DRIVER CHARACTERISTICS AND BEHAVIORS ASSOCIATED WITH HIGHER INJURY SEVERITY LARGE LOGGING TRUCK CRASHES ON PUBLIC ROADWAYS IN LOUISIANA (2010-2018)

A Dissertation

by

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ABSTRACT

This dissertation involved an in-depth analysis of statewide crash data (2010-2018) from the Louisiana Department of Transportation and Development (LaDOTD) Highway Safety that focused on large logging truck crashes. The objective of this cross-sectional study was to determine driver characteristics and behaviors associated with more severe large logging truck crashes in Louisiana. The findings can be used to develop targeted educational activities to promote roadway safety and reduce the number of crashes or reduce their severity.

The leading cause of fatal occupational injuries in the United States in 2018 was traffic roadway crashes. The Agriculture, Forestry, and Fishing (AgFF) sector of the American economy is one of the most hazardous sectors, as evidenced by extremely high occupational injury rates in the United States. Transportation-related injuries make a large contribution to the high injury rates. Two-thirds of fatal occupational injuries in the AgFF sector were from transportation incidents (67%) in Louisiana in 2018.

The logging industry is a part of the AgFF sector and is one of the most dangerous commercial enterprises in the United States. Logging workers suffered the highest number of fatal occupational injuries in the United States from 2006 to 2020. However, limited data and research are available on transportation-related injuries in the logging industry in the United States and Louisiana, specifically.

This dissertation utilized unordered discrete outcome models to identify factors associated with more severe crashes. Large logging truck-related single-vehicle and multiple vehicles crashes were estimated separately. The outcome for both single-vehicle and multi vehicle crashes was defined as higher injury severity (i.e., fatal, severe, or moderate) versus lower injury severity (i.e., possible injury, no injury, or property damage). Adjusted odds ratios and 95% confidence intervals were used for the interpretation of the final model.

Along with recommendations to improve the safety of logging transportation, this dissertation offer suggestions to modify the crash data collection forms and definitions to improve the classification of cargo body type and avoid misclassification of large logging truck crashes. The findings of this study also provide recommendations for future research.

DEDICATION

I dedicate my dissertation research to my parents and family. A special thanks to my mother, Pushpalata Maindale, for supporting me during my long dissertation journey. I would like to dedicate my dissertation to my husband and daughter for their unconditional support and love. I also dedicate my dissertation to my sister and brother-in-law Shubhada and Vinayak Labade. They believed in my dreams and guided me to achieve them. I would dedicate this work to Dr. Eva Shipp for helping me through my academic and professional journey.

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The dissertation data analyzed was guided by Professor Eva Shipp and Tanya Garcia. All analyses were conducted by the student.

All other work conducted for the dissertation was completed by the student independently.

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NOMENCLATURE

AgFF	Agriculture, Forestry, and Fishing sector
BIC	Bayesian Information Criterion
BLS	Bureau of Labor Statistics
CAB	Centre for Agriculture and Biosciences International
CDC	Centers for Disease Control and Prevention
CDL	Commercial Driver's License
CI	Confidence Interval
DOT	Department of Transportation
DUI	Driving Under the Influence
EBSCO	Elton B. Stephens Co. database
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTE	Full-Time Equivalents
GEV	Generalized Extreme Value
HOS	Hours-of-service
LaDOTD	Louisiana Department of Transportation and Development
LTCCS	Large Truck Crash Causation Study
MCMIS	Motor Carrier Management Information System databases
MNL	Multinomial Logit
NAICS	North American Industry Classification System

NHTSA	National Highway Traffic Safety Administration
NIOSH	National Institute for Occupational Safety and Health
NTOF	National Traumatic Occupational Fatalities
OR	Odds Ratio
OSHA	Occupational Safety and Health Administration
TBI	Traumatic Brain Injuries
TIFA	Trucks Involved in Fatal Accidents
U.P.	Upper Peninsula
VIF	Variance Inflation Factors
WSDOL	Washington State Department of Licensing

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CHAPTER I

INTRODUCTION

Agriculture, Forestry, and Fishing (AgFF) sector

The Agriculture, Forestry, and Fishing sector is one of the most hazardous in the economy, as evidenced by extremely high rates of occupational injury in the United States (Bureau of Labor Statistics [BLS], 2019; National Research Council, 2008). The AgFF sector is comprised of agriculture, forestry (including logging), fishing and hunting industries. The United States Census Bureau's North American Industry Classification System (NAICS) specifies that the AgFF sector includes establishments involved in growing crops, raising animals, harvesting timber, and harvesting fish and other animals from a farm, ranch, or natural habitat (U.S. Census Bureau, 2017).

Data from 2006-2020 show that occupational injury rates are much higher in the AgFF sector than in all sectors combined in the United States (BLS, 2019). The AgFF sector had an occupational mortality rate of 23.4 deaths per 100,000 full-time equivalents (FTE) workers in the United States in 2018. This rate is far higher than the average rate of 3.5 deaths per 100,000 FTE workers for all industries combined in that same year (BLS, 2019).

Injury and fatality rates vary by state and industry. The occupational fatality rate in the AgFF industry was much higher in Louisiana (31.3 per 100,000 FTE workers) than for the United States (23.4 per 100,000 FTE workers) as a whole in 2018 (BLS, 2020).

Other data sources show that the forestry industry has experienced a higher fatality rate than other industries (Bell, 2002; Cole, 2018; Lefort et al., 2003; Peters, 1991).

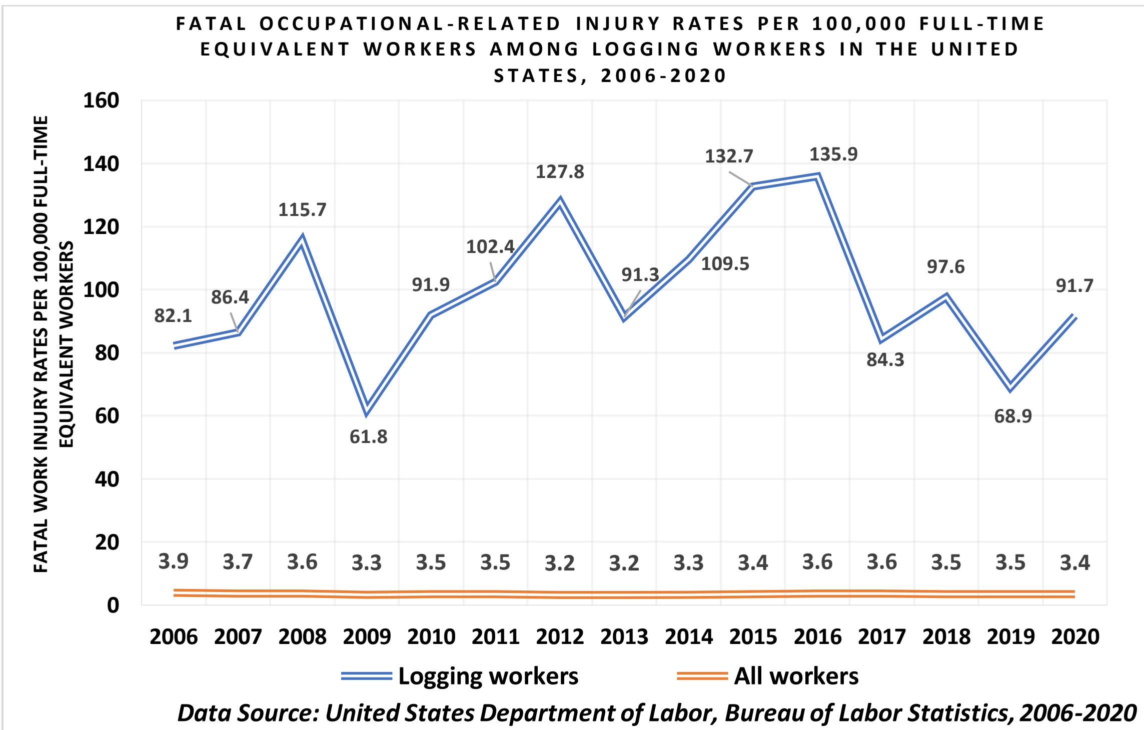
The biggest challenge to research in this area is that the national and state occupational injury and fatality data describe the injuries and fatalities experienced in the AgFF sector as the sum of the injuries and fatalities in agriculture, forestry (including logging), fishing and hunting industries. This grouping of injuries and fatalities in the AgFF makes it challenging to understand the injury risk in the individual industries. Louisiana's data for fatal and non-fatal injuries in forestry alone are not readily accessible.

Logging Industry

The forestry industry comprises four sub-industries, which include logging, solid wood products, pulp and paper, and wood furniture manufacturing. Logging is a primary source of raw materials for all other forest products companies (Tanger & Henderson, 2014). Logging is considered one of the most hazardous industries in the United States, and, in 2018, logging workers were at the highest risk of fatal occupational injuries (National Institute for Occupational Safety and Health, 2012; BLS, 2019). The fatal occupational injury rate among logging workers is higher than that for workers from all American industries combined (BLS, 2019). Figure 1.1 shows the fatal occupational-related injury rates per 100,000 FTE workers for logging workers and all workers in the United States, 2006-2020. Logging workers had the highest published rates of fatal occupational injury of (97.6 per 100,000 FTEs) compared to the fatal occupational rate

(3.5 per 100,000 FTEs) for all industries combined in the United States in 2018 (BLS, 2018a to BLS,2019). Unfortunately, the information on the fatal occupational injury rate among logging workers is not readily accessible at the state level, which prevents a clear understanding of this issue.

Figure 1.1: Fatal occupational-related injury rates per 100,000 full-time equivalent workers among logging workers in the United States, 2006-2020



Logging includes cutting and transporting timber and producing wood chips in the field (U.S. Census Bureau, 2017). Transportation of timber or logs is a significant part of the logging industry. Logging vehicles serve as the primary transportation mode of forestry products from remote locations to various processing facilities. Trucking is a vital part of the transportation of forestry products (Roberts, Shaffer, & Bush, 2005). Trucking contributed 40-60% of the total logging-related business expenses and is considered the most expensive phase of timber harvesting operations (Shaffer & Stuart, 2009). Given that truck driving is an everyday activity in the logging industry, the limited information on traffic-related injuries in the logging industry is concerning.

Occupational Motor Vehicle Crashes

In 2016, the leading cause of fatal occupational injuries in the United States was roadway crashes (Centers for Disease Control and Prevention [CDC], 2018). In 2017, 1,299 fatalities resulted from occupational-related motor vehicle crashes, almost one-quarter of all occupational-related fatalities (BLS, 2018b). In 2017 (63%) and 2018 (78%), most transportation-related occupational fatalities involved drivers of heavy trucks and tractor-trailers in the United States (BLS, 2018b; BLS, 2019). More than 80% of logging trucks in the United States are tractor-trailers, 11-axle trucks, or pulp trailer combinations (Cole, 2018; Green, 2005), although data and research on this issue are lacking.

Log Trucking

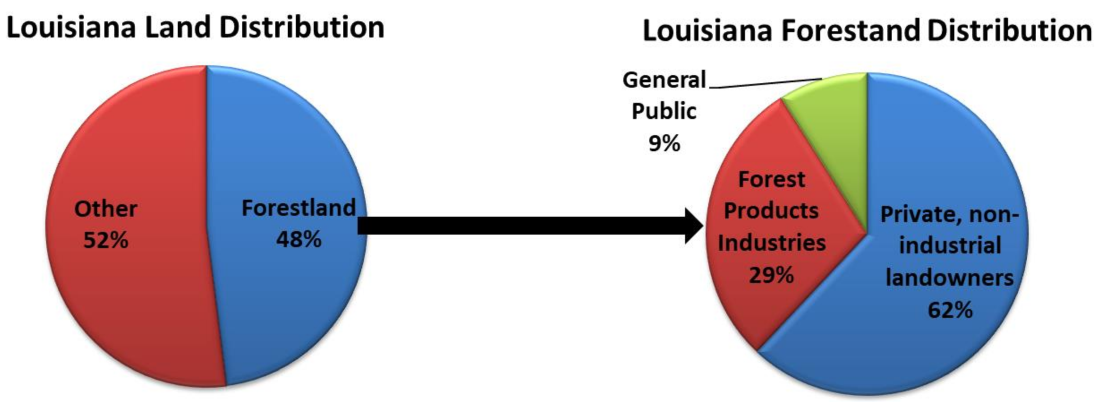
Fatal occupational injuries from transportation crashes are higher in the AgFF sector than in other sectors in the United States. In 2018, transportation crashes contributed to almost 48% of fatal occupational injuries in the AgFF sector (BLS, 2019). Also, in 2018, transportation crashes contributed 28% of total fatal occupational injuries in the logging industry (BLS, 2019). Fatal occupational injuries from transportation crashes in the logging industry increased from 26% in 2016 to 38% of total fatal occupational injuries in 2017 (BLS, 2016a; BLS, 2017). Fatal occupational injuries from transportation crashes in the logging industry decreased from 38% in 2017 to 28% of total fatal occupational injuries in 2018 (BLS, 2017; BLS, 2019).

Limited information is available on large logging truck crashes on roadways in general and specifically in Louisiana. Two-thirds of fatal occupational injuries in the AgFF sector were from transportation incidents (67%) in Louisiana in 2018 (BLS, 2019). Fatal injuries from transportation crashes in the AgFF sector slightly decreased from 70% in 2017 to 67% of total fatal occupational injuries in 2018 in Louisiana (BLS, 2019; BLS, 2018b).

Forestland Area

Almost one-third of the total United States land area is forestland (more than 750 million acres of land), and the two-thirds of forestland is timberland, producing or capable of producing wood for industrial use (Smith & Darr, 2004). One-third of forestland (more than 4 million acres of land) in Louisiana is owned by the forest products industry. Overall, Louisiana forestland is owned by private, non-industrial landowners (81%), forest products industries 10%), and the public (9%) (Louisiana Department of Agriculture and Forestry, 2013). Figure 1.2 shows the distribution of land and forestland in Louisiana.

Figure 1.2: Distribution of land and forestland of the State of Louisiana



(Data Source: Louisiana Department of Agriculture and Forestry)

Economic Contributions

The United States

The forest product industry is one of the top 10 manufacturing employers in the 48 contiguous United States (Smith & Darr, 2014). This industry generates more than $300 billion annually in sales and $55 billion in annual payroll, as per 2018 data (American Forest & Paper Association, 2020). The United States forestry and forestry products industry employed 950,000 employees in 2019 (American Forest & Paper Association, 2020). Therefore, the forestry product industry is a major employer and contributes substantially to the United States economy.

Louisiana

The forestry industry is the second largest manufacturing industry in Louisiana. Trees are the state's number one crop (Louisiana Forestry Association, 2018). Forestry alone contributed 25% of the value of agricultural commodities in 2013 (Louisiana

Forestry Association, 2018). The state's forests supply wood to approximately 180 primary wood-using industries (e.g., sawmills and paper mills) distributed throughout the state and 780 secondary wood-using industries. These include furniture manufacturers, cabinetmakers, millwork plants, and others that use the products produced by primary wood-using industries (Louisiana Forestry Association, 2018).

Notably, the logging industry makes a significant contribution to Louisiana's economy due to its employment and income generation. Louisiana is among the top five states for the highest employment level in logging occupations (BLS, 2018c). Louisiana is also in the top eight states for highest employment in all other categories (including logging workers) in the logging industry and top four states for the highest concentration of jobs and location quotients in all other categories in logging occupations (BLS, 2018c). Additionally, timber harvesting and transportation employed 8,000 people in Louisiana in 2017 (Louisiana Forestry Association, 2018). These make the logging industry one of the most significant employers and contributors to the state's economy.

Logging Industry Problems Related to Safety and Health

The truck driver shortage is the biggest concern for the American trucking industry. Due to this driver shortage, logging truck company owners are struggling to employ qualified truck drivers (Costello & Suarez, 2015). Mason et al. (2008) collected information from log truck companies (N=129 companies) and found that 87% of surveyed respondents indicated that it was challenging to find and retain qualified truck drivers in Washington State.

One difficulty retaining truck drivers could be lower wages for logging truck drivers than drivers in other industries (Baker & Mendell, 2016). A log truck registration data analysis from the WA Department of Licensing (WSDOL) indicated a 36% decline in the number of log trucks registered from 1998 to 2006 in Washington State (Mason et al., 2008).

