program in Michigan," *Accident Analysis and Prevention*, vol. 125, no. November 2017, pp. 20–28, 2019, doi: 10.1016/j.aap.2019.01.023.

[60] M. Steadman, J. K. Bush, S. M. Thygerson, and M. D. Barnes, "Graduated Driver Licensing Provisions: An Analysis of State Policies and What Works," *Traffic Injury Prevention*, vol. 15, no. 4, pp. 343–348, 2014, doi: 10.1080/15389588.2013.822493.

[61] S. V. Masten, R. D. Foss, and S. W. Marshall, "Graduated driver licensing program component calibrations and their association with fatal crash involvement," *Accident Analysis and Prevention*, vol. 57, pp. 105–113, 2013, doi: 10.1016/j.aap.2013.04.013.

[62] S. V. Masten, D. Thomas, K. Korbelak, R. Peck, and R. D. Blomberg, "Meta-Analysis of Graduated Driver Licensing Laws: Effectiveness of Specific Program Components," no. November, p. 2p, 2015, doi: 10.13140/RG.2.1.2842.1208.

[63] NHTSA, "Countermeasures That Work: A Highway Safety Countermeasure Guide For State Highway Safety Offices," Washington DC, 2017.

[64] R. B. Isler, N. J. Starkey, and P. Sheppard, "Effects of higher-order driving skill training on young, inexperienced drivers' on-road driving performance," *Accident Analysis and Prevention*, vol. 43, no. 5, pp. 1818–1827, 2011, doi: 10.1016/j.aap.2011.04.017.

[65] A. E. Curry, M. R. Elliott, M. R. Pfeiffer, K. H. Kim, and D. R. Durbin, "Long-term changes in crash rates after introduction of a graduated driver licensing decal provision," *American Journal of Preventive Medicine*, vol. 48, no. 2, pp. 121–127, 2015, doi: 10.1016/j.amepre.2014.08.024.

[66] National Highway Traffic Safety Administration, "Fatality Analysis Reporting System Repository: FTP Access." https://www.nhtsa.gov/content/nhtsa-ftp/251.

[67] D. T. Mann-kendall, "Statistical Methods for Environmental Pollution Monitoring," Wiley, 1987.

[68] G. E. P. Box, G. M. Jenkins, and G. C. Reinsel, *Time Series Analysis: Forecasting and Control*, Englewood Cliffs: Prentice-Hall, 1994.

[69] D. Z. Huang, H. Hu, and Y. Z. Li, "Spatial analysis of maritime accidents using the geographic information system," *Transportation Research Record*, no. 2326, pp. 39–44, 2013, doi: 10.3141/2326-06.

[70] D. M. DeJoy, "An examination of gender differences in traffic accident risk

perception," *Accident Analysis and Prevention*, vol. 24, no. 3, pp. 237–246, 1992, doi: 10.1016/0001-4575(92)90003-2.

[71] M. Sivak, "Female Drivers in the United States, 1963-2010: From a Minority to a Majority?," *Traffic Injury Prevention*, vol. 14, no. 3, pp. 259–260, 2013, doi: 10.1080/15389588.2012.755736.

[72] E. Mitran, T. Ellender, and D. Cummins, "Distracted Driving: Strategies and State of the Practices," Baton Rouge, 2019. [Online]. Available: https://www.ltrc.lsu.edu/pdf/2019/17-02TA-SA.pdf.

[73] X. Sun and M. A. Rahman, "Investigating Problem of Distracted Drivers on Louisiana Roadways," Baton Rouge, 2018. [Online]. Available: https://digitalcommons.lsu.edu/transet_pubs/25.

[74] LHSC, "2019 Louisiana Seat Belt Observation Survey Result," Baton Rouge, 2019.

[75] Louisiana Highway Safety Commission, "Louisiana Highway Safety Plan: Federal Fiscal Year 2020," Baton Rouge, 2019. [Online]. Available: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/la_fy20_hsp.pdf.

[76] A. E. Curry, M. R. Pfeiffer, D. R. Durbin, and M. R. Elliott, "Young driver crash rates by licensing age, driving experience, and license phase," *Accident Analysis and Prevention*, vol. 80, pp. 243–250, 2015, doi: 10.1016/j.aap.2015.04.019.

[77] A. E. Curry, C. Peek-Asa, C. J. Hamann, and J. H. Mirman, "Effectiveness of parent-focused interventions to increase teen driver safety: A critical review," *Journal of Adolescent Health*, vol. 57, no. 1, pp. s6–s14, 2015, doi: 10.1016/j.jadohealth.2015.01.003.