Another primary concern for the logging industry is qualifying for truck insurance due to the hazardous nature of transporting logs. To qualify for insurance coverage, logging truck drivers must have two to three years of driving experience after getting a Commercial Driver's License (CDL) (Baker & Tyson, 2017; Costello & Suarez, 2015). Insurance companies can deny them coverage if logging truck drivers have serious traffic violations, such as speeding and DUI (Baker & Tyson, 2017).

Insurance coverage for logging trucks can be costly as well as complicated. The average insurance premium for logging trucks increased by 53% from 2011 to 2016, whereas, for other heavy vehicles, it increased by 12% for the same period in Georgia (Conrad, 2018). Covering logging trucks for insurance companies is riskier than providing other commercial auto insurance because logging trucks tend to be more expensive than other heavy vehicles (Conrad, 2018). The average cost of logging truck per claim has increased by approximately 40% since 2008 for a subset of carriers that offer log truck insurance (Baker & Tyson, 2017; Conrad, 2018). Among the ways to reduce the insurance premium could be to reduce crashes by offering targeted training and enhanced safety measures for logging truck drivers.

Vehicle Regulation

The lighting and marking regulations for projecting loads on logging trucks are similar to those required for other heavy trucks (LaDOTD, 2013). A red flag must be displayed if the rear projection is more than 15 feet beyond the end of the truck bed (LaDOTD, 2013). Logging trucks are prohibited from traveling at night, but there is no restriction on traveling during moderate rain and holidays (LaDOTD, 2013). Required oversize permits can be obtained on a daily, monthly, or yearly basis (LaDOTD, 2013).

Louisiana requires a commercial driver's license (CDL) for logging truck drivers. Class A (CDL for Combination Vehicles) and B (CDL for Heavy Straight Vehicle) licenses are required for drivers of the logging truck and logging operators (Classes of licenses and age requirements, 2018). The forest product license plate (Class 2) registration is required for vehicles carrying or transporting forest products in their natural form of logs, untreated ties, stave bolts, plywood bolts, plywood billets, wood chips, stumps, sawdust, moss, bark, and wood shavings, and property used in carrying and transporting sugarcane (Class 2) (Classes of licenses and age requirements, 2018).

Objectives

This dissertation uses current Louisiana crash data to perform an in-depth analysis of large logging truck crashes on public roadway crashes (2010-2018). To address gaps in the literature, the objectives of this dissertation are: 1) to examine associations between driver, vehicle, and crash factors and crash severity, stratified by vehicle type (logging and non-logging large truck crashes) and by crash type (single and multiple vehicle crash) in Louisiana from 2010 to 2018; and 2) to estimate the associations between driver characteristics and behaviors, and higher injury severity in large logging truck crashes on public roadways in Louisiana from 2010-2018 while accounting for the driver's age and gender, vehicle, and crash variables; and to stratify crashes by single versus multi-vehicle involvement.

Summary of Background

Logging-related traffic roadway crashes cause a considerable proportion of fatal occupational injuries in the United States (CDC, 2018). More than 50% of fatal occupational injuries among logging equipment operators in the United States were transportation-related (BLS, 2016). Also, fatalities and injuries due to logging-related roadway crashes in the United States have increased since 2012 (BLS, 2019). The only accessible information at the state level is that two-thirds of fatal occupational injuries in the AgFF sector in Louisiana were from transportation incidents (67%) in 2018 (BLS, 2019).

Logging trucks are the primary transport mode for forestry products to various processing facilities, and crashes are frequent. The American trucking industry is facing several related challenges. First, there is a continuing truck driver shortage due to drivers aging out of the workforce with insufficient replacement and increasing demand for truck drivers across industries. Second, the truck driver shortage makes it difficult to ensure a qualified and experienced truck driver workforce in the logging industry (Costello Bob, 2017). Last, the truck driver shortage further highlights the need to prevent crashes and ensure the health and safety of this workforce. Moreover, by reducing logging truck crashes on roadways, forestry industries could see lower insurance premiums and better coverage for their drivers.

Yet, limited data and research are available on logging truck crashes on roadways in the United States in general and Louisiana specifically. There is a need for research on such transportation so that these events can be tracked, risk factors identified, and countermeasures are put in place.

Design and Methods

Introduction

The current study analyzed logging truck crash data from the Louisiana Department of Transportation and Development (LaDOTD) Highway Safety database from 2010 to 2018. The purpose was to identify the driver and behavioral crash characteristics associated with higher crash severity for events involving logging trucks on a public roadway in Louisiana during those seven years. The researcher used a cross-sectional study design.

There is no gold standard for modeling crash data. The selection of the method for model fit is dependent mainly on the phenomena of interest and the data available. The model fit for this study consist of the characteristics of the crash incident, the driver's behavior, the vehicle(s) involved, and road and environmental conditions to identify the factors surrounding higher injury crash severity crashes (see Chapter 1, Data Description

Section and Appendix Table A-2 for specific details of dependent and independent variables).

STATA 16 (StataCorp LP, College Station, TX) was utilized to analyze crash data from Louisiana (2010-2018). This analysis determined the association between driver, vehicle, and crash factors and crash severity in large logging and non-logging truck crashes and identified driver characteristics and behaviors associated with higher crash severity in logging truck crashes on public roadways in Louisiana. Descriptive statistics and binary or multinomial logistic regression models were utilized to determine the associations between driver characteristics and behaviors and crash severity (higher or lower crash severity) in logging truck-related, single and multi-vehicle crashes. This study's findings provide evidence for informing future research and laying the foundation for targeted educational or other measures to promote roadway safety and reduce the number of crashes.

Data Source

The Louisiana Department of Transportation and Development (LaDOTD) Highway Safety (2010-2017) is the data source for all analyses. In Louisiana, a crash is defined as an incident resulting in injury or death for any person involved in the crash or property damage of more than five hundred dollars. The severity level of fatal crashes is updated within 30 days. The crash database is considered a complete census and not a sample of crashes in the state. The police officers who respond to the scene collect the crash data and complete the reports based on the evidence at the scene and interviews with the victims and witnesses.

The Louisiana crash data contain information on the characteristics of the crash, the vehicles, and people (drivers, injured and uninjured occupants, and injured pedestrians and bicyclists) involved. LaDOTD collects the crash data using six forms identified with the report number. The crash reporting forms that the LaDOTD uses are listed in Table 1.1., in which DPSSP stands for the Department of Public Safety and Corrections Office of State Police.

Table 1.1: List of forms used for crash reporting by the Louisiana Department of Transportation and Development (LaDOTD)

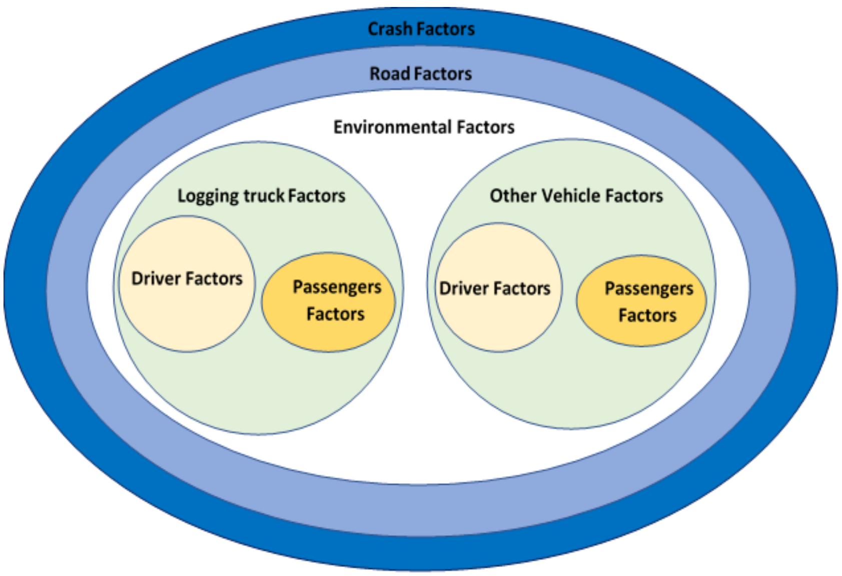
1. DPSSP 3105	Crash Report
2. DPSSP 3106	Vehicle/Pedestrian Information
3. DPSSP 3108	Additional Occupant Supplement
4. DPSSP 3110	Narrative Supplement/Alternative Grid
5. DPSSP 3111	Driver/Witness Voluntary Statement
6. DPSSP 3112	Uniform Railroad Grade Crossing Crash Supplement

Data Description

Data Structure

The study datasets with crash information were extracted for each year between 2010 and 2018 from the LaDOTD database. The study datasets were converted to STATA formats from a CSV file format for further statistical analysis. Crash data have information describing the characteristics of the crash, vehicle, and occupants. Crash level information includes the year of the crash, time of day or year, day of the week, weather, and lighting conditions, road type, road condition, crash location type, traffic control factors, and manner of collision. Vehicle level information refers to factors related to each vehicle involved in the crash (vehicle type, vehicle condition, vehicle light conditions, prior movement of the vehicle, the reason for the movement of the vehicle, and harmful events). Person-level information refers to drivers, injured and uninjured occupants, and injured pedestrians and bicyclists involved in the crash (e.g., age, gender, seatbelt use, distraction, impairment variables, and traffic violations). Details on the variables in the crash dataset are listed in Appendix Table A-3. Figure 4.1 shows the structure of the crash database for two vehicles involved in a logging truck-related crash.

Figure 1.3: Example of the data structure for a two-vehicle logging-related crash



Creating Logging Truck Crash Database

The logging truck crashes were extracted from the crash database with the person, vehicle, and crash factors. The large logging truck crashes were identified by selecting those flagged as “H” (logging truck) in the cargo body type field with vehicle configuration type of single-unit 2 axle (L), single-unit 3 axel (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), and truck double (R). Large non-logging truck crashes were identified as those that were not flagged as “H” (logging truck) or “K” (pole-trailer) in cargo body type with vehicle configuration type of single-unit 2 axle (L), single-unit 3 axel (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), truck double (R). Cargo body type pole trailer (K) was excluded from large logging truck crashes because it is unclear whether this cargo body type is heavily involved in logging transport. There is some anecdotal evidence that body type pole trailers are also used for logging. A crash type variable was created using the number of vehicles involved in crashes. A crash type “single logging truck crash” was defined as a situation in which only one logging truck was involved in a crash. The multi-vehicle crash was defined as more than one vehicle involved in a crash, but for this dissertation, a “multi-vehicle crash” was defined as a crash type that involved at least one logging truck and at least one other vehicle in a collision. The sample size for large logging truck crashes is 1,120, and large non-logging truck crashes 43,927.

Vehicle Types

The uniform motor vehicle traffic crash report for the State of Louisiana defines a logging vehicle as a logging truck, and the definition used for logging truck is “a truck or trailer designed to transport forestry products in their natural state such as logs and pulpwood” (State of Louisiana Uniform Motor Vehicle Traffic Crash Report, 2005). Figure 1.4 shows examples of cargo body type- logging trucks from the State of

Louisiana Uniform Motor Vehicle Traffic Crash report. The logging truck crashes were identified as those involving a cargo body type coded as logging truck (H) with vehicle configuration type of single-unit 2 axle (L), single-unit 3 axel (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), truck double (R) and not a pole trailer (K) cargo body type in Louisiana crash data 2010-2018. The large non-logging truck crashes were identified as those involving tractor-trailers, which were not flagged as logging truck (H) or pole-trailer (K) in cargo body type with vehicle configuration type of single-unit 2 axle (L), single-unit 3 axel (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), truck double (R).

Figure 1.4: State of Louisiana Uniform Motor Vehicle Traffic Crash Report: Examples of Cargo Body Type-Logging trucks (Coded as “H”)

(Data Source: State of Louisiana Uniform Motor Vehicle Traffic Crash Report)

Description of Selected Variables for study

Crash Severity Variable

LaDOTD codes crash severity based on the KABCO Injury Classification Scale (U.S. Department of Transportation, Federal Highway Administration, 2017). KABCO stands for a fatality (K), incapacitating/severe injury (A), non-incapacitating/moderate injury (B), possible injury/complaint (C), and no injury (O). Each person involved in a crash is assigned a severity code. The overall crash severity is determined by the highest severity assigned to an individual involved in the crash. The dependent variable for this dissertation was based on crash severity.

The following section describes each type of injury from the KABCO Injury Classification Scale (U.S. Department of Transportation. Federal Highway Administration, 2017).

Fatal crash (K) is defined as any injury that resulted in death within 30 days after the motor vehicle crash. Fatal crashes are updated with details of the cause of death within 30 days of the crash.

Severe crash (A) leads to incapacitating injury, defined as a non-fatal injury that prevents the injured person from walking, driving, or normally continuing the activities due to the crash.

Moderate crash (B) leads to a non-incapacitating apparent injury, which is defined as any injury, except a fatal injury or an incapacitating injury, which is apparent to observers at the scene of the crash.

Complaint crash (C) is a possible injury or any injury reported or claimed and not a fatal injury, incapacitating injury, or non-incapacitating evident injury.

No injury crash (O) is one in which no injury was reported or claimed, and there was no fatal injury, incapacitating injury or non-incapacitating evident injury, or possible injury.

Independent Variables

The following factors were studied for the association with the injury versus non-injury crashes. Detailed information on the variable categorization is included in Appendix Table A-2.

Driver demographic factors were the driver characteristics, including age and gender. **Driver behavioral factors** included seat belt use, violation code (e.g., failure to yield, following too closely, and careless operation of the vehicle), and a driver's condition (e.g., distracted, and fatigue, impairment as a result of alcohol and/or illegal or prescription drug use, and at-fault status).

Vehicle-related factors included vehicle condition (e.g., defective headlights or steering, tire or engine failure), vehicle light condition (e.g., headlights on or off and daytime running lights), type of vehicle (e.g., single-unit truck, truck/tractor, truck/trailer, or tractor semi-trailer), the motion of the vehicle prior to the crash (e.g., backing, crossed median or center line into the opposite lane and making a turn), and reason for motion (e.g., to avoid the other vehicle, vehicle out of control or traffic congestion), and the most harmful event (e.g., overturn or rollover, jackknife and cargo equipment loss or shift).

Crash-related factors included crash year (2010 to 2018), manner of collision (e.g., rear-end, head-on, and angle collision), traffic conditions (e.g., controls functioning or not functioning), daylight (yes or no), road alignment (straight or curve level), road surface conditions (dry, wet and ice), road surface type (blacktop or other) weather conditions (clear, cloudy and rain), roadway system classification (one-way road, and two-way road with no physical separation or with/without a physical separation or barrier), highway Type (interstate and US highway or state highway or parish road), intersection flag (yes or no), kind of location (manufacturing or industrial or business area or residential related area or open country), the day of the week (weekday or weekend) and time of the day (peak time or no peak time).

Specific Aims

Previous literature has provided very little information on logging truck crashes and no information on the associated driver and behavioral crash characteristics. The identification of the driver and behavioral crash characteristics is important because they may be more readily addressable than roadway design and other engineering or vehicle design factors. Knowledge of the driver and behavioral crash characteristics associated with crashes can be used to modify driver training programs and employer policies. Data from the Louisiana Department of Transportation and Development crash database from 2010-2018 were analyzed to address gaps in knowledge regarding logging truck crashes.

Specific Aim 1

Examine associations between driver, vehicle, and crash factors and crash severity, stratified by vehicle type and crash type, using data from the Louisiana Department of Transportation and Development from 2010-2018.

Specific Aim 1A

Determine whether driver, vehicle, and crash factors are associated with crash severity (higher severity versus lower severity) in large logging truck crashes, stratified by crash type (single versus multiple vehicles), using data from the Louisiana Department of Transportation and Development from 2010-2018.

For specific aim 1A, the null hypothesis was that there are no statistically significant associations between driver, vehicle, and crash variables and crash severity (higher severity versus lower severity) in large logging truck crashes for single-vehicle crashes or multi-vehicle crashes in Louisiana from 2010-2018.

Specific Aim 1B

Determine whether driver, vehicle, and crash factors are associated with crash severity (higher severity versus lower severity) in non-logging large truck crashes, stratified by crash type (single versus multiple vehicles), using data from the Louisiana Department of Transportation and Development from 2010-2018.

For specific aim 1B, the null hypothesis was that there are no statistically significant associations between driver, vehicle, and crash variables and crash severity (higher severity versus lower severity), in other large truck crashes for single-vehicle crashes or multi-vehicle crashes in Louisiana from 2010-2018.

For specific aim 1A and aim 1B, the dependent variable is binary and classified as higher crash severity crashes (KAB) and lower severity crashes (CO). The higher severity category coded as (1) fatal (K), severe (A), and moderate (B) injuries. The lower severity category coded as (0) included complaints or possible injury (C) and no injury or property damage only (O). Independent variables were driver, vehicle, and crash variables. The driver factors included driver's demographics and behavioral characteristics (e.g., age, gender, seatbelt use, distraction, and impairment variables and traffic violations). Vehicle variables included vehicle type, vehicle condition, vehicle light conditions, prior movement of the vehicle, the reason for the movement of the vehicle, and harmful events. Crash variables included the year of the crash, time of day or year, day of the week, weather, and lighting conditions, road type, road condition, crash location type, traffic control factors, and manner of collision (See Appendix Table A-2 for details).

The Pearson chi-square test was used to determine whether there was a statistically significant relationship between crash characteristics (all variables are either binary or categorical) and crash severity (KAB versus CO crash severity) by crash type (single versus multiple vehicle crashes) in large logging truck crashes. A similar analysis was conducted for large non-logging truck crashes. If the frequency for one or more of the cells is five or less for independent variables by the dependent variable then, Fisher's exact test was conducted in place of the Pearson chi-square test. An alpha level of 0.05 was used to define statistical significance. False discovery rate post hoc analysis was conducted to examine the issue of multiple comparisons between crash characteristics and crash severity (KAB versus CO crash severity) by crash type (single versus multiple vehicle crashes) in large logging truck and non-logging truck crashes. Conducting multiple comparisons or hypothesis tests can result in obtaining statistically significant findings just by chance. The false discovery rate control method (also known as

Benjamini–Hochberg procedure) can address and correct potential problems that may arise from conducting multiple comparisons (Benjamini & Hochberg, 1995; Glickman et al., 2014). After analyzing chi-square or Fisher's exact test results, the false discovery rate was computed and interpreted. STATA 16 (StataCorp LP, College Station, TX) was used to conduct the analysis.

Specific Aim 2

Estimate the associations between driver characteristics and behaviors and higher crash severity, stratified by crash type (single and multi-vehicle crashes) in large logging truck crashes while adjusting for vehicle and crash variables, using data from the Louisiana Department of Transportation and Development from 2010-2018.

Specific Aim 2A

Estimate the associations between driver characteristics and behaviors and higher crash severity in single-vehicle crashes involving a large logging truck while adjusting for vehicle and crash variables, using data from the Louisiana Department of Transportation and Development from 2010-2018.

For specific aim 2A, the null hypothesis is that there is no association between driver characteristics and behaviors and higher crash severity in single-vehicle crashes involving a large logging truck on public roadways in Louisiana from 2010-2018 while adjusting for the vehicle and crash variables.

For specific aim 2A, the dependent variable is binary and classified as higher crash severity (KAB) crashes and lower severity crashes (CO). The dependent variable was created from the crash severity variable (see Chapter 1, Data Description Section). The higher crash severity (KAB) was coded as 1 and included fatal (K), severe (A), and moderate (B) injuries. The lower crash severity (CO) category (coded as 0 or the reference category) included complaints or possible injury (C) and no injury or property damage only (O).

Independent variables were the driver (e.g., age) and behavioral factors (use of seat belt, impairment, distraction, fatigue, and violations), and they were adjusted for vehicle factors (vehicle condition, vehicle light condition, type of vehicle, most harmful event, motion of the vehicle prior to the crash, reason for motion), crash-related factors (crash year, the day of the week, time of the day, manner of collision, daylight conditions, weather conditions, traffic control conditions, road alignment, road surface conditions, road surface types, road type, roadway relation, road alignment, kind of location, intersection and highway type) (see Appendix Table A-2 for detailed information on categorization). Pearson Correlation Coefficients were calculated for all independent variables to identify highly correlated independent variables to help determine which independent variables should be considered during the modeling process. Before removing them from the final model, highly correlated independent variables were also examined during the model fit process.

After adjusting the model for vehicle and environmental factors, a binary logistic regression model was utilized to identify the associated driver, and behavioral crash characteristics in higher severity crashes involving only a large logging truck. Although multinomial logistic regression (MNL) would have been preferred, the available sample size was insufficient. The final results were interpreted using adjusted odds ratios (OR) and 95% confidence intervals (CI).

Specific Aim 2B

Estimate the associations between driver characteristics and behaviors and higher severity crashes in multi-vehicle crashes involving a large logging truck while adjusting for vehicle and crash variables, using data from the Louisiana Department of Transportation and Development from 2010-2018.

For specific aim 2B, the null hypothesis is that there is no association between driver and behavioral crash characteristics and higher crash severity in multi-vehicle crashes involving a large logging truck in Louisiana from 2010-2018 while adjusting for the vehicle and crash variables.

For specific aim 2B, the dependent variable was categorical and classified as higher crash severity crashes (KAB), minor severity crashes (C), and no injury or property damage (O). The dependent variable was created from the crash severity variable (see Chapter 1, Data Description Section). The higher crash severity category was coded as (1) and included fatal (K), severe (A), and moderate (B) injuries. The minor crash severity category was coded as (2) included complaints or possible injury (C). The no injury category coded as (0) included no injury or property damage only (O).

Independent variables were the driver characteristics (e.g., age) and behavioral factors (use of seat belt, impairment, distraction, fatigue, violations, and at-fault status) and adjusted for vehicle factors (vehicle condition, vehicle light condition, type of vehicle, most harmful event, motion of the vehicle prior to the crash, reason for motion), and crash-related factors (crash year, the day of the week, time of the day, manner of collision, daylight conditions, weather conditions, traffic control conditions, road alignment, road surface conditions, road surface types, road type, roadway relation, road alignment, kind of location, intersection and highway type,) (see Appendix Table A-2 for detail information on categorization). Pearson Correlation Coefficients were calculated for all independent variables to identify highly correlated independent variables to help determine which independent variables should be considered during the modeling process. Before removing them from the final model, highly correlated independent variables were also examined during the model fit process.

Hausman test and suest-based Hausman test were conducted to determine if the MNL specification is appropriate for the use of the model. Multinomial logistic regression was utilized to identify the associations between driver and behavioral factors and higher crash severity in multi-vehicle crashes involving large logging trucks while adjusting the model for vehicle and crash factors. The final results were interpreted using adjusted odds ratios and 95% confidence intervals.

Literature Review

Methods

Literature search

The researcher looked for relevant articles in the following databases: PubMed, Google Scholar, EBSCO, CAB Abstracts, Scopus, Web of Science, ProQuest Agriculture Journals, Forestry Compendium, Mechanical & Transportation Engineering Abstracts, Engineering Research Database, and Materials Science & Engineering Database. Studies identified using the search term "logging or forestry-related fatal or non-fatal injuries from transportation crashes that occurred on the public roadways."

Logging, forestry, log, timber, lumber, log-haul, log-hauling, truck, vehicle, motor vehicle, crash, accident, injury, fatal, road, roadway, highway, traffic, transportation, and transport were words used in various combinations to perform a literature search. The search terms used for the literature review are shown in Table 1.2. No restriction was placed on publication year to maximize the number of relevant articles. The retrieved materials included technical formal and informal reports, peer-reviewed articles, conference papers and presentations, and dissertation papers (number of articles = 198).

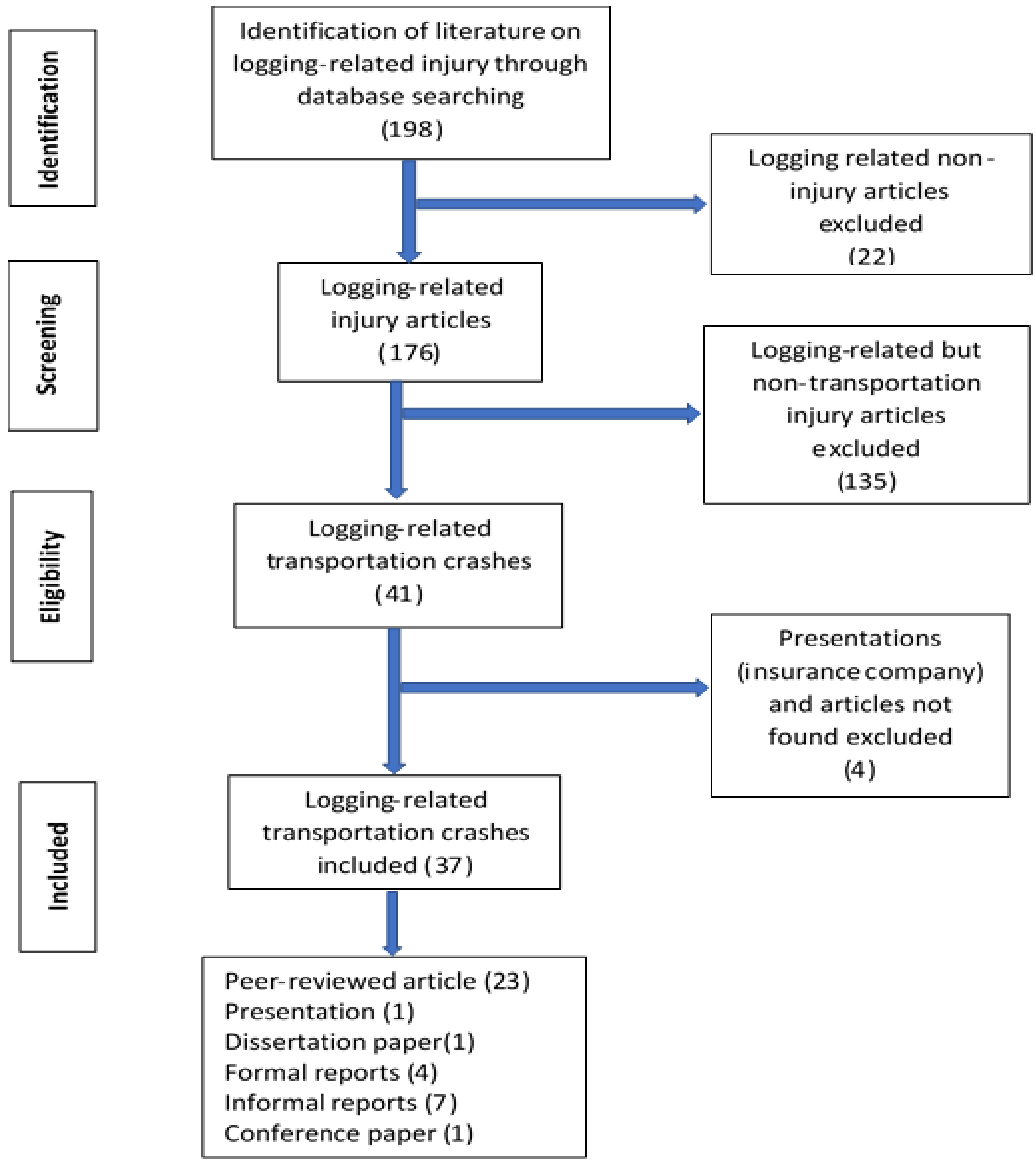
Inclusion and exclusion criteria

After identifying logging-related injury articles, the researcher then screened for only transportation-related injuries in the logging industry (number of articles = 176). The included articles related to logging or forestry-related public roadway crashes involved a large logging truck or vehicle, covered all injury severities, and/or made use of crash records or other surveillance data for statistical or qualitative analysis. The articles analyzing only logging-related injuries on the worksite, non-transportation logging-related injuries, and transportation-related crashes on the worksite (and not the public roadway) were excluded from the literature review.

Literature selection

Due to the lack of literature on the study topic, all relevant published articles and reports were selected for examination. The researcher screened the articles based on titles and abstracts. Then, the full text was reviewed for selected eligible articles (number of articles = 41). In addition to the electronic search, the researcher also searched the references list from the included articles (number of articles = 37). Figure 3.1 is a flow chart showing the selection process for the literature review.

Figure 1.5: Flow Chart for Literature Selection



Note: Refer to Appendix Table A-1 for a detailed description of articles included in the literature review.

Logging Vehicle Definitions

Vehicle Definitions

Previous literature has used different terms to define logging vehicles, namely the logging truck or logging tractor-trailer. For this study, a logging truck was defined as "a straight-frame (non-articulated) truck that is equipped to handle short pulpwood loaded across the frame or longer lengths loaded parallel to the frame…." (Greene, Dale, n.d.; Greene et al., 2007). A logging tractor-trailer was defined as an articulated vehicle consisting of a tractor with an attached trailer that most often hauls tree-length stems or two bunks of random-length wood parallel to the frame." (Greene, n.d.; Greene et al., 2007).

Cole (2018), who studied fatal logging-related crashes on U.S. highways from 2011 to 2015, may have confounded the two types of logging vehicles. He referred to logging vehicles as logging trucks from the Fatality Analysis Reporting System (FARS) database, which may have included both logging tractor-trailers and logging trucks. The State of Louisiana Uniform Motor Vehicle Traffic Crash Report defines a logging truck as "A truck or trailer designed to transport forestry products in their natural states such as logs and pulpwood" (Louisiana Department of Transportation and Development (LaDOTD), 2005). There is no specific definition of a logging tractor-trailer.

Table 1.2: Search terms used for literature review

Logging-related		Vehicle-related		Crash-related		Roadway-related
Logging Forestry Log Timber Lumber Log-haul Log-hauling	AND /OR	Truck Vehicle Motor Motor vehicle	AND/ OR	Crash Accident Injury Fatal	AND/ OR	Road Roadway Highway Traffic Transportation Transport

Vehicle configurations

Logging vehicles commonly include tractor-trailers, trucks with or without trailers, vans, and lorries. However, more than 80% of logging trucks are tractors trailers, often referred to as logging trucks. Tractor-trailers were the most common vehicle configuration (83%) for logging trucks on US highways from 2011 to 2015 (Cole, 2018).

Vehicle legal weight limits

Logging vehicles often are large vehicles and are designated as heavyweight, overweight, and oversized. In Louisiana, logging trucks must have forestry product permits and forest management equipment permits, which allow vehicles to exceed the legal limitation on width, which is currently 10 feet (Louisiana Department of Transportation & Development [LaDOTD], 2013). The maximum gross vehicle legal weight limit for forestry product transportation on interstate highways is 83,400 lbs. and 86,600 lbs. on non-interstate highways in Louisiana (LaDOTD, 2013). The maximum legal length of vehicles transporting forest products in their natural or treated state is 65 feet plus 1-foot additional tolerance in length (LaDOTD, 2013).

Occupational Surveillance Data & Workers' Compensation

Occupational Surveillance Data

Only one international study compares the fatality rate for work-related (including logging) motor vehicle traffic crashes. Driscoll et al. (2005) compared crashes in Australia (1989–92), New Zealand (1985–98), and the United States (1989–92) but provided limited information specifically for the logging industry. Based on surveillance data in each country, the highest rates were observed for the United States at 2.69 per 100,000 person-years (95% CI 2.42–2.96) compared to New Zealand (0.91 per 100,000 person-years; 95% CI 0.54 to 1.42) and Australia (1.84 per 100,000 person-years; 95% CI 1.25 to 2.61) (Driscoll et al., 2005).

Several other studies have focused on occupational injuries in the logging industry, but none of these studies provided detailed information on traffic-related injuries or focused on the offsite (especially on public roadways) injuries in logging truck drivers. Logging truck drivers are at high-risk for sustaining injury and deaths while driving (Conway et al., 2017; Patterson, 2007; Rosecrance, Lagerstrom, & Murgia, 2017). In Louisiana, limited data are accessible at the state level, and these data do not provide the complete picture of occupational traffic-related fatal and non-fatal injuries in the logging industry.

Truck drivers working in the logging industry mostly sustained injuries from motor vehicle crashes. An OSHA report provided information on the frequency of logging-related injuries but little information on logging truck crashes. (Occupational Safety and Health Administration [OSHA], 2000).

Traffic-related fatal and non-fatal injuries are evidently high in the logging industry. However, these studies have provided little information on the risk of traffic-related injuries in logging truck drivers, and additional research is needed to fill the gap in knowledge on traffic-related injuries in logging truck drivers.