Appendices

Appendix A: Comparison of GDL Components State by State

Table A1. Comparison of GDL Components State by State[1]

Stage	Components	Categories	States	Count
Stage 1 (Learner Permit)	Minimum Entry Age	Less than 15 Years	AK, AR, IA, ID, KS, MT, MI, ND, SD	9
		15 Years	AL, CO, FL, GA, IL, IN, *LA*, ME, MN, MS, MO, NE, NM, NC, OR, SC, TN, TX, UT, VT, WA, WV, WY	23
		Between 15 and 16 Years	AZ, CA, HI, MD, NV, NH, OH, OK, VA, WI	10
		16 Years	CT, DE, DC, KY, MA, NJ, NY, PA, RI	9
	Holding Period	10 Days	WY	1
		4-6 Months	AL, AK, AZ, AR, CA, CT, DE, DC, HI, ID, IN, KY, *LA*, ME, MA, MI, MN, MO, MT, NE, NV, NJ, NM, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, WA, WV, WI	37
		9-12 Months	CO, FL, GA, IA, IL, KS, MD, MS, NC, ND, VA, VT	12
		None	NH	1
	Minimum Hours of Supervised Driving	None	AR, MS, NJ, SD	4
		20-40 Hours	AK, CT, DC, GA, IA, KS, MA, MN, NH, SC, UT, VT, VA, AZ, MO, TX, WI	17
		50 Hours	AL, CA, CO, DE, FL, HI, ID, IL, IN, *LA*, MI, MT, NE, NV, NM, NY, ND, OH, OK, OR, RI, TN, WA, WV, WY	25
		60-70 Hours	KY, MD, ME, NC, PA	5

Stage	Components	Categories	States	Count
Stage 2 (Intermediate License)	Minimum Age	Less than 16 Years	ID, MT, NM, SC, SD	5
		16 Years	AL, AK, AZ, AR, CA, CO, FL, GA, HI, IL, IA, KS, *LA*, ME, MI, MN, MS, MO, NE, NV, NH, NC, ND, OH, OK, OR, TN, TX, UT, VT, WA, WV, WI, WY	34
		Between 16 and 17 Years	CT, DE, DC, IN, KY, MD, MA, NJ, NY, PA, RI, VA	12
	Unsupervised Driving Prohibited	10 pm–6 am	DE, IL, MI, MS, KS, NC, ND, NV, NY, OK, SD, WV	12
		11 pm–5 am	AR, CA, CT, HI, IN, *LA*, MT, NJ, PA, TN, WY	11
		Midnight–6 am	AL, DC, KY, NE, OH, AZ, CO, GA, IA, ME, MD, MA, MN, NM, OR, TX, UT, VA, WI	19
		1 am–5 am	AK, FL, MO, NH, RI, WA	6
		Sunset–Sunrise	ID, SC	2
		None	VT	1
	Passenger Restriction	No Restriction	DC, FL, GA, IN, ME, MS, ND, SD, UT, VT	10
		No More than One	AL, AZ, AR, CO, DE, HI, ID, IL, KS, KY, *LA*, MI, MO, MT, NE, NH, NJ, NM, NY, NC, OH, OK, PA, RI, TN, TX, VA, WI, WY	29
		No Passenger Younger than 21-year-old	AK, CA, CT, IA, MD, MA, MN, NV, OR, WA, WV	11
		No More than Two	SC	1
Stage 3 (Permanent License)	Minimum Age	16 Years	ID, MT, ND, OH, SD	5
		Between 16 and 17 Years	AK, AZ, KS, ME, MS, NM, NC, OK, PA, SC, VT, WI, WY	13
		17 Years	AL, CA, CO, DE, HI, IA, KY, *LA*, MI, MN, NE, NY, OR, TN, UT, WA, WV	17
		18 Years	AR, CT, DC, FL, GA, IL, IN, MD, MA, MO, NV, NH, NJ, RI, TX, VA	16

[1] As of January 2021.