Workers' Compensation Data

Workers' compensation claim data is a reliable source for analyzing occupational injury claims by logging truck drivers. Using this data, Smith et al. (1999) found that highway and non-highway vehicle crashes were the second most common cause of fatalities in logging workers in Louisiana. About 20% of logging injury claims were from logging truck drivers in Louisiana between 1985 and 1992 (Pine, Marx, & de Hoop, 1994). However, all of these studies are outdated, and they provide little to no information on the characteristics of the driver, vehicle, and environment in traffic-related occupational injuries in logging truck drivers.

Existing literature indicates that more than 10% of logging injury claims were the result of vehicular incidents. About 12% of the logging injury claims occurred on roads or highways in the Southeastern United States in 2001 (Roberts et al., 2005) and Washington between 1998 and 2005 (Mason et al., 2008). Considering that a significant proportion of logging-related injury claims are traffic-related, there is a need for further detailed analysis of traffic-related injuries in logging truck drivers.

Moreover, the analysis of Workers' Compensation claims and other qualitative data indicated that driving a logging truck is one of the highest risk jobs. Roberts et al. (2005) reported that logging truck drivers were the third most frequent job classification listed under Workers' Compensation claims for injury while on the job in the Southeastern United States in 2001. Equipment operators (38%) and deck hands (27%) were numbers one and two.

Only one study has analyzed the trend of injury claim data for logging truck drivers. Roberts et al. (2005) found an increasing number of injury claims from logging truck drivers involved in motor vehicle crashes. This study compared the characteristics of injuries on mechanized logging operations from injury claims data of four worker compensation insurance providers from the Southeastern United States in 1996 and 2001. They found a 6% increase in traffic-related logging truck injury in the five-year period, which climbed from 35% to 41% (Roberts et al., 2005). While this is an interesting addition to the literature, limited information exists on the overall trend of injury claims by logging truck drivers.

Log hauling (transporting logs) is another term used in the literature to indicate transporting logs. A literature search using this term produced one study that estimated traumatic brain injuries (TBI) in the log-hauling industry (Wrona, 2006). Log hauling was one industry with a higher relative risk of 14.3 among the insurance risk classes with seven or more cases of traumatic brain injuries (TBI) in Washington State from 1994 to 2001 (Wrona, 2006).

Previous literature indicates that logging truck drivers were more likely to sustain injuries while driving a truck than while loading a truck. Roberts et al. (2005) found that logging truck drivers (22%) received injuries more frequently, and in those, 48% mainly were injured while driving. The logging truck drivers most often sustained injuries while driving a loaded truck (79%) than driving empty trucks (21%) (Roberts et al., 2005). Logging truck drivers more often sustained injuries (24%) among all logging workers, and of this, 24% of injuries in logging truck drivers mostly happened while driving a truck (35%), performing maintenance (14%), trimming the load (10%), or getting into or out of the truck (8%) (Shaffer & Milburn, 1999).

Limitations

The analysis of Workers' Compensation claim data provided limited information on injuries in logging truck drivers. The Workers' Compensation claims data used to study logging-related injuries have inherent limitations. Small employers are not included in the routine surveillance system and remain exempt from federal regulations (Lagerstrom, Magzamen, & Rosecrance, 2017). Moreover, the administration database is subject to a certain degree of miscoding, data entry errors, missing data, and misclassification. For example, the coding of data for cause of injury is not required by workers' compensation claim administration: so, the source of injury information often is missing (Alexander, Franklin, & Fulton-Kehoe, 1999).

The limited information on working hours, number of workers, and estimated productivity complicate comparing different states' Workers' Compensation claim data to national statistics (Lagerstrom et al., 2017). However, it is crucial to keep in mind that most studies based on Workers' Compensation claim data are old and might not be relevant to the current situation. Importantly, the details of Workers' Compensation claim data collection may vary in each state. Because of this, comparing the data of different states can be challenging.

Logging-Related Crashes

Logging-Related Crashes: Crash Database Analysis

There are few national-level and state-level studies on logging-related crashes. By reviewing the existing literature, logging-related motor crashes could be related to driver characteristics, vehicle condition or configuration, environmental characteristics, roadway factors, geometrics, and crash-related characteristics. The following section contains a comprehensive overview of the review findings.

Frequencies and Proportions

Overall logging-related roadway crashes have risen in the United States since 2012 (Cole, 2018; and Conrad, 2018). Cole (2018) characterized the fatal logging-related crashes nationally and regionally using FARS and Motor Carrier Management Information System (MCMIS) databases between 2011 and 2015. Fatal logging truck crashes have increased by 41% in the United States between 2011 and 2015 (Cole, 2018). Using the Federal Motor Carrier Safety Administration (FMCSA) database, an analysis of logging truck crashes indicated that logging truck crashes doubled in the United States from 2010 to 2015 (Baker &Tyson, 2017).

This increasing trend in logging-related crashes is anticipated to continue (Baker & Tyson, 2017). Therefore, there is a need for more research to add more knowledge about crash characteristics in logging-related incidents. An increase in logging truck crashes on the roadways is expected in the future due to the recovery of the forestry industry (Baker and Tyson, 2017). Timber markets have recovered after the recession, but so have severe logging truck crashes (Conrad, 2018).

Reporting

Information about precise vehicle miles traveled for logging trucks is not readily available. Existing literature uses different units to calculate crash rates. The accessible data to calculate the crash rates is on wood produced, wood harvested, and wood consumed. Cole (2018) calculated national and regional fatalities per 100 million cubic feet (ft3) of wood harvested in the United States. The national crash rate for log trucks was 0.7 fatal crashes per 100 million ft3 of wood harvested (Cole, 2018). The highest crash rate for log trucks was reported in the Southeast region with 0.9 fatal crashes per 100 million ft3 of wood harvested, compared to the Northeast (0.7 fatal crashes per 100 million ft3 of wood harvested), West (0.4 fatal crashes per 100 million ft3 of wood harvested), and Midwest (0.3 fatal crashes per 100 million ft3 of wood harvested) (Cole, 2018).

Greene et al. (2007) analyzed logging truck crash data in one of those southern states. Based on the Georgia Department of Motor Vehicle Safety data, the authors estimated crashes per million tons of wood consumed. Like Cole, they concluded that there was an increase in crashes with 19 crashes per million tons of wood consumed in 2003 compared to 11 crashes per million tons of wood consumed in 1991 in Georgia (Greene et al., 2007). Conrad (2018) calculated logging truck crashes per million tons hauled in Georgia from 2006 to 2016. The logging truck crashes per million tons hauled declined from 16.1 crashes in 2006 to 5.1 crashes in 2012 but increased to 6.3 per million tons hauled (Conrad, 2018), paralleling the economic condition of the logging industry. Moreover, since 2012, the crashes have become increasingly severe, with injury-producing logging truck crashes increasing by 72% in Georgia (Conrad, 2018).

The geographical location of prior studies

So far, logging-related crash studies have been conducted in Georgia (Baker, Cutshall, & Greene, 2012; Conrad, 2018; Greene., n.d.; Greene et al., 1996; Greene, Baker, & Lowrimore, 2007), Washington (Mason et al., 2008), Upper Peninsula of Michigan (Green, 2005) and regional analyses that included Northeast, West, Midwest and Southeast regions of the United States (Cole, 2018). The overall pattern of logging truck crashes in the United States has been analyzed, but this analysis was limited to fatal crashes only (Cole, 2018). None of these crash analyses have been conducted for Louisiana specifically.

Crash Outcomes

Injury Severity

Fatal and injury crashes have been increasing in the United States since 2012 (Cole, 2018; Conrad, 2018). Logging trucks are involved in slightly more fatal and injury crashes than truck or bus and all-vehicle crashes, as logging trucks are the largest and heaviest vehicles on the public roadways, especially in logging intensive areas (Green, 2005).

Conrad (2018) studied the frequency of fatal, injury, and tow-away logging truck crashes in the United States from 2010 to 2015, which indicated that they increased by 46%, 85%, and 117, respectively (Conrad, 2018). A more concerning issue is that fatal logging truck crashes increased by 41% in the United States between 2011 and 2015 (Cole, 2018). Additionally, fatal logging tractor-trailer crashes increased by 33% in the United States between 2011 and 2015 (Cole, 2018). The analysis of the FMCSA data between 2010 and 2015 indicated that logging truck crashes were more severe than other types of crashes (Baker & Tyson, 2017).

Single Versus Multiple Vehicle Crashes

Existing literature suggests that there may be a difference in single and multiple vehicle crashes in terms of numbers and characteristics (Kockelman & Kweon, 2002; Savolainen & Mannering, 2007; Ulfarsson & Mannering, 2004). Similarly, research on single and multiple logging-related crashes indicates that the proportions of single and multiple logging-related crashes are different. The analysis of fatal logging truck crashes found that there are more multiple vehicle crashes (82.5%) than single-vehicle crashes (17.5%) in the United States (Cole, 2018). However, the available literature has limited information on identifying behavioral and other crash factors associated with logging-related single and multiple motor vehicle crashes.

Kind of locations: Intersections

More than 20% of fatal logging truck crashes happened in intersections in the United States during 2011-2015 (Cole, 2018).

Driver Factors

Driver's age

In general, an aging workforce compounds the problem of qualified truck driver shortage (Costello, 2017). Cole (2018) found that logging truck drivers are slightly older than other heavy truck drivers based on an analysis of fatal crashes from FARS data involving log trucks in the United States. Logging truck drivers are older drivers, with an average age of 48.8 years, ranging from 18 to 80 years (Cole, 2018). The average logging truck driver age for the Southeast was 48.5 years; in the Northeast, the average was 46 years, in the Western region, the average was 53.4 years; and in the Midwest, the average was 45.5 years (Cole, 2018).

Gender

None of the previous crash analyses included gender, considering that most truck drivers are male. Only 6% of all truck drivers are female in the United States (Costello, 2017). Most qualitative studies interviewed male logging truck drivers in the Southern region, specifically Alabama, Georgia, and Mississippi (Carnahan, 2014).

Race

Carnahan (2014) conducted a survey during one-day truck driving safety courses by a professional training company for logging truck drivers in Alabama, Georgia, and

Mississippi. The author reported that 65% of participants were Caucasian, 20% were African American, and 15% were Hispanic (Carnahan 2014). This was the only study the researcher could find dealing with ethnicity/race distributions of logging truck drivers. Certainly, there is a need for more research using this as a variable.

Impairment

Scant information is available about the effect of impairment from alcohol, legal and illegal drugs, and both alcohol and drugs on injury severity of logging-related crashes. There is no data for Louisiana, but there were statistics from nearby Georgia. Here, Driving Under the Influence (DUI) was identified in 0.1% of logging truck crashes and 1.2% for other heavy vehicles (Conrad, 2018). DUI alcohol-related crashes involving logging tractor-trailers (0.9%) and logging trucks (2.3%) were higher than crashes involving other heavy trucks (0.5%) (Greene et al., 2007). However, DUI alcohol-related crash proportion for logging tractor-trailer (0.3%), logging trucks (0.7%), and other heavy trucks (0.2%) in that state have declined slightly in recent years (Greene et al., 2007).

The overall proportion of DUI is small in logging-related crashes. The United States Department of Transportation (DOT) requires drivers of heavy vehicles, commercial vehicles, and hazardous waste vehicles to comply with drug and alcohol testing before employment and post-crash (Federal Motor Carrier Safety Administration [FMCSA], 2019). This could be a reason for the reduction in DUI-related logging truck crashes.

Seatbelt Use

The use of a seatbelt is mandatory for all vehicle drivers, but only 56% of logging truck drivers responded that they always wore the seat belt (Carnahan, 2004). This was the only study that looked at seatbelt use.

Fatigue

Extensive research has been done on the association between fatigue and increased risk of crashes. A research synthesis of the Transportation Research Board (TRB) publications concluded that sleep deficits, night driving, reduced sleep, and fatigue are associated with dangerous driving, reduced performance, and falling asleep while driving (Orris, 2005). There is an increased connection between the risk of a truck crash and hours of driving after the fourth hour, and this likelihood increases with each additional hour of driving (Campbell, 2002; Lin, Jovanis, & Yang, 1993). However, these statistics are for truck driving in general; logging-related crash analysis has not provided insights on fatigue and its association with crash involvement.

Some qualitative studies have discussed the association between fatigue and increased risk of logging truck crashes. In a focus group, 16 professional loggers noted that they believed driving a logging truck for many hours in the day and at night was associated with fatigue and elevated risk of crashes (Rosecrance et al., 2017). In another study, logging truck drivers reported the risk of being in an accident due to fatigue caused by driving long distances to sawmills (Lagerstrom et al., 2017).

Fatigue in truck drivers is a significant public safety issue. Hours-of-service (HOS) rules prohibit truckers from driving more than 11 hours consecutively, working more than 14 hours per shift, and driving more than 60 hours in a week or 70 hours over an eight-day period (FMCSA, 2015). Logging truck drivers often operate beyond the legal limit of hours of service. Logging truck company owners confirmed this in a survey conducted in Washington in 2006 (Mason et al., 2008). Logging truck drivers work long hours with an average of 12.2 hours per day (average 69 working hours per week) and transport multiple loads per day (average 2.9 loads per day) (Mason et al., 2008). This is alarming, but additional research is needed to better understand fatigue in logging truck drivers.

Years of Experience

The finding of a statewide survey of 129 logging truck companies recorded that the logging truck drivers' average experience in trucking operations was 27 years, ranging from 0 to 54 years (Mason et al., 2008). However, there is no published information on the relationship between the driving experience of the log truck operator and logging truck crashes. Crash records do not contain the driver’s work experience. This association could only be studied by interviewing drivers who were involved in crashes.

Job Change

The logging trucking industry faces issues of recruiting and retaining a highly qualified workforce, as the pay for logging truck drivers is frequently lower than that of drivers in other industries (Baker and Mendell, 2016). American trucking industries are experiencing truck driver shortages (Costello & Suarez, 2015). Logging truck drivers often do not work for a logging company. Baker and Mendell (2016) indicated that more than 40% of logging truck drivers work on a contract basis. Independent contractors often do not get benefits from logging companies, which could be another reason for difficulties in retaining the drivers. Therefore, the stability of this workforce is a concern due to the limited information available about contractor truck drivers (Baker & Mendell, 2016). Of further concern, an analysis of the Commercial Driver's License program and the Motor Carrier Management Information System (MCMIS) database found a connection between frequent job change by commercial drivers and a higher crash involvement rate (FMCSA, 2003).

At-Fault Status

Existing literature suggests that other vehicles often contribute to logging-related truck crashes. In multiple-vehicle crashes involving logging trucks, 53.2% of fatal crashes involved another vehicle from 2011 to 2015 (Cole, 2018) whose driver was at fault for the collision. The literature on commercial motor vehicle crashes indicated that passenger vehicles are often at fault in commercial motor vehicles crashes (Blower, 1998; Hanowski, Hickman et al., 2007; Mason et al., 2008; Wang et al., Blincoe, 1999).

Existing research provides limited information on the association between at-fault status and logging-related crashes on public roadways. Additional research is needed to understand this association and design targeted safety measures and training programs for logging truck drivers.

Violations

Violation of traffic safety rules is another indicator of the driver's behavior in a crash (Mason et al., 2008). One crash analysis estimated that the most commonly cited violations were the failure to keep in the proper lane (20.7%) and careless driving (14.7%) (Cole, 2018). Other common violations contributing to collisions are following too closely, misjudging overpass clearance, and improper lane changing. (Conrad, 2018). The most common contributing factor (29.1%) for fatal logging trucks crashes from 2011 to 2015 was another vehicle crossing the centerline into the opposite lane or a logging truck lane (Cole, 2018).

Vehicle Factors

Vehicle age

Logging trucks are older than other heavy trucks, which could increase the risk of a crash or increase injury severity. Few studies on logging-related crashes have compared vehicle ages of logging trucks and all trucks. The latest data reveals that the average age of logging trucks involved in crashes was 14 years, seven years older than other heavy vehicles on the road at the time (Conrad, 2018). The average age of log trucks was 13 years, which was older than the overall average age of all trucks of 7.6 years (Cole, 2018).