Appendix B: Detailed Seasonal Mann-Kendal Test Results

Table B1. Detailed Seasonal M-K Test Results

Crash Type	Timeline	Total Crashes				Fatal and Injury Crashes			
		Trend Magnitude, $\hat{S}$	Variance, $\hat{\sigma}_g^2$	z-value	p-value	Trend Magnitude, $\hat{S}$	Variance, $\hat{\sigma}_g^2$	z-value	p-value
Novice Teen (15-16 Years)	Pre-GDL (1990[a]/91[b]–1997)	207	783	7.36	<0.001	161	531	6.94	<0.001
	Post-GDL (1998–2018)	-1,222	11,391.33	-11.44	<0.001	-1,496	13,133.33	-13.05	<0.001
	Overall (1990[a]/91[b]–2018)	-2,741	34,090.33	-14.84	<0.001	-2,704	30,711.33	-15.42	<0.001
Young Teen (17-19 Years)	Pre-GDL (1990[a]/91[b]–1997)	208	782	7.40	<0.001	180	530	7.78	<0.001
	Post-GDL (1998–2018)	-1,542	13,160	-13.43	<0.001	-1,614	13,154	-14.06	<0.001
	Overall (1990[a]/91[b]–2018)	-400	34,008	-2.16	0.031	-1,427	30,735	-8.13	<0.001
Young Adult (20-24 Years)	Pre-GDL (1990[a]/91[b]–1997)	169	783	6.00	<0.001	103	527	4.44	<0.001
	Post-GDL (1998–2018)	-221	13,157	-1.92	0.055	-749	13,149	-6.52	<0.001
	Overall (1990[a]/91[b]–2018)	1589	34,097	8.60	<0.001	-284	30,722	-1.61	0.11

Crash Type	Timeline	Total Crashes				Fatal and Injury Crashes			
		Trend Magnitude, $\hat{S}$	Variance, $\hat{\sigma}_g^2$	z-value	p-value	Trend Magnitude, $\hat{S}$	Variance, $\hat{\sigma}_g^2$	z-value	p-value
All Young Drivers (15-24 Years)	Pre-GDL (1990[a]/91[b]–1997)	207	783	7.36	<0.001	172	532	7.41	<0.001
	Post-GDL (1998–2018)	-1,247	13,159	-10.86	<0.001	-1,411	13,157	-12.29	<0.001
	Overall (1990[a]/91[b] –2018)	-318	34,102	-1.72	0.086	-1,505	30,739	-8.57	<0.001
Underage (15-20 Years) Alcohol Driving	2005-2018	-401	3959	-6.36	<0.001	-400	3940.67	-6.36	<0.001
Cellphone Use for Young Drivers (15-24 Years)	2005-2018	-214	3976.67	-3.37	<0.001	-193	3928.33	-3.06	0.002
No Restraints for Young Drivers (15-24 Years)	2005-2018	-724	3990	-11.45	<0.001	-703	3991	-11.11	<0.001
15 Year-Old-Drivers with no passenger	2005-2018	-243	3920.33	-3.87	<0.001	-244	3812	-3.94	<0.001
16 Year-Old-Drivers with no Passengers during 11 pm – 5 am	2005-2018	-360	3920	-5.73	<0.001	-401	3959	-6.36	<0.001