An analysis of logging-related crashes shows that the old logging trucks could have a higher mechanical failure rate than other heavy trucks (Greene et al., 1996). New trucks are adequately maintained and have traveled fewer miles compared to old trucks, and old trucks have fewer safety features than new trucks. This lack of proper maintenance and safety technologies could be a reason for old trucks being less safe (Greene et al., 1996).

Mechanical Failure

Mechanical failure is one of the common contributing factors in logging-related crashes. The mechanical failure rate significantly declined in some states due to the beginning of the random roadside inspection (Baker et al., 2012; and Conrad, 2018: Greene et al., 1996; Greene et al., 2007; Greene, n.d.). Mechanical failure-related crashes dropped from 10.9% to 5.5% for logging tractor-trailers, 12.9% to 3.2% for logging trucks, and 3.8% to 2.3% for other heavy trucks from 1988-1991 to 2005-2008 (Greene, n.d.). Mechanical failure-related crashes declined for logging vehicles from 11.5% during 1988-1991 to 5.0% during 2005-2008 in Georgia (Bakers et al., 2012).

Other common contributing factors to logging truck crashes were brake failure and slick or damaged tires. However, the number of these accidents has gone down by at least half since 2013 (Conrad, 2018; Greene, 2010), perhaps due to better equipment and more frequent inspection.

Rollover or Overturn

Logging trucks have a higher occurrence of rollovers during fatal crashes than other cargo body types. In a study of crashes from 2011-2015, researchers found that the most common harmful event in fatal logging truck crashes was rollover (32.4%) (Cole, 2018). Logging trucks experienced rollovers in 78% of fatal crashes at some point during the crash (Cole, 2018). There are more rollovers in single-vehicle crashes involving logging trucks than in multiple vehicle crashes involving logging trucks (Cole, 2018). Logging trucks are often heavier than other trucks and have a higher center of gravity, which increases the likelihood of rollover in an accident (McKnight & Bahouth, 2008).

Loss of load

Securing the load is a critical part of the transportation of logs, and loss of load is a public safety issue that can directly affect the likelihood and severity of a crash. The load loss from a logging truck could result in fatalities or serious injuries. Pre-crash cargo shift (due to improperly secured log-loads) is a contributing factor in large truck crashes had the highest relative risk ratio of 56.3 in the Large Truck Crash Causation Study (LTCCS) (FMCSA, 2007).

Environmental Factors

Very limited information is available about the relationship between environmental factors and fatal and non-fatal logging crashes. None of the previous studies have studied the impact of environmental conditions and logging-related crashes, except for the studies conducted by Cole (2018) and Green (2005).

Time of day

Logging trucks are not permitted to travel on public roadways at night. Logging trucks are on the road only during business hours. So, logging truck crashes decline after 6:00 PM, whereas all other vehicle crashes begin to rise at that time (Green, 2005). The pattern for logging trucks and all vehicle crashes is similar during early morning and business hours (Green, 2005). Despite the prohibition on nighttime driving, more than 25% of logging truck drivers reported in a survey that they traveled between 6:00 p.m. and 6:00 a.m. in Alabama, Georgia, and Mississippi (Carnahan, 2004). Driving logging trucks at night is the biggest concern for violation of safety regulations.

Day of week

Logging trucks are prohibited from traveling on the public roadways on weekends and holidays in most states. Logging truck crashes are significantly low on weekends compared to weekdays (Green, 2005). Logging truck crashes are strongly correlated with truck and bus crashes and have closely identical patterns of crashes concerning the day of the week (Green, 2005), with Friday being the most dangerous day.

Weather conditions

Almost two-thirds of fatal logging truck crashes happened in clear weather in the United States from 2011 to 2015 (Cole, 2018). More than 25% of logging truck crashes happened in adverse weather conditions, and 15% of fatal logging truck crashes happened in cloudy weather (Cole, 2018). About 5-6% of fatal logging truck crashes happened in the rain (Cole, 2018: Green, 2005). About 4% of fatal logging truck crashes happened in other weather conditions (fog, snow, sleet hail) (Cole, 2018).

Light conditions

Most fatal logging truck crashes happened in daylight (76%) in the United States during 2011-2015 (Cole, 2018). Lack of visibility could contribute to 15% of fatal logging truck crashes and those that happened in the dark with no environmental lighting (Cole, 2018).

Roadways Classification

Most logging truck crashes happened on a state highway (69%), whereas 61% of truck and bus crashes happened on state highways (Green, 2005). More than 45% of fatal logging truck crashes happened on State highways and 33.7%' on US highways from 2011 to 2015 (Cole, 2018).

Limitations in the data

Previous literature does not include an in-depth analysis of factors associated with more severe crash severity in large logging truck-related crashes. Minimal research has examined the behavioral factors including impairment and seatbelt use in logging truck crashes, but not in Louisiana. Most studies are outdated and may no longer be relevant.

Logging-Related Crashes: Qualitative Research

A small number of qualitative studies are available. Logging truck drivers are considered being at high risk of sustaining injury and death. Professional loggers recognize that the primary risk for injury and death is transporting logs in trucks (Rosecrance et al., 2017). Additionally, logging contractors also noted that logging trucks are at high risk of fatalities should there be a collision (Conway et al., 2017; Patterson, 2007).

Logging truck driving is one of the job tasks recognized as contributing factors for increased risk for logging-related injuries. Driving a logging truck for many hours in the day and at night was found to be associated with fatigue and elevated risk of crashes (Rosecrance et al., 2017). Logging truck drivers reported a high risk of involvement in road crashes due to poor drivers on the highways and fatigue from driving long distances to sawmills (Lagerstrom et al., 2017).

Most logging truck drivers (89%) said that traffic and roads conditions are the most significant dangerous part of their job (Mason et al., 2008). Loading and unloading of logs (11%) were considered the most dangerous part of their job (Mason et al., 2008).

Targeted driving training and safety measures are necessary for logging truck drivers, as they often do not follow safety measures (Cole, 2018). For example, the use of a seatbelt is mandatory for all vehicle drivers, but only 56% of logging truck drivers responded that they always wore the seat belt (Carnahan, 2004). More than one-third of logging truck drivers in those same three states received a moving violation in the past three years. They also did not always perform pre-trip inspections. Logging truck drivers often operate beyond the legal limit of hours of service (Mason et al., 2008) and travel illegally on the road at night (Carnahan, 2004). This might explain why more than 15% of these drivers were involved in roadway crashes (Carnahan, 2004). However, additional research is needed to identify contributing factors in logging-related crashes to design targeted driving training and safety measures.

Limitations

Results from qualitative data provide helpful information, but the information is subjective and contains self-evaluations of the driver’s job responsibilities, which need to be validated with analysis crash records (Carnahan, 2004; Enez, Topbas, & Acar, 2014). Another reason to analyze crash records is that the findings of qualitative studies do not include information on fatal crashes (Enez et al., 2014).

Almost all of the study population comprises male logging truck drivers: so, the findings may not apply to female logging truck drivers (Carnahan, 2004), although they are few. Most of the studies mentioned above also have a limited sample size. The results need to be interpreted carefully, and expanding the study population is necessary for future studies (Rosecrance et al., 2017).

Summary of the Literature Review

Only a few studies have provided insights on the association of contributing factors and injury in logging-related roadway crashes using crash data (Baker et al., 2012; Cole 2018; Conrad, 2018; Greene et al., 2007; Green 2005; Greene et al., 1996; and Greene, n.d.; Mason 2008;). Cole (2018) provided descriptive statistics of crash characteristics in fatal logging-related crashes using FARS in the United States from 2011 to 2015 but did not compare it with other injury severity crashes. This study did not provide information on the crash characteristics in the non-fatal injury crashes involving logging trucks. A few studies have been conducted in Georgia, with the primary focus being on mechanical failure rate in logging-related crashes but have provided limited information on the other contributing factors (Baker et al., 2012; Conrad, 2018; Greene et al., 1996; Greene et al., 2007; Greene, n.d.;). Qualitative studies provide helpful information about logging-related injuries, but the sample sizes are small, with limited generalizability (Rosecrance et al., 2017). Little to no information is available for the Southwest Agricultural Region, including Louisiana.

CHAPTER II

SPECIFIC AIM 1A: THE ASSOCIATION OF DRIVER, VEHICLE, AND CRASH FACTORS WITH CRASH SEVERITY (HIGHER SEVERITY VERSUS LOWER SEVERITY) IN LOGGING TRUCK CRASHES

Introduction

Overall logging-related roadway crashes have risen in the United States since 2012 (Cole, 2018; Conrad, 2018). Cole (2018) characterized the fatal logging-related crashes nationally and regionally using FARS and Motor Carrier Management Information System (MCMIS) databases between 2011 and 2015. Fatal logging truck crashes increased by 41% in the United States between 2011 and 2015 (Cole, 2018). An analysis of logging truck crashes using the Federal Motor Carrier Safety Administration (FMCSA) database indicated that logging truck crashes doubled in the United States from 2010 to 2015 (Baker & Tyson, 2017). This increasing trend in logging-related crashes is anticipated to continue (Baker & Tyson, 2017). This study provides insights on associated crash characteristics in logging-related incidents. An increase in logging truck crashes on the roadways is expected in the future due to the recovery of the forestry industry (Baker & Tyson, 2017). Timber markets have recovered after the recession, but so have severe logging truck crashes (Conrad, 2018).

The available literature provides limited information on occupationally-related roadway crashes in the logging industry. Most research on injuries in the logging industry has focused on work-site injuries from logging-related operations. The statistically significant relationship among driver, vehicle, and crash variables and crash severity (higher severity versus lower severity) and by crash type (single and multiple vehicle crash) was determined. This analysis provides baseline information for further analysis and how crash patterns differ between large logging and other non-logging truck crashes.

Long-haul drivers are at higher risk of involving in serious crashes. According to CDC (2020), more than 1 in 3 long-haul truck drivers have been involved in a serious truck crash during their driving career (CDC, 2015). Fatalities from motor vehicle crashes are increasing for occupants of large trucks, and about a 25% increase in deaths of occupants of large trucks occurred between 2015 and 2018 (NHTSA, 2020). However, limited data and research are available on transportation-related injuries in the United States and Louisiana, specifically in the logging industry.

Only a handful of studies have identified crash characteristics associated with logging truck crashes, but none of these studies have studied the association between crash severity and crash characteristics (Baker et al., 2012; Cole 2018; Conrad, 2018; Greene et al., 2007; Green 2005; Greene et al., 1996; Greene, n.d.; Mason 2008). A dissertation analysis provided descriptive statistics of crash characteristics in fatal logging-related crashes using FARS in the United States from 2011 to 2015 but did not compare them with other severe injury crashes (Cole, 2018). This study provided no information on the crash characteristics in non-fatal injury crashes involving logging trucks. The highest rate of fatal logging truck crashes was reported in the United States Southern region than any other United States region between 2010 and 2015 (Cole, 2019).

A few studies have been conducted in Georgia, with a primary focus being on mechanical failure rate in logging-related crashes but provided limited information on the other contributing factors (Baker et al., 2012; Conrad, 2018; Greene et al., 1996; Greene et al., 2007; Greene, n.d.). The average cost of a fatal crash involving a medium or large truck was $3,604,518 per crash and $195,258 for a non-fatal crash (Zaloshnja & Miller 2007). Improving timber transportation safety could save lives and decrease costs related to crash incidents, which could be more than $1 million per fatal or non-fatal incident (Conard, 2020; Zaloshnja & Miller, 2007). Some qualitative studies provide helpful information about logging-related injuries, but the sample sizes are small, with limited generalizability (Rosecrance et al., 2017). Little to no information is available for the Southwest Agricultural Region, including Louisiana.

Existing literature has shown that single and multiple vehicle crashes may differ in numbers and characteristics (Kockelman & Kweon, 2002; Savolainen & Mannering, 2007; Ulfarsson & Mannering, 2004). Similarly, research on single and multiple logging-related crashes indicates that the proportions of single and multiple vehicle logging-related crashes are different. For example, Cole (2018) analyzed fatal logging truck crashes and estimated that there are more multiple vehicle crashes (82.5%) than single-vehicle crashes (17.5%) in the United States. However, limited literature identifies behavioral and other crash factors associated with logging-related single and multiple motor vehicle crashes. The analysis in this current study provides insights on associated crash characteristics by crash severity in large logging truck crashes in Louisiana from 2010 to 2018.

Methods

Hypothesis

The null hypothesis was that no statistically significant associations existed between driver, vehicle, crash variables, and crash severity (higher severity versus lower severity) in logging truck crashes for single-vehicle crashes or multi-vehicle crashes in Louisiana from 2010-2018. The hypothesis was that statistically significant associations were present between driver, vehicle, and crash variables and crash severity (higher severity versus lower severity) in logging truck crashes for single-vehicle crashes or multi-vehicle crashes in Louisiana from 2010-2018.

Data Source

A crash database from the Louisiana Department of Transportation and Development from 2010-2018 was analyzed to determine the associations between driver, vehicle, and crash variables and crash (higher severity versus lower severity) by crash type (single and multiple vehicle crash) involving large logging trucks. The Louisiana Department of Transportation and Development (LaDOTD) Highway Safety database from 2010 to 2018 included information on fatal, non-fatal, or property damage for crashes greater than $500 and information on the person, vehicle, and crash factors. The severity level of fatal crashes is updated within 30 days. The police officers who respond to the scene collect crash data and complete the reports based on the evidence at the scene and interviews with the victims and witnesses.

Variables

The logging truck crashes were identified as those involving a cargo body type coded as logging truck (H) with vehicle configuration type of single-unit 2 axle (L), single-unit 3 axel (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), truck double (R) and not a pole trailer (K) cargo body type in Louisiana crash data from 2010 to 2018.

A crash type variable was created using the number of vehicles involved in crashes. A crash type labeled "single large logging truck crash" was defined as a situation where only one large logging truck was involved in a crash. A multi-vehicle crash was defined as more than one vehicle involved in a crash. For this dissertation, a "multi-vehicle crash" was defined as a crash type that involved at least one large logging truck and at least one other vehicle in a collision.

LaDOTD code crash severity was based on the KABCO Injury Classification Scale (U.S. Department of Transportation, Federal Highway Administration, 2017). The dependent variable (crash severity) was binary and classified as a higher severity crash (KAB) and a lower crash severity (CO) crash. The higher severity crash (KAB) category (1) included fatal (K), severe (A), and moderate (B) injuries. Lower crash severity (CO) crash category (0) included complaints or possible injury (C) and no injury or property damage only (O) as coded by the responding law enforcement officer. The dependent variable was created from the crash severity variable (see Chapter 1, Data Description Section). Independent variables were the driver, vehicle, and crash factors. The driver factors included driver demographics (age and gender) and behavioral characteristics (seatbelt use, distraction, impairment variables, and traffic violations). Vehicle factors included vehicle type, vehicle condition, vehicle light conditions, prior movement of the vehicle, the reason for the movement of the vehicle, and harmful events. Crash factors included the year of the crash, time of day or year, day of the week, weather, and lighting conditions, intersection flag, highway type, road type, road condition, crash location type, traffic control factors, and manner of collision. For detailed information about the dependent and independent variables and their categorization, see Appendix Table A-2.

Analysis

Cross-tabulations were performed to estimate the frequency and proportions of crash severity (higher severity versus lower severity) among independent variables (driver, vehicle, and crash factors) in large logging truck crashes, stratified by crash type (single and multiple vehicle crash). Pearson chi-square tests were used to determine whether a statistically significant relationship was present between crash characteristics (all variables are either binary or categorical) and crash severity (higher severity versus lower severity), stratified by crash type (single versus multiple vehicle crashes) in logging truck crashes.

The following Pearson chi-square test formula was used for this method:

$$X^2 = \sum_{i=1}^{S} \frac{(O_i - E_i)^2}{E_i}$$

O = observed frequency

E = expected frequency

If the expected frequency for one or more of the cells was five or less for independent variables by the dependent variable then, Fisher's exact test was conducted in place of the Pearson chi-square test. STATA 16 (StataCorp LP, College Station, TX) to analyze the descriptive statistics and Pearson chi-square or Fisher's exact test. An alpha level of 0.05 was used to define statistical significance.