[a] Time period for total crashes

[b] Time period for fatal & injury crashes

Appendix C: ARIMAX Model Results

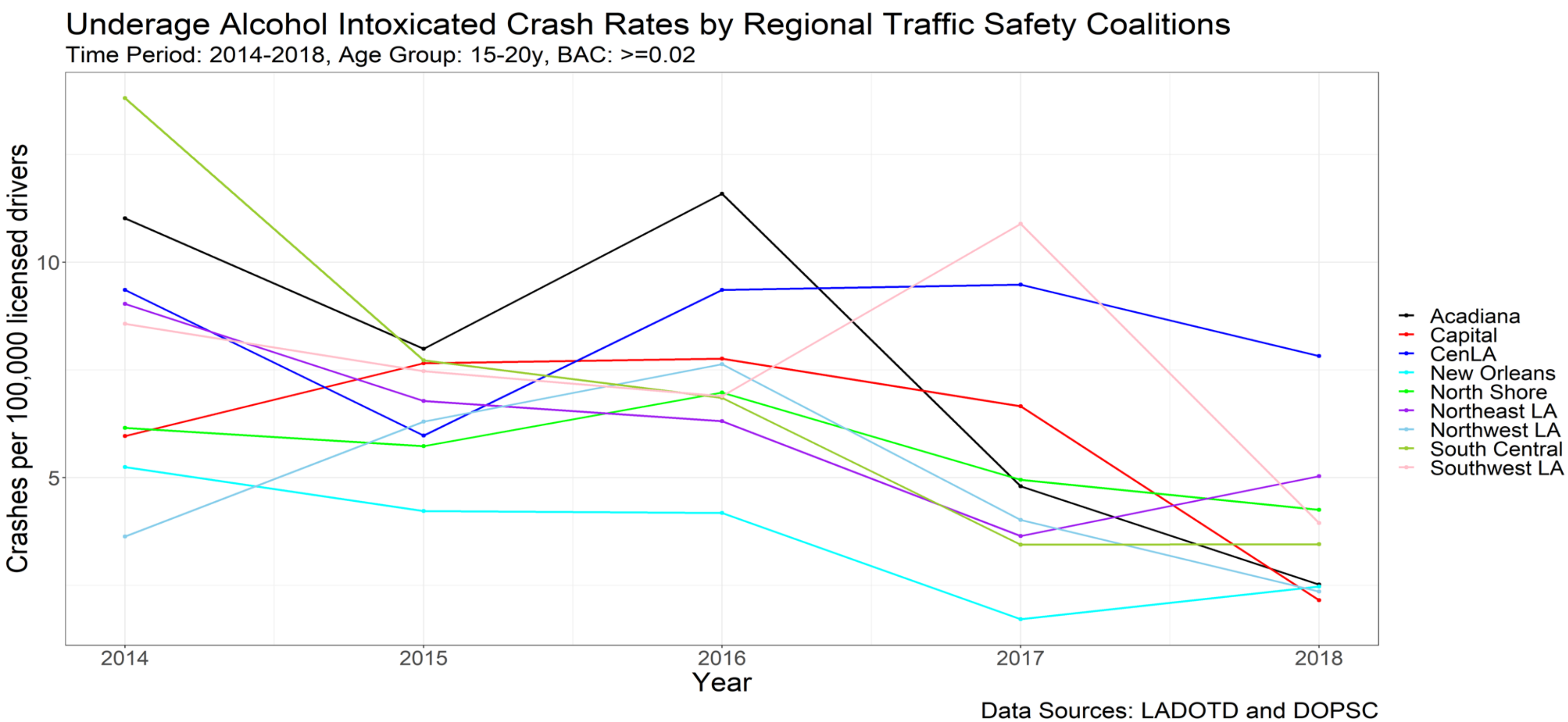
Table C1. ARIMAX Models on Aggregated Time Series Data (1991-2018)

Driver Age	**Young Drivers (15-24 Years)**		**Novice Teen (15-16 Years)**		**Young Teen (17-19 Years)**		**Young Adult (20-24 Years)**		**Drivers aged 15-17 Years at 11pm-5am**		**Young Drivers (15-24 Years) at 11pm-5am**	
Best Model	(0,1,0)		(0,1,0)		(0,1,0)		(0,0,1)		(0,1,0)		(0,1,1)	
	Coeff.	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**
ma1			–	–	–	–	–	–	–	–	-0.317	0.143
ln(Annual Crash Count)	*0.999*	*<0.001*	*0.903*	*<0.001*	*1.017*	*<0.001*	*0.952*	*<0.001*	*0.919*	*<0.001*	*0.967*	*<0.001*
GDL Implementation	*1.054*	*<0.001*	-0.079	0.144	-0.048	0.141	*-0.074*	*<0.001*	*-0.186*	*<0.001*	-0.032	0.337
Learners Policy Change 1	*-0.052*	*0.032*	0.007	0.885	0.035	0.284	-0.009	0.696	*0.144*	*0.005*	0.009	0.768
Learners Policy Change 2	0.038	0.112	0.004	0.93	-0.026	0.418	-0.016	0.467	*0.132*	*0.011*	0.001	0.973
Holding Period Extension	-0.017	0.472	0.028	0.605	-0.006	0.855	-0.012	0.507	-0.068	0.188	-0.011	0.7425
Cellphone Ban	0.003	0.891	-0.074	0.175	*-0.065*	*0.047*	*-0.06*	*<0.001*	*-0.212*	*<0.001*	-0.041	0.261

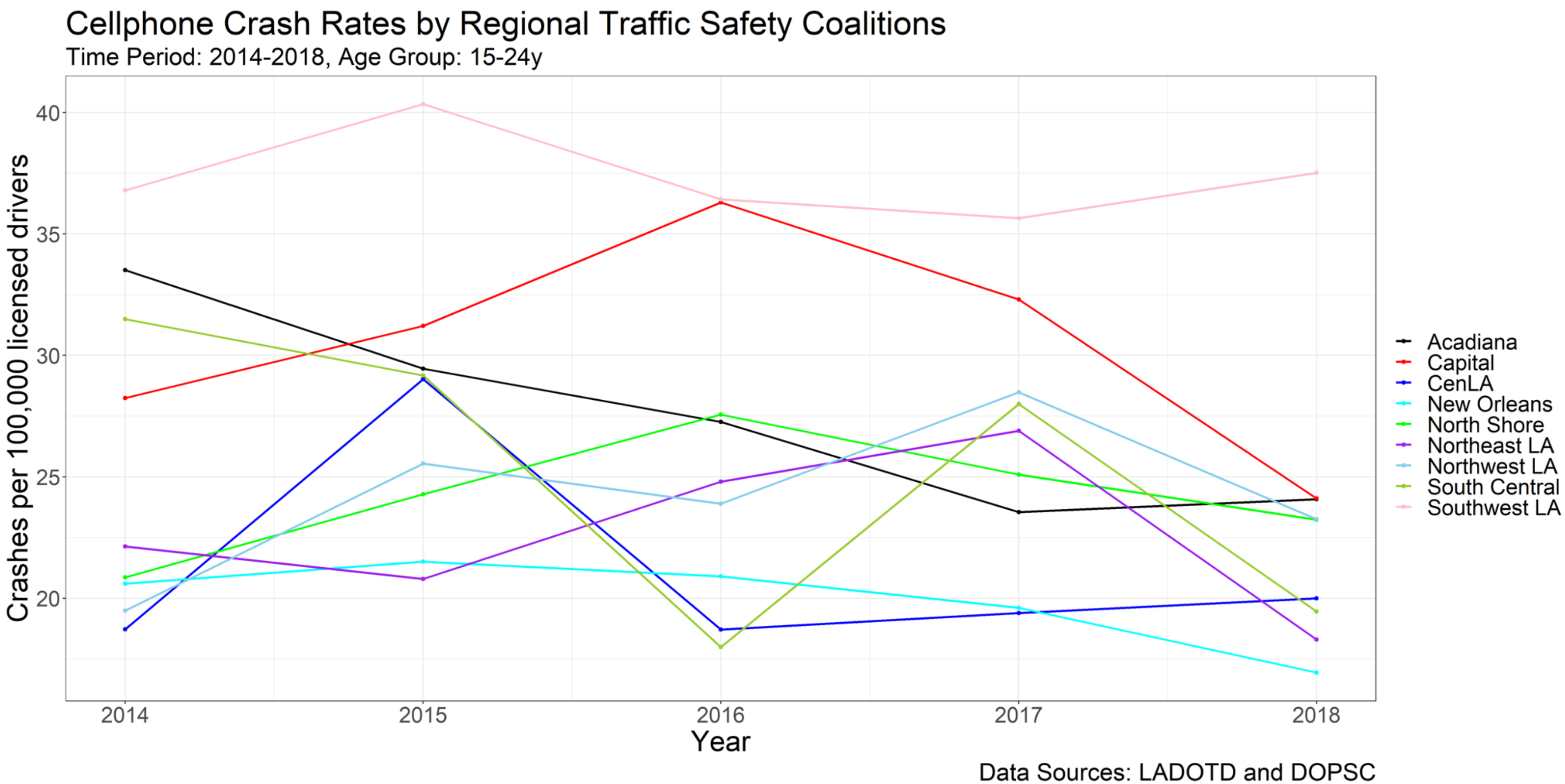
Driver Age	**Young Drivers (15-24 Years)**		**Novice Teen (15-16 Years)**		**Young Teen (17-19 Years)**		**Young Adult (20-24 Years)**		**Drivers aged 15-17 Years at 11pm-5am**		**Young Drivers (15-24 Years) at 11pm-5am**	
Passenger Restriction + Increase of On-Road Instruction Hours + Supervised Hours Extension	-0.022	0.372	0.022	0.678	-0.02	0.538	-0.016	0.256	0.097	0.062	0.0004	0.989
Log-likelihood	64.67		41.66		55.88		69.67		43.14		56.19	

Appendix D: Five-Year Trend of Young Driver Crash Characteristics by Safety Coalitions