False discovery rate post hoc analysis was conducted to examine the issue of multiple comparisons between crash characteristics and crash severity (KAB versus CO crash severity) by crash type (single versus multiple vehicle crashes) in large logging truck crashes (Benjamini & Hochberg, 1995; Glickman et al. 2014). Conducting multiple comparisons or hypothesis tests can result in obtaining statistically significant findings just by chance. The false discovery rate control method (also known as Benjamini–Hochberg procedure) was used to address and correct potential problems from conducting multiple comparisons.

The adjusted p-values were computed using a false discovery rate control method. The number of hypotheses was denoted by n tests with maximum false discovery rate d (here, α=0.05). The p-value was calculated from the Pearson Chi-square or Fisher's exact tests. These p-values were sorted in ascending order (p1, p2, ..., pn). These n hypotheses tests were ranked in the ascending order based on the p-value smallest to largest. The pi was calculated d*i/n for all tests (p1, p2, ..., pk), and the largest index value was indicated by k. Based on the calculated p-values (p1, p2, ..., pk), the significance of the tests was interpreted.

Results

Overview

Of the 1,432,250 crashes in Louisiana, 0.1% (1,428) crashes involved a logging truck from 2010-2018. In total, 1,360 logging-related crashes involved a large truck, and 518 were single-vehicle (SV) logging-related large truck crashes (only involved a large logging truck and no other vehicles in a crash) in Louisiana from 2010 to 2018. Six hit-and-run crashes were excluded from the analysis because hit-and-run crashes often have missing information for most of the variables. A crash with a data entry error that a parked vehicle was hit by the non-moving vehicle at the time crash was excluded from the analysis (refer to Appendix Flowchart 1). Twenty-seven (5.2%) crashes were excluded from the analysis due to missing values for most variables.

Regarding multiple-vehicle (MV) crashes, 748 of the 1,360 logging-related large truck crashes involved at least one large logging truck and another vehicle in Louisiana from 2010 to 2018. Fifty-four hit-and-run crashes were excluded from the analysis because hit-and-run crashes often have missing information for most of the variables. Two crashes with data entry errors for a parked vehicle hit by a non-moving vehicle at the time of the crash were excluded from the analysis (refer to Appendix Flowchart 1). Fifty-six (8.0%) crashes were excluded from the analysis due to missing values for most variables.

The analyzed sample included 1,120 large logging truck crashes from the Louisiana crash database from 2010 to 2018. The analyzed sample included 484 SV crashes involving a large logging truck and 636 MV crashes involving at least one large logging truck in Louisiana. Overall, 14.1% of SV and 18.6% of MV crashes were fatal or severe crashes. Tables 2.1 to 2.6 show the frequency of driver characteristics and behaviors, vehicle movement, and crash characteristics stratified by crash severity (higher severity versus lower severity) and for SV and MV crashes separately.

Driver Characteristics and behaviors

The average age of large logging truck drivers involved in SV crashes was 45 years (range 18 to 80 years). The average age of large logging truck drivers involved in MV crashes was 47 years (range 19 to 77 years), and the average age of other vehicle drivers involved in MV crashes was 43 years (range 15 to 91 years). The age group, 36-45 drivers of logging truck, was more prevalent in higher severity SV crashes (30.9%) than lower severity crashes (29.3%). Older drivers aged 56-65 of logging truck were involved in more higher severity SV crashes (20.6%) than lower severity crashes (13.2%). The middle-aged 46–55-year-old drivers of large logging trucks were involved in more higher severity MV crashes (39.0%) than lower severity crashes (29.5%). Younger drivers (below 25 years) of large logging trucks were more often involved in higher severity MV crashes (5.9%) than lower severity MV crashes (2.5%). The middle-aged drivers (26-35 years) of other vehicles were involved more often in higher severity MV crashes (32.2%) than lower severity MV crashes (20.9%). Older drivers (above 56 years) of other vehicles were more often involved in higher severity MV crashes (31.4%)

than lower severity MV crashes (27.6%). There were no statistically significant differences in the distribution of age groups by crash severity and crash type.

Male drivers of large logging trucks were involved in 98.4% of SV and 98.6% of MV large logging truck crashes. About 64.0% of other vehicle drivers involved in MV large logging truck crashes were male drivers. Male drivers involved in SV crashes were less prevalent in higher severity crashes (97.1%) than lower severity crashes (98.6%). Female drivers involved in SV crashes were more prevalent in higher severity crashes (2.9%) than lower severity crashes (1.4%). Male drivers of large logging trucks involved in MV crashes were more prevalent in higher severity crashes (99.2%) than lower severity crashes (98.5%). Female drivers of large logging trucks involved in MV crashes were less prevalent in higher severity crashes (0.9%) than lower severity crashes (1.5%). There were no statistically significant differences in the distribution of driver gender by crash severity and crash type.

Distracted driving was a behavioral factor often assigned to SV and MV crashes. Distracted driving was a factor for 62.4% of drivers in SV crashes and 35.4% of the large logging truck drivers involved in MV crashes (data not shown in tables). Distracted driving in large logging truck drivers was less prevalent among higher severity MV crashes (25.4%) than lower severity MV crashes (37.6%), and the difference was statistically significant ($p=0.007$). About 36.0% of the other vehicle drivers involved in MV large logging truck crashes were assigned as distracted drivers.

Concerning seat belt use, 11.2% of SV logging truck drivers were not wearing seat belts at the time of the crash. The higher severity SV crashes (22.1%) involving a single large logging truck had higher proportions of the driver not wearing a seat belt than lower severity SV crashes (9.4%). The difference was statistically significant (p=0.000). A lower proportion (3.0%) of large logging truck drivers involved in MV crashes were not wearing a seat belt.

A small proportion of SV and MV large logging truck crashes involved fatigued drivers. However, the frequency differed significantly among higher (1.5%) versus lower severity (0.5%) SV crashes (p=0.001). None of the truck drivers involved in MV crashes were assigned as fatigued. Overall, 0.6% of SV crashes and 1.6% of MV crashes involved impaired drivers (data not shown in tables). Impaired driving was more prevalent (2.9%) in higher severity SV crashes than among lower severity SV crashes (0.2%), but the frequency was not significantly different by crash severity. Impaired driving was more prevalent (5.1%) in higher severity MV crashes than among lower severity MV crashes (0.8%), and the frequency varied significantly by crash severity (p=0.004).

Careless operation was the most common citation assigned to drivers involved in SV large logging truck crashes (67.4%) (data not shown in tables). Higher severity SV crashes were more prevalent in careless large logging truck drivers (82.4%) than lower severity SV crashes (64.9%). The frequency varied significantly by crash severity (p=0.004). Speeding violations were assigned to a small proportion of drivers involved in

SV crashes. The proportion among higher severity (1.5%) versus lower severity (2.4%) SV crashes was not significantly different.

Among MV crashes, large logging truck drivers received the following citations: careless operation (8.5% higher versus 11.0% lower severity, p=0.419), failure to yield (8.5% higher versus 7.5% lower severity, p=0.728), following other vehicles too closely (2.5% higher versus 8.3% lower severity, p=0.029), driving left of center (5.1% higher versus 3.3% lower severity, p=0.344), cutting-in or improper passing (1.7% higher versus 3.1% lower severity, p=0.549), and speeding (0.0% higher versus 0.2% lower severity, p=1.000). None of the citations were significantly differed by crash severity at an adjusted significance level.

Vehicle Characteristics and Movement

Most SV and MV crashes happened when the truck's headlights were off, and there was no daylight (57.4% for SV and 48.1% for MV) (data not shown in tables). The truck headlights that were off at the time of the crash were more prevalent in higher severity crashes (61.8%) than lower severity SV crashes (56.7%), and its distribution significantly varied by crash severity (p=0.004). The truck headlights being off at the time of the crash was less prevalent in higher severity crashes (40.7%) than lower severity MV crashes (49.8%), and it did not significantly vary by crash severity (p=0.093).

Vehicle defects include defective brakes, headlights, rear lights, signal lights, steering, suspension, all lights out, tire failure, worn or smooth tires, and engine failure.

About 14.9% of SV crashes and 6.5% of MV crashes had vehicle defects at the time of the crash. A truck with a vehicle defect at the time of the crash was less prevalent in higher severity crashes (8.8%) than lower severity crashes (15.9%) in SV crashes, and it did not significantly vary by crash severity (p=0.130). A truck with a vehicle defect at the time of the crash was less prevalent in higher severity crashes (4.2%) than lower severity MV crashes (7.0%) and significantly varied by crash severity (p=0.344).

The majority of SV and MV large logging truck crashes (88.2% and 79.7%, respectively) involved a truck model older than ten years (data not shown in tables). Older trucks were involved in more SV crashes but were less prevalent in higher severity crashes (85.3%) than lower severity crashes (88.7%). This was not statistically significant (p=0.419). Similarly, older trucks were involved more often in MV crashes but were less prevalent in higher severity crashes (78.8%) than lower severity MV crashes (79.8%) and did not significantly vary by crash severity (p=0.787).

The most harmful events are the sequence of events that led to the most severe injury or, if no injury, the most significant property damage involving a vehicle. Among SV crashes, the most harmful event of run off the road to the left was the most prevalent in higher severity crashes compared to lower severity crashes (29.4% higher versus 14.7% lower severity), and it significantly varied by crash severity (p=0.003).

The most prevalent harmful event reported for the large logging truck in MV crashes was vehicle crossed median or centerline (10.5%), the vehicle ran off the road to the right side (6.1%), a vehicle ran off the road to the left side (4.3%), the vehicle overturned or rolled over (4.1%), cargo shift or loss of cargo or equipment (2.2%), and the vehicle hit standing tree (1.3%) (data not shown in tables). These most harmful events significantly varied by crash severity. In MV truck crashes, the following harmful events were more often assigned to the large logging truck in higher severity compared to lower severity crashes: vehicle overturn or rollover (9.3% higher versus 2.9% lower severity, p=0.001), the vehicle ran off the road to the right side (11.9% higher versus 4.8% lower severity, p=0.008), and the vehicle ran off the road to left side (9.3% higher versus 3.1% lower severity, p=0.002).

Prior movement is defined as a vehicle maneuver immediately prior to the crash. The most common prior movements in SV crashes were vehicle ran off the road (50.2%), the vehicle was making a left turn (8.3%), and the vehicle crossed median or center line into the opposite lane (9.3%). Truck running off the road prior to the crash was more prevalent in higher severity SV crashes (63.2%) than lower severity SV crashes (48.1%). A truck making a left turn prior to a crash was less prevalent in higher severity SV crashes (4.4%) than lower severity SV crashes (8.9%). The truck crossing the median or center line into the opposite lane prior to the crash was more prevalent in higher severity SV crashes (13.2%) than lower severity SV crashes (8.7%). There was no statistically significant difference in the distribution of any prior movements in SV crashes by crash severity.

The most common prior movements in MV crashes for the large logging truck were ran off the road (3.0%), making a left turn (8.2%), and crossed the median or center line into the opposite lane (8.0%). There was no statistically significant difference in the distribution of trucks' prior movements in MV crashes by crash severity. Truck running off the road prior to the crash was more prevalent in higher severity MV crashes (5.1%) than lower severity MV crashes (2.5%). Truck making left turn prior to the crash was less prevalent in higher severity MV crashes (5.1%) than lower severity MV crashes (8.9%). Truck crossed the median or center line into opposite the lane prior to the crash was more prevalent in higher severity MV crashes (12.7%) than lower severity MV crashes (7.0%). There was no statistically significant difference in the distribution of any prior movements in MV crashes by crash severity.

The reason for movement is the driver's actions or reasons why a driver made a movement prior to a crash. About 3.9% of SV crashes involved trucks trying to avoid hitting other vehicles at the time of the crash. There was no statistically significant difference in the distribution of reason for movement in SV crashes by crash severity. About 8.7% of large logging trucks and 5.5% of other vehicles involved in MV crashes were trying to avoid hitting another vehicle at the time of the crash. Among MV crashes, the large logging truck trying to avoid hitting the vehicles at the time of the crash was more prevalent in higher severity crashes than lower severity crashes (13.6% higher versus 7.5% lower severity), and its distribution was significantly different by crash severity (p=0.013).

The traffic control for a vehicle is the type of traffic control present at the crash location. The common traffic controls assigned to large logging trucks were yellow no-passing line (64.7% higher versus 56.2% lower severity, p=0.191), yellow dashed line (10.3% higher versus 14.7% lower severity, p=0.336), no traffic control present (13.2% higher versus 9.9% lower severity, p=0.396), white dashed line (4.4% higher versus 8.9% lower severity, p=0.339), and stop sign (4.4% higher versus 5.3% lower severity, p=1.000) in SV crashes. There was no statistically significant difference in the distribution of reason for any traffic controls in SV crashes by crash severity.

The common traffic controls assigned to large logging trucks involved in MV crashes were yellow no-passing line (33.1% higher versus 33.8% lower severity, p=0.879), white dashed line (21.2% higher versus 20.7% lower severity, p=0.898), yellow dashed line (22.9% higher versus 15.6% lower severity, p=0.059), stop sign (5.9% higher versus 7.0% lower severity, p=0.691), and no traffic control present (6.8% higher versus 5.6% lower severity, p=0.621).

Crash Characteristics

The frequency of types of the manner of collision by crash severity was significantly different in MV crashes (p=0.000). Angle MV collisions were more prevalent in higher severity crashes (26.3%) than lower severity crashes (18.0%). Head-on MV collisions were more prevalent in higher severity crashes (13.6%) than lower severity crashes (0.2%). Opposite-direction MV collisions were more prevalent in higher severity crashes (16.1%) than lower severity crashes (14.5%). Rear-end MV collisions were more prevalent in higher severity crashes (28.8%) than lower severity crashes (27.4%).

Most SV large logging truck crashes (84.9%) and MV large logging truck crashes (82.2%) happened in daylight. The SV large logging truck crashes happening in daylight were more prevalent in higher severity crashes than lower severity crashes (91.2% higher versus 82.9% lower severity), and the distribution was significantly different by crash severity (p=0.000). The MV large logging truck crashes that happened in daylight were less prevalent in higher severity crashes than lower severity crashes (67.8% higher versus 85.5% lower severity), and the distribution was significantly different by crash severity (p=0.000). About 15.8% of SV large logging truck crashes and 31.1% of MV large logging truck crashes happened at intersections. The SV large logging truck crashes that happened on intersections were less frequent in higher severity crashes than lower severity crashes (4.4% higher versus 17.1% lower severity), and the distribution was significantly different by crash severity (p=0.006).

Most SV large logging truck crashes happened in clear weather (76.5%), dry road surface conditions (76.5%), blacktop road surface type (91.7%), and straight road alignment (50.0%). There were no statistically significant differences in the distribution of clear weather, dry road surface conditions, blacktop road surface type, and straight road alignment in SV crashes by crash severity. Most MV large logging truck crashes happened in clear weather (78.6%), dry road surface conditions (89.9%), blacktop road surface type (81.5%), and straight road alignment (84.8%). There were no statistically significant differences in the distribution of clear weather, dry road surface conditions, and blacktop road surface type in MV crashes by crash severity. The MV large logging truck crashes that happened on curve roads were more prevalent in higher severity crashes than lower severity crashes (22.9% higher versus 13.5% lower severity), and the distribution was significantly different by crash severity (p=0.011). The driver at-fault in MV crashes was assigned to 35.9% of large logging truck drivers, 38.8% of other vehicle drivers, and 25.3% of both drivers and unclear. The other vehicle drivers who were at fault for MV crashes involved more higher severity crashes (46.6%) than lower severity crashes (37.1%), and the distribution was significantly different by crash severity (p=0.000).

Discussion

This study identified the crash characteristics by crash severity and crash type in large logging truck crashes in Louisiana from 2010 to 2018. About 56.8% were MV crashes, and 43.2% of large logging truck crashes were SV in Louisiana from 2010 to 2018. A prior analysis of FMCSA data indicated that logging truck crashes were more severe than other types of crashes between 2010 and 2015 (Baker & Tyson 2017). Current study findings also show that large logging trucks were more involved in higher severity crashes (16.6%) than large non-logging truck crashes (6.9%) (data not shown in tables).

Due to limited information on logging truck crashes by crash severity, comparing the study results with previous research findings is challenging. Cole (2018) analyzed FARS fatal logging truck crash data in the United States from 2010 to 2015 and found that there were more MV crashes (82.5%) than SV crashes (17.5%). The present study's findings were similar, with 79.3% of fatal crashes being MV and 20.7% being SV (data not shown in tables). However, the present study focused on higher severity crashes wherein the proportion of SV crashes was higher at 36.6% than for all severities combined.