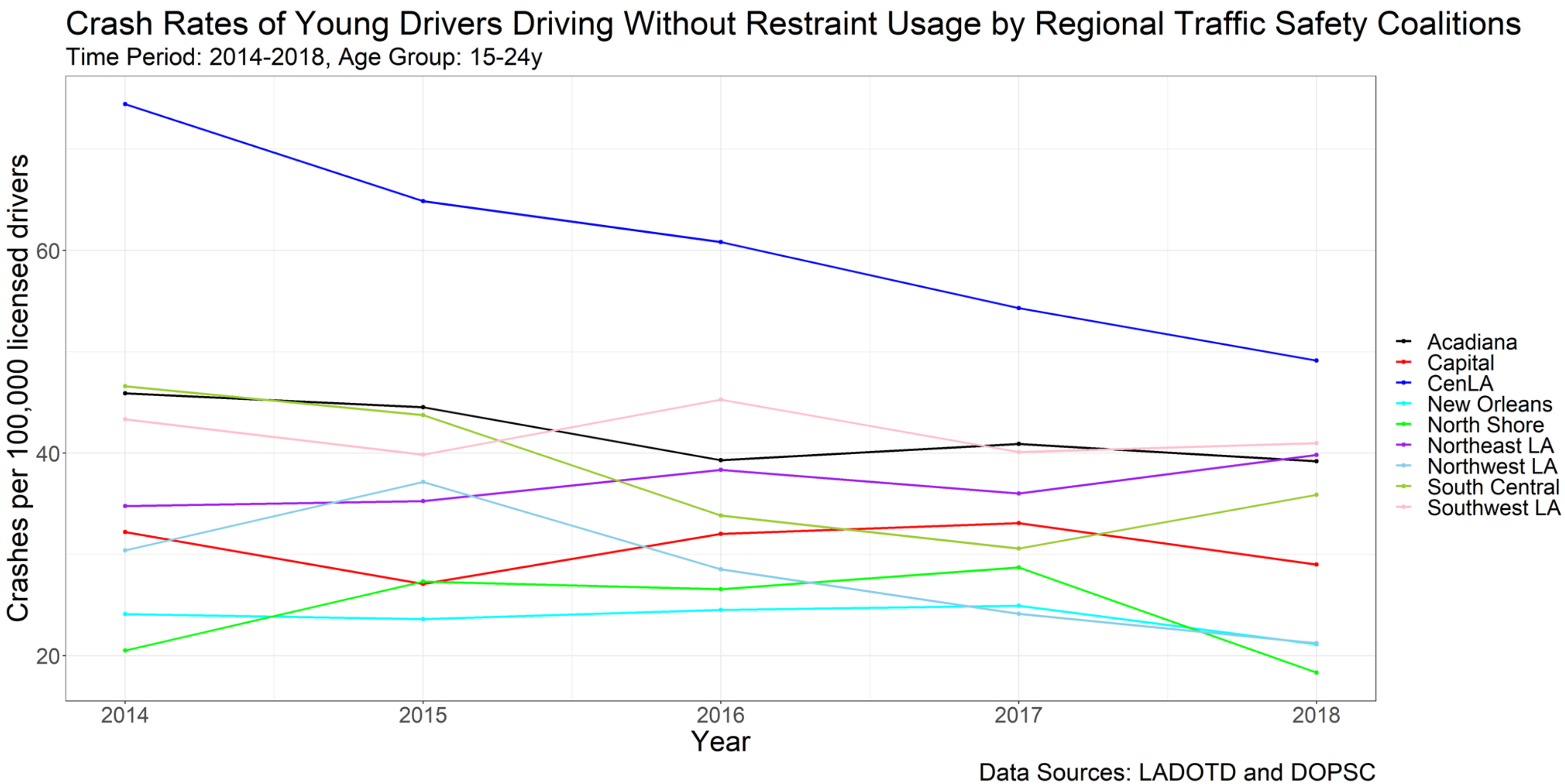
Figure D1. Five-Year Trend of Young Driver Crash Characteristics by Safety Coalitions for (a) underage alcohol intoxication, (b) cellphone use, (c) restraint non-usage, (d) night time crash



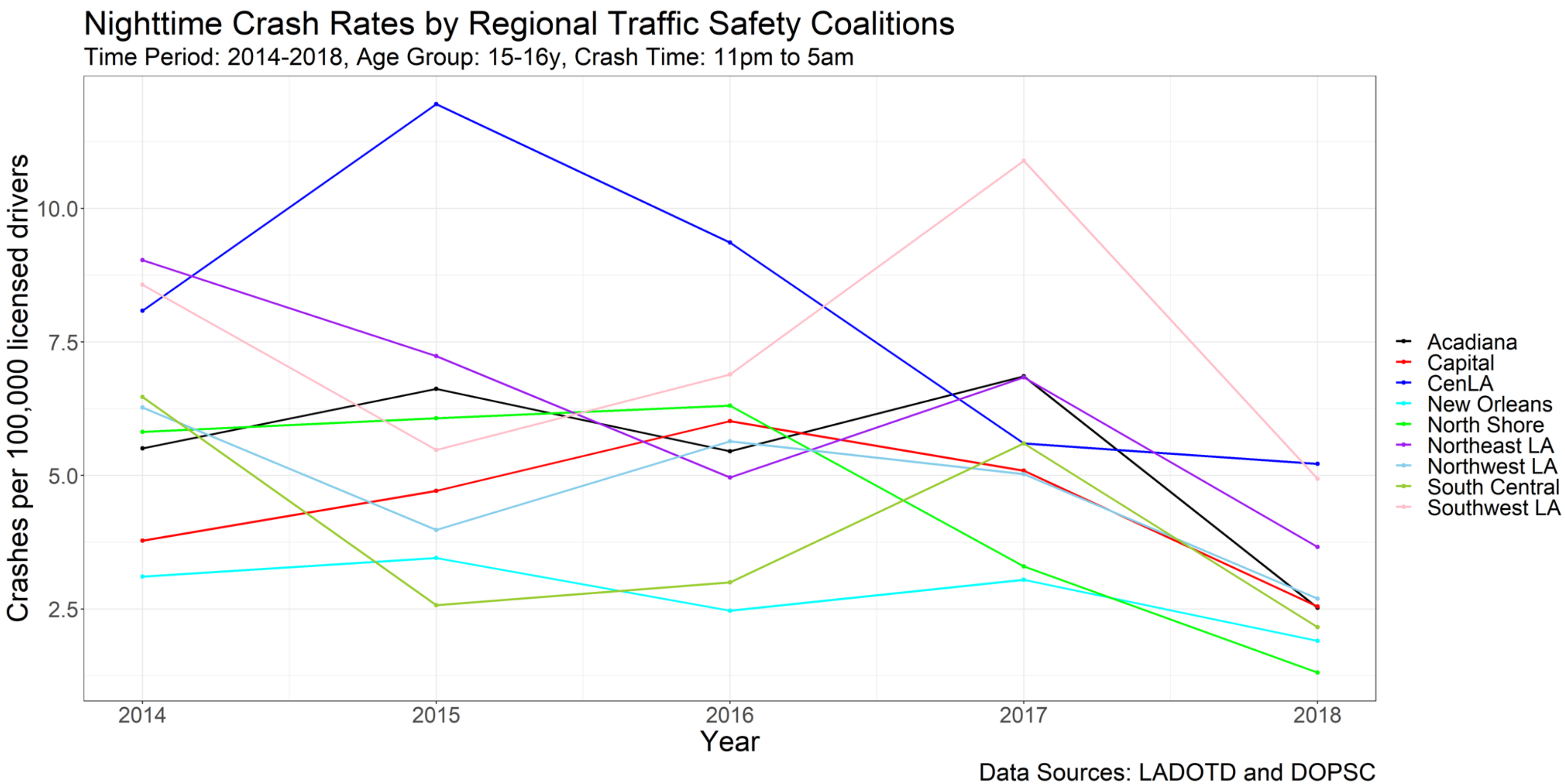
(a)


Cellphone Crash Rates by Regional Traffic Safety Coalitions
Time Period: 2014-2018, Age Group: 15-24y
Crashes per 100,000 licensed drivers
40
35
30
25
20
2014
2015
2016
2017
2018
Year
Acadiana
Capital
CenLA
New Orleans
North Shore
Northeast LA
Northwest LA
South Central
Southwest LA
Data Sources: LADOTD and DOPSC

(b)


Crash Rates of Young Drivers Driving Without Restraint Usage by Regional Traffic Safety Coalitions
Time Period: 2014-2018, Age Group: 15-24y
Crashes per 100,000 licensed drivers
60
40
20
2014
2015
2016
2017
2018
Year
Acadiana
Capital
CenLA
New Orleans
North Shore
Northeast LA
Northwest LA
South Central
Southwest LA
Data Sources: LADOTD and DOPSC