Demographic characteristics

Driver's Age

The present study indicated that logging truck drivers were primarily middle-aged and older, which was in line with the analysis by Cole (2018). Based on an analysis of fatal crashes in the FARS data, he found that the logging truck drivers in fatal crashes had an average age of 48.8 years and ranged in age from 18 to 80 years (Cole, 2018). In comparison, the average age of logging truck drivers in the present study was 45 years (range 18-80 years) for SV crashes and 47 years (range 19-77 years) for MV crashes. It should be noted that older age groups are more likely to be severely injured due to reduced physiological strength and injury-sustaining capability of older people (Islam & Hernandez, 2013) and why in SV crashes, logging truck drivers tended to be older. Limited additional information exists on the association between crash severity and driver's age in logging truck crashes.

Driver's Gender

None of the previous crash analyses included gender, possibly because most logging truck drivers are male. The American Trucking Association analyzed BLS data to study truck driver shortages, and historical data indicated that only 6% of all truck drivers were female in the United States in 2016 (Costello, 2017). A possible explanation is the greater physiological strength and injury-sustaining capability of males over that of females. O'Donnell & Connor (1996) estimated the relationship between eleven road user attributes and the probabilities of sustaining four different level injuries in public roadway crashes in New South Wales, Australia, in 1991. This study indicated that females were more likely to sustain severe injuries than male occupants (O'Donnell & Connor 1996). Abdel-Aty (2003) analyzed the 1996 and 1997 crash data from Orange, Osceola, and Seminole counties in Florida and found that female drivers were more likely to be involved in more severe crashes.

In line with previous literature findings in the present study, a small number of female drivers were involved in logging-related SV (n=8), and MV (n=9) crashes. About 25.0% of female drivers involved in SV crashes were higher severity crashes, and 11.1% of female drivers involved in MV crashes were higher severity crashes. The proportion of higher severity SV crashes in female drivers (25.0%) was greater than male drivers involved in higher severity crashes (13.9%).

Behavioral characteristics

Impaired driving

About 0.6% of SV crashes and 1.6% of MV crashes involved impaired logging truck drivers in this study, a very low proportion. Impaired drivers were more involved in higher severity SV crashes (2.9%) than lower severity SV crashes (0.2%). Similarly, impaired logging truck drivers were involved more often in higher severity MV crashes (5.1%) than lower severity MV crashes (0.8%).

Driving Under the Influence (DUI) was identified as a contributing factor to crashes involving logging trucks and other heavy vehicles in Georgia from 2006 to 2016 (Conrad, 2018). DUI was reported in 0.1% of logging truck crashes and 1.2% for other heavy vehicles (Conrad, 2018). Greene and Colleagues also indicated that DUI alcohol-related crashes happened slightly higher in logging trucks than other heavy trucks in Georgia between 1988 and 2004. Mercer and Jeffery (1995) examined the role of alcohol and drugs in trends and causes of fatal crashes using the driver's blood samples of drivers involved in traffic crashes in British Columbia from October 1, 1990, and September 31, 1991. The impairment from alcohol and drugs often is misclassified as alcohol-only impairment. Drug-only impairment often is mistaken for driving without attention (Mercer & Jeffery, 1995). Kim (1999) analyzed a combined crash database from police crash reports and hospital records of all types of crashes happening in1990 using probabilistic linkage in Hawaii. This study found that police crash records underreported the alcohol involvement rate.

Distracted driving

About 62.4% of SV crashes and 35.4% of MV crashes involved distracted large logging truck drivers (data not shown in tables). Distracted truck drivers were more prevalent in the higher severity crashes than lower severity crashes in SV crashes. Distracted truck drivers were less prevalent in the higher severity crashes than lower severity crashes in MV crashes. None of the studies have analyzed distracted driving in large logging truck crashes. National Highway Traffic Safety Administration estimated the motor vehicle traffic fatalities in 2019 and reported that 8.7 % of all fatal crashes were affected by distracted driving, with 3,142 people killed (National Center for Statistics and Analysis, 2019). The information about driver distraction is complicated to collect, and the data often are unknown or missing. Stutts & Hunter (2003) analyzed the national Crashworthiness Data System (1995-1999) to evaluate the role of distracted driving in crashes and identify the specific source of distraction. In general, driver distraction and inattention are likely to be underreported, as these factors are difficult to verify and measure (Stutts & Hunter, 2003).

Seatbelt Use

The present study found that a notable proportion of SV (11.2%) and MV (3.0%) logging truck drivers were not wearing seat belts at the time of the crash. This is a concern given that proper use of an in-vehicle seatbelt has been proven to protect against fatalities and serious injuries. Islam and Hernandez (2013) found that the vehicle occupants restrained by lap/shoulder belts were less prone to being severely injured. In general, several studies identified that not wearing a seat belt may lead to higher injury severities suffered by occupants of any type of vehicle (Abdel-Aty, 2003; Gkritza & Mannering, 2008; Boufous et al.,2008). In the present study, failure to use a seatbelt was more frequent in SV and MV crashes that were also more severe. Although the use of a seatbelt is mandatory for all vehicle drivers, only 56% of logging truck drivers from Alabama, Georgia, and Mississippi participating in one-day truck driving safety courses said that they always wore the seat belt in a survey conducted at driving safety courses (Carnahan, 2004). This is the only study that has looked at seatbelt use in logging truck drivers. This self-report survey, coupled with the findings from crash analyses, suggests that efforts to improve seatbelt use in logging truck drivers is an area for intervention.

Fatigue

A small proportion of SV and MV large logging truck crashes involved fatigued drivers. However, the frequency differed significantly among higher (1.5%) versus lower severity (0.5%) SV crashes. The frequency differed significantly among higher (0.9%) versus lower severity (0.4%) MV crashes. Lagerstrom et al. (2017) recruited a focus group of professional loggers attending the annual Intermountain Logging Conference at Spokane, Washington, in 2016. Logging truck drivers who participated reported that they are at high risk of being in a crash due to fatigue caused by driving long distances to sawmills for wood processing.

Fatigue in truck drivers is a major public safety issue. Hours-of-service (HOS) rules prohibit truckers from driving more than 11 hours consecutively, working more than a 14- hour shift, and driving more than 60 hours in a week or 70 hours over an eight-day period (FMCSA, 2015). Logging truck drivers often operate beyond the legal limit of hours of service. Logging truck company owners confirmed this in a survey conducted in Washington in 2006 (Mason et al., 2008). Logging truck drivers work long hours with an average of 12.2 hours per day (average 69 working hours per week) and transport multiple loads per day (average 2.9 loads per day) (Mason et al., 2008). This is alarming, of course, but additional research is needed to better understand fatigue in logging truck drivers. Misclassification of fatigue is common due to the difficulty of observing and identifying this behavior (Filtness, Armstrong, Watson, & Smith, 2017; Radun et al., 2013).

Violations

Violation of traffic safety rules is another indicator of the driver's behavior in a crash (Mason et al., 2008). Mason et al. (2008) summarized the traffic crashes involving logging trucks from WA State Patrol (WSP) data (2004) and reported that 25% of logging trucks in crashes were cited with violations. Careless operation was the most common citation assigned to drivers involved in SV large logging truck crashes (67.4%) (data not shown in tables), and it was more prevalent in higher severity SV crashes (82.4%) than lower severity SV crashes (64.9%). Cole (2018) analyzed the fatal logging-related crashes nationally and regionally using FARS and Motor Carrier Management Information System (MCMIS) databases between 2011 and 2015. Cole (2018) estimated that careless driving (14.7%) was among the most commonly cited violations in fatal crashes.

At-Fault Status

In general, the literature on commercial motor vehicle crashes indicated that passenger vehicles are often at fault in commercial motor vehicles crashes (Blower, 1998; Hanowski et al., 2007; Mason et al., 2008; Wang, Jing-shiarn, Knipling, & Blincoe, 1999). FMCSA (2007) indicated that in the LTCCS study, human errors were more often the major contributor in large truck crashes (89.0%). Existing literature suggests that other vehicles often contribute to logging-related truck crashes as well. In multiple-vehicle crashes involving logging trucks, the fault was assigned to other vehicle drivers in 53.2% of fatal crashes and logging truck drivers in 29.3% of fatal crashes in the United States from 2011 to 2015 (Cole, 2018). In the present study for MV crashes, the other vehicle driver was coded at fault in 46.6% of higher severity crashes compared to 37.1% of lower severity crashes.

Vehicle characteristics and vehicle movement

Vehicle age

Few studies on logging-related crashes have compared vehicle ages of logging trucks and all trucks. One study of fatal crashes found that the average age of log trucks was 13 years and was the oldest compared to the overall average age of all trucks of 7.6 years in the United States from 2010 to 2015 (Cole, 2018). The latest data reveals that the average age of logging trucks involved in crashes was 14 years, seven years older than other heavy vehicles on the road at the time in Georgia from 2006 to 2016 (Conrad, 2018). An analysis of logging-related crashes shows that the older logging trucks could have a higher mechanical failure rate than other heavy trucks in Georgia from 1988 to 1994 (Greene et al., 1996). New trucks may be more like to be better maintained and have traveled fewer miles than old trucks, and old trucks have fewer safety features than new trucks. A lack of proper maintenance and safety technologies could be why old trucks are less safe (Greene et al., 1996). In the present study, most SV and MV large logging truck crashes (88.2% and 79.7%, respectively) involved a truck model older than ten years (data not shown in tables). However, there was no large difference in vehicle age compared with more versus less severe SV and MV crashes.

Mechanical Failure

Mechanical failure is one of the common contributing factors in logging-related crashes (Conrad, 2018). Mechanical failure was the eighth most common contributing factor (3.3%) in logging truck crashes in Georgia from 2006 to 2016 (Conrad, 2018). Vehicle defects include defective brakes, headlights, rear lights, signal lights, steering, suspension, all lights out, tire failure, worn or smooth tires, and engine failure. About 14.9% of SV crashes and 6.5% of MV crashes involved large logging trucks that had vehicle defects at the time of the crash. A truck with a vehicle defect at the time of the crash was less prevalent in higher severity crashes (8.8%) than lower severity crashes (15.9%) in SV crashes. The truck had a vehicle defect at the time of a crash and was less prevalent in higher severity crashes (4.2%) than lower severity crashes (7.0%) in MV crashes.

The mechanical failure rate significantly declined in Georgia due to the beginning of the random roadside inspection in Georgia (Baker et al., 2012; Conrad, 2018: Greene et al., 1996; Greene et al., 2007; Greene, n.d.). Mechanical failure-related crashes dropped from 10.9% to 5.5% for logging tractor-trailers, from 12.9% to 3.2% for logging trucks, and from 3.8% to 2.3% for other heavy trucks in Georgia from 1988-1991 to 2005-2008 (Greene, n.d.). Other common contributing factors to logging truck crashes were brake failure and slick or damaged tires in Georgia (Bakers et al., 2012). However, these crashes have gone down by at least half since 2013 in Georgia (Conrad, 2018; Greene, 2010), perhaps due to better equipment and more frequent inspections.

Harmful Event

Ran off the road

Among SV crashes, run off the road (ROR) to the left was most prevalent in higher severity crashes than lower severity crashes (29.4% higher versus 14.7% lower severity). Among MV crashes, the harmful event was ROR to the left and it was more prevalent in higher severity crashes than lower severity crashes (9.3% higher versus 3.1% lower severity). Among SV crashes, run off the road to the right was more prevalent in higher severity crashes than lower severity crashes (51.5% higher versus 47.4% lower severity). Among MV crashes, ROR to the right was more prevalent in higher severity crashes than lower severity crashes (11.9% higher versus 4.8% lower severity). FMCSA and the NHTSA conducted the Large Truck Crash Causation Study (LTCCS) to examine the contributing factors for serious crashes involving large trucks. The major critical events assigned to at-fault truck crashes include running out of the travel lane or off the road (32%), loss of control due to speed, cargo shift, vehicle failure or other problems (29%), and colliding with the rear end of another vehicle (22%) (FMCSA 2007). Additionally, fatal log truck crashes have higher occurrences of ROR (9.6 %) than fatal other tractor-trailers crashes (7.9%) in the United States from 2010 to 2015 (Cole 2018).

Rollover or Overturn

Logging trucks have a higher occurrence of rollovers during fatal crashes than other cargo body types. Logging trucks are often heavier than other trucks and have a higher center of gravity, which increases the likelihood of rollover in a crash. McKnight & Bahouth (2008) analyzed the rollover in large truck crashes from LTCCS data and stated that the large truck's high center of gravity increases the likelihood of vehicle rollovers.

In a study of crashes from 2011-2015, researchers found that the most common harmful event in fatal logging truck crashes was rollover (32.4%) in the United States (Cole, 2018). Logging trucks experienced rollovers in 78% of fatal crashes at some point during the crash (Cole, 2018). There are more rollovers in SV crashes involving logging trucks than in MV crashes involving logging trucks (Cole, 2018). This was true for the present study too. In the present study, most rollover large logging truck crashes were SV crashes (93.4%), and 6.6% were MV crashes. A higher proportion of rollover of the truck crashes were higher severity crashes than lower severity crashes. Comparatively less proportion of MV crashes were assigned harmful event overturn or rollover (4.1%) and had a higher proportion of higher severity crashes than lower severity crashes.

Loss of load

Securing the load is a critical part of the transportation of logs, and loss of load is a public safety issue that can directly affect the likelihood and severity of a crash. Pre-crash cargo shift (due to improperly secured loads) is a contributing factor in large truck crashes had the highest relative risk ratio of 56.3 of being involved in a crash based on the Large Truck Crash Causation Study (LTCCS) (FMCSA, 2007). In the present study, cargo or equipment shift of loss was common among SV crashes (21.3%) versus MV crashes (2.2%) and greater in higher severity crashes (29.4%) than lower severity crashes (19.9%).

Crash Characteristics

Manner of Collision

In terms of the manner of collision, Cole (2018) found that 30.0% of fatal crashes were angle collisions, 21.4% were head-on collisions, 17.0% were front to the rear collision in the United States from 2010 to 2015. The present study estimated that 29.7% of higher severity crashes were head-on or opposite direction collisions (13.6% and 16.1%, respectively), 28.8% were rear-end collisions, and 26.3% were angle collisions (Table 2.6). The current findings for Louisiana data slightly vary from national data. But this study looked at higher severity crashes, including fatal crashes, and Cole (2018) analyzed only fatal crashes. Blower (1999) analyzed Trucks Involved in Fatal Accidents (TIFA) (1994-1995) two-vehicle crash data involving a large truck and a passenger car collision and found that 28.3% of fatal crashes were head-on collisions similar to the current study and the study by Cole (2018).

Time of day

Logging trucks are not permitted to travel on public roadways at night. Logging trucks should only be on the road only during business hours. Michigan Log Truck Study II compared the distribution of the time of crash occurrence of log truck crashes, and all-vehicle crashes in the Upper Peninsula (U.P.), Michigan, between 2001 and 2003 (Green, 2005). So, logging truck crashes decline after 6:00 PM, whereas all other vehicle crashes begin to rise at that time in U.P., Michigan (Green, 2005). The pattern for logging trucks and all vehicle crashes is similar during early morning and business hours (Green, 2005). Despite the prohibition on nighttime driving, more than 25% of logging truck drivers participating in a survey reported traveling between 6:00 p.m. and 6:00 a.m. in Alabama, Georgia, and Mississippi (Carnahan, 2004). Driving logging trucks at night is the biggest concern and violation of safety regulations. In the present study, about 6.0% of SV crashes happened at night in Louisiana, but none were higher severity crashes. About 11.3% of MV crashes happened at night, and a higher proportion of those crashes were higher severity crashes (17.8%) than lower severity (9.9%).

Day of week

Logging trucks are prohibited from traveling on public roadways on weekends and holidays in most states. Logging truck crashes were significantly lower on weekends than weekdays in the Upper Peninsula (U.P). in Michigan from 2001 to 2003 (Green, 2005). Green (2005) compared the distribution of the day of crash occurrence of log truck crashes and all-vehicle crashes in U.P., Michigan, between 2001 and 2003. The present study found that 9.1% of SV crashes and 5.8% of MV crashes happened on weekends. The SV and MV crashes did not vary by crash severity. Logging truck crashes are strongly correlated with truck and bus crashes. They have near-identical patterns of crashes concerning the day of the week, with Friday being the most dangerous day in the U.P., Michigan, from 2001 to 2003 (Green, 2005).