(c)

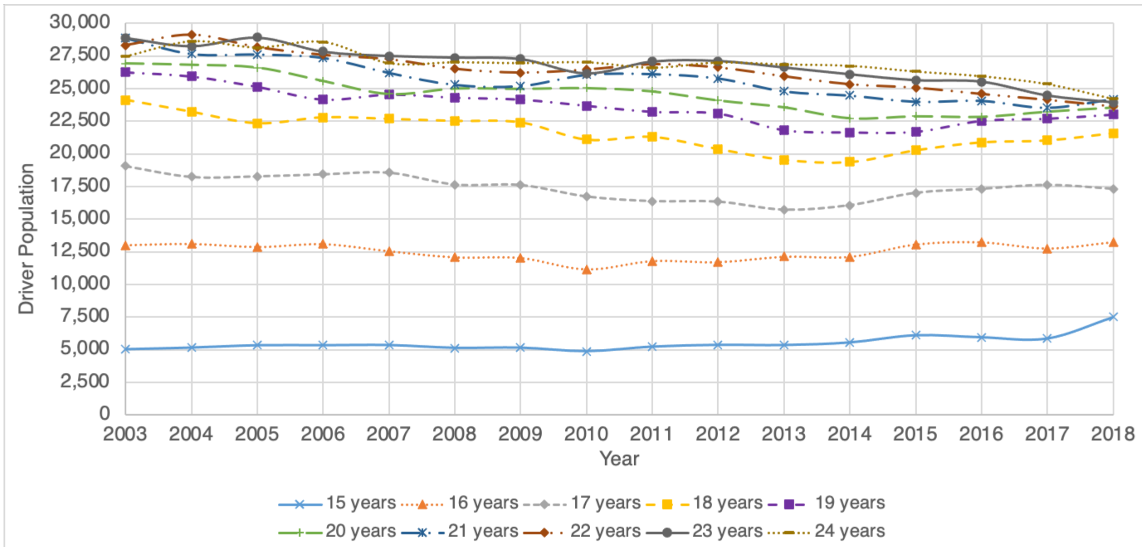


Nighttime Crash Rates by Regional Traffic Safety Coalitions
Time Period: 2014-2018, Age Group: 15-16y, Crash Time: 11pm to 5am
Crashes per 100,000 licensed drivers
10.0
7.5
5.0
2.5
2014
2015
2016
2017
2018
Year
Acadiana
Capital
CenLA
New Orleans
North Shore
Northeast LA
Northwest LA
South Central
Southwest LA
Data Sources: LADOTD and DOPSC

(d

Appendix E: Trend of Young Driver Population by Age

Figure E1. Trend of Young Driver Population by Age



Appendix F: Ongoing Young and Teen Driver Safety Programs

Table F1. List of Ongoing Young and Teen Driver Safety Programs

	Name of the Project	**Actions**
Education	You Are Worth It, Inc.	High school students in Northeast Louisiana to educate young drivers about the negative effects of impaired driving
	Bayou Council Behavior – Lafourche	Two high schools within Lafourche Parish to create peer–to-peer video messages aimed at teaching students the dangers of impaired driving
	Ready Set DRIVE!	Teen driver safety educational program focused on traffic laws, driver education, and other strategies in the East Baton Rouge, East Feliciana, Iberville, Point Coupee, and West Baton Rouge parishes.
	Sudden Impact Program	Statewide comprehensive injury prevention program to decrease the number of alcohol-impaired traffic fatalities. Also, the program is related to distracted driving and occupant protection.
	ThinkFirst Teen Program	One- to two-hour programs on underage drinking and impaired driving in Northwest Louisiana.
	Drugs and Alcohol Prevention Program	Impaired driving education to the youth of Concordia Parish.
Enforcement	Alcohol Beverage Control Juvenile Underage Drinking Enforcement (J.U.D.E.) Task Force	Targeting underage drinking and impaired driving in East Baton Rouge Parish
	Overtime Traffic Safety Enforcement	Identifying areas of critical need and sustained high-visibility overtime enforcement of traffic safety laws in cooperation of local agencies.

This public document is published at a total cost of $200.
29 copies of this public document were published in this first printing at a cost of $200. The total cost of all printings of this document including reprints is $200. This document was published by Louisiana Transportation Research Center to report and publish research findings as required in R.S. 48:105. This material was duplicated in accordance with standards for printing by state agencies established pursuant to R.S. 43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.