Weather and lighting conditions

In the present study, the vast majority of crashes occurred under clear weather conditions and in daylight, similar to prior research. Almost two-thirds of fatal logging truck crashes happened in clear weather in the United States from 2011 to 2015 (Cole, 2018). The present study also found that most SV and MV crashes happened in clear weather, both at 76.5%. Similarly, Cole (2018) found that most fatal logging truck crashes happened in daylight (76%) in the United States during 2011-2015. The present study estimated that a higher proportion of higher severity MV crashes happened in adverse or no clear weather (28.0%) and in no daylight (32.2%) than lower severity crashes (19.9% and 14.5%, respectively).

Roadways Classification

About 15.8% of SV and 31.1% of MV large logging truck crashes happened at intersections. Most logging truck crashes happened within 150 feet of an intersection (56.0%). Cole (2018) found that 23.0% of fatal crashes involved logging trucks that happened at an intersection or were intersection-related.

The present study found that 24.3% of logging truck crashes and about 17.7% of higher severity crashes happened at intersections. The Michigan Log Truck Study II stated that most logging truck crashes happened on a state highway (69.0%), whereas 61.0% of truck and bus crashes happened on state highways in U.P., Michigan, from 2001 to 2003 (Green, 2005). More than 45% of fatal logging truck crashes happened on State highways and 33.7% on US highways in the United States from 2011 to 2015 (Cole, 2018). The present study also reports that more higher severity crashes happened on State highways (72.1%) than on Interstate and US highways (14.7%).

Curve Road alignment

Previous logging-related crash literature proves little information about the distribution of logging-related crashes on curve roads. An NHTSA study of fatal crashes compared general large truck rollover to non-rollovers crashes from 1996 to 2000 using FARS and TIFA data and found a 6-fold increased risk of rollover on curves (Moonesinghe et al. 2003). McKnight (2009) identified the behavioral contributor to the 239 rollovers from the LTCCS sample and concluded that almost 50.0% of truck rollover crashes resulted from failure to adjust to an adequate speed to keep control around a curve.

The present study found that 50% of SV and 15.3% of MV crashes happened on a curve-aligned road, and higher proportions were higher severity crashes. The present study data show that 67.2% of higher severity crashes in rollover events happened on curved roads (data not shown in tables). More research is needed to determine why logging trucks have more rollover occurrences, but a failure to keep control around curves on rural roads where log trucks often navigate may contribute to these crashes.

Limitations

Several potential limitations are associated with crash database analysis. For example, not all police officers receive the same training. Training differences could result in variations in how they report roadway crashes, with the same crash factors and conditions being recorded differently by different police officers. As a result, the officer or officers on the scene may not have the time to collect all the information about the crash to complete the crash report fully and correctly. Time on-scene may be limited for two reasons: fatal or severe injuries require an officer's immediate attention and coordination with other first responders, and the crash may cause traffic congestion that needs to be cleared (Farmers, 2003).

Previous literature on crash data analysis suggests the potential underreporting of non-fatal and less severe crashes. No injury or minor injury crashes are less likely to be reported to police to avoid the involvement of insurance companies and the possibility of getting traffic citations (Farmer, 2003; Savolainen et al., 2011). The underreporting of no injury and less severe injuries could lead to overestimating the odds of higher injury severity crashes and underestimating lower severity crashes (Ye & Lord, 2011). Misclassification of injury severity can be an issue, as law enforcement officers are not clinicians. The police officers identify fatal injury and no injury reasonably accurately, but they can misclassify various types of non-fatal (Farmers, 2003).

Fatal crashes get updated within 30 days of the incident with detailed information about the death (LaDOTD, 2005). Except in the case of fatal crashes, the police reports may not classify injuries as accurately as medical providers. The accuracy of the reporting rate for fatalities ranged from 85% to 100% (Aptel et al., 1999; Blincoe et al., 2002). The accuracy of police reports improves compared to hospital records as injury severity increases (Agran, Castillo, & Winn, 1990; Aptel et al., 1999; Cercarelli, Rosman, & Ryan, 1996; Harris, 1990; Rosman & Knuiman, 1994). The misclassification between possible and no injury levels could affect the parameter estimates (Winston et al., 2006).

Hausman, Abrevaya, and Scott-Morton (1998) developed correction procedures to analyze misclassification in discrete data. Winston et al. (2006) applied this procedure and found that misclassification was insignificant in their study. The grouping of injury severity levels into two broad categories as injury (fatal, severe, and moderate injury) and no injury (possible or no injury) can reduce the misclassification bias (Winston et al., 2006).

Misclassification of injury severity can be an issue, as law enforcement officers are not clinicians. The police officers identify fatal injury and no injury reasonably accurately, but they can misclassify various types of non-fatal (Farmers, 2003). Fatal crashes get updated within 30 days of the incident with detailed information about the death (LaDOTD, 2005). Except in fatal crashes, the police reports may not classify the injuries as accurately as medical providers. The accuracy of police reports improves as injury severity increases compared to hospital records (Agran, Castillo, & Winn, 1990; Aptel et al., 1999; Cercarelli, Rosman, & Ryan, 1996; Harris, 1990; Rosman & Knuiman, 1994).

Historically, misclassification of severe injuries was more common when the victims were males and elderly drivers rather than female and younger drivers (Farmer, 2003), but this may not be true for current trends with advances in reporting technologies. The misclassification between possible and no injury levels could affect the parameter estimates (Winston et al., 2006). Hausman, Abrevaya, and Scott-Morton (1998) developed correction procedures to analyze misclassification in discrete data. Winston et al. (2006) applied this procedure, and the authors found that misclassification was not a significant factor in their study.

Conclusion

This study identified and compared the crash factors in SV and MV crashes by type of crash severity. Overall, there is a difference in crash factors associated with higher severity crashes comparing SV and MV crashes. Distracted driving, no use of a seatbelt, careless driving, and a truck that ran off the road to the left side were more prevalent in higher severity SV crashes than lower severity SV crashes. Truck drivers involved in higher severity MV crashes were associated with truck rollover, truck ROR to the right side, and truck ROR to the left side. Other vehicle drivers involved in higher severity MV crashes were associated with distracted driving, no retrain use, citation for driving left of center, and a citation for careless driving. However, the current study only examined bivariate associations. Consequently, future research should use multiple logistic regression to identify the most strongly associated with higher severity crashes after statistical adjustment. Targeted safety training programs for logging truck drivers may help to reduce the frequency of crashes by focusing on increasing seatbelt use, careless driving, better prior crash maneuver training, and safely securing loads.

<u>Single Vehicle - large logging truck crashes in Louisiana (2010-2018)</u>

Table 2.1: Driver variables and crash severity for single large logging truck crashes in Louisiana (2010-2018)

Independent Variable	Logging truck crashes (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Driver's Demographics					
Age (years)					
25 and younger	3 (4.4%)	16 (3.9%)	0.545	34	0.039
26-35	10 (14.7%)	92 (22.1%)			
36-45	21 (30.9%)	122 (29.3%)			
46-55	17 (25.0%)	110 (26.4%)			
56-65	14 (20.6%)	55 (13.2%)			
66 & older	3 (4.4%)	21 (5.1%)			
Gender					
Male	66 (97.1%)	410 (98.6%)	0.313	26	0.030
Female	2 (2.9%)	6 (1.4%)			
Driver's Behaviors					
Impairment- Alcohol Estimates					
Yes	2 (2.9%)	1 (0.2%)	0.053	13	0.015
No	66 (97.1%)	415 (99.8%)			
Distraction					
Yes	45 (66.2%)	257 (61.8%)	0.003*	5	0.006
No	16 (23.5%)	148 (35.6%)			
Unknown	7 (10.3%)	11 (2.6%)			
Fatigue					
Yes	1 (1.5%)	2 (0.5%)	0.001*	3	0.003
No	63 (92.7%)	413 (99.3%)			
Unknown	4 (5.9%)	1 (0.2%)			
Occupant Seatbelt Use					
Used	45 (66.2%)	368 (88.5%)	0.000*	1	0.001
Not Used	15 (22.1%)	39 (9.4%)			
Unknown	8 (11.8%)	9 (2.2%)			
Driver Violations					
Failure to Yield					
Yes	0 (0.0%)	2 (0.5%)	1.000	38	0.043
No	68 (100.0%)	414 (99.5%)			
Following Too Closely					
Yes	0 (0.0%)	6 (1.4%)	1.000	39	0.044
No	68 (100.0%)	410 (98.6%)			

Table 2.1 Continued

Independent Variable	Logging truck crashes (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Driving Left of Center					
Yes	0 (0.0%)	2 (0.5%)	1.000	40	0.045
No	68 (100.0%)	414 (99.5%)			
Speeding					
Yes	1 (1.5%)	10 (2.4%)	1.000	41	0.047
No	67 (98.5%)	406 (97.6%)			
Careless Operation					
Yes	56 (82.4%)	270 (64.9%)	0.004*	7	0.008
No	12 (17.7%)	146 (35.1%)			

Notes: (1) Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (3) [a] Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (4) [b] Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =$d*i/n$ (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). *i* is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (5) * P-value is significant at the adjusted cutoff p-value level.

Table 2.2: Vehicle variables and crash severity for single large logging truck crashes in Louisiana (2010-2018)

Independent Variable	Logging truck crashes (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Vehicle Defects Observed					
Yes	6 (8.8%)	66 (15.9%)	0.130	18	0.021
No	62 (91.2%)	350 (84.1%)			
Vehicle Lighting Condition					
Headlights on or Daytime Running Lights	17 (25.0%)	161 (38.7%)	0.004*	8	0.009
Headlights off	42 (61.8%)	236 (56.7%)			
Unknown	9 (13.2%)	19 (4.6%)			
Vehicle Age					
Less than 10 years	10 (14.7%)	47 (11.3%)	0.419	31	0.035
More than 10 years	58 (85.3%)	369 (88.7%)			

Table 2.2 Continued

Independent Variable	Logging truck crashes (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Vehicle Movement-Harmful Events					
Vehicle Overturn/Rollover					
Yes	58 (85.3%)	310 (74.5%)	0.054	14	0.016
No	10 (14.7%)	106 (25.5%)			
Cargo/Equipment Loss or Shift					
Yes	20 (29.4%)	83 (19.9%)	0.077	15	0.017
No	48 (70.6%)	333 (80.1%)			
Ran Off Road Right					
Yes	35 (51.5%)	197 (47.4%)	0.529	32	0.036
No	33 (48.5%)	219 (52.6%)			
Ran Off Road Left					
Yes	20 (29.4%)	61 (14.7%)	0.003*	6	0.007
No	48 (70.6%)	355 (85.3%)			
Hit Standing Tree					
Yes	8 (11.8%)	39 (9.4%)	0.537	33	0.038
No	60 (88.2%)	377 (90.6%)			
Crossed Median/Centerline					
Yes	17 (25.0%)	80 (19.2%)	0.271	25	0.028
No	51 (75.0%)	336 (80.8%)			
Hit Pedestrian					
Yes	2 (2.9%)	2 (0.5%)	0.097	16	0.018
No	66 (97.1%)	414 (99.5%)			
Vehicle Movement-Prior Movement					
Vehicle Ran Off Road					
Yes	43 (63.2%)	200 (48.1%)	0.020	11	0.013
No	25 (36.8%)	216 (51.9%)			
Making Left Turn					
Yes	3 (4.4%)	37 (8.9%)	0.339	28	0.032
No	65 (95.6%)	379 (91.1%)			
Crossed Median or Center Line into Opposite Lane					
Yes	9 (13.2%)	36 (8.7%)	0.228	22	0.025
No	59 (86.8%)	380 (91.4%)			
Vehicle Movement-Reason for Movement					
To Avoid Other Vehicle					
Yes	3 (4.4%)	16 (3.9%)	0.740	37	0.042
No	65 (95.6%)	400 (96.2%)			

Table 2.2 Continued

Independent Variable	Logging truck crashes (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Vehicle Out of Control, Not Passing					
Yes	4 (5.9%)	27 (6.5%)	1.000	42	0.048
No	64 (94.2%)	389 (93.5%)			
Vehicle Movement-Traffic Control					
Stop Sign					
Yes	3 (4.4%)	22 (5.3%)	1.000	43	0.049
No	65 (95.6%)	394 (94.7%)			
Yellow No Passing Line					
Yes	44 (64.7%)	234 (56.2%)	0.191	19	0.022
No	24 (35.3%)	182 (43.8%)			
White Dashed Line					
Yes	3 (4.4%)	37 (8.9%)	0.339	29	0.033
No	65 (95.6%)	379 (91.1%)			
Yellow Dashed Line					
Yes	7 (10.3%)	61 (14.7%)	0.336	27	0.031
No	61 (89.7%)	355 (85.3%)			
No Control					
Yes	9 (13.2%)	41 (9.9%)	0.396	30	0.034
No	59 (86.8%)	375 (90.1%)			

Notes: (1) Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (3) [a] Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (4) [b] Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =$d*i/n$ (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). *i* is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (5) *P-value is significant at the adjusted cutoff p-value level.

Table 2.3: Crash variables and crash severity for single large logging truck crashes in Louisiana (2010-2018)

Independent Variable	Logging truck crashes (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Crash Time					
Morning	24 (35.3%)	128 (30.8%)	0.017	10	0.011
Afternoon	28 (41.2%)	124 (29.8%)			
Evening/Night	0 (0.0%)	29 (7.0%)			
Unknown	16 (23.5%)	135 (32.5%)			
Crash Year					
2010	10 (14.7%)	56 (13.5%)	0.000*	2	0.002
2011	7 (10.3%)	57 (13.7%)			
2012	7 (10.3%)	46 (11.1%)			
2013	3 (4.4%)	40 (9.6%)			
2014	13 (19.1%)	43 (10.3%)			
2015	5 (7.4%)	61 (14.7%)			
2016	12 (17.7%)	39 (9.4%)			
2017	6 (8.8%)	35 (8.4%)			
2018	5 (7.4%)	39 (9.4%)			
Day of the Week					
Weekday	62 (91.2%)	378 (90.9%)	0.934	44	0.050
Weekend	6 (8.8%)	38 (9.1%)			
Clear Weather Conditions					
Yes	57 (83.8%)	313 (75.2%)	0.122	17	0.019
No	11 (16.2%)	103 (24.8%)			
Daylight					
Yes	66 (97.1%)	345 (82.9%)	0.001*	4	0.005
No	2 (2.9%)	71 (17.1%)			
Road Surface Condition-Dry					
Yes	67 (98.5%)	377 (90.6%)	0.029	12	0.014
No	1 (1.5%)	39 (9.4%)			
Road Surface Type-Blacktop					
Yes	63 (92.7%)	380 (91.4%)	0.721	36	0.041
No	5 (7.4%)	36 (8.7%)			
Road Alignment					
Straight	29 (42.7%)	213 (51.2%)	0.191	20	0.023
Curved	39 (57.4%)	203 (48.8%)			
Manner of Collision					
Non-Collision with Motor Vehicle	64 (94.1%)	404 (97.1%)	0.260	24	0.027
Other or Unknown	4 (6.0%)	12 (2.9%)			
Road Type No Physical Barrier					
Yes	63 (92.7%)	365 (87.7%)	0.241	23	0.026
No	5 (7.4%)	51 (12.3%)			

Table 2.3 Continued

Independent Variable	Logging truck crashes (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Location Type					
Manufacturing or Industrial or business area	29 (42.7%)	153 (36.8%)	0.212	21	0.024
Residential related area	4 (5.9%)	54 (13.0%)			
Open country	35 (51.5%)	209 (50.2%)			
Intersection					
Yes	3 (4.4%)	71 (17.1%)	0.006*	9	0.010
No	65 (95.6%)	345 (82.9%)			
Highway Type					
Interstate and US highway	10 (14.7%)	79 (19.0%)	0.649	35	0.040
State highway	49 (72.1%)	291 (70.0%)			
Other (Parish Road, City Street)	9 (13.2%)	46 (11.1%)			

Notes: (1) Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (3) a Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (4) b Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =d*i/n (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). i is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (5) *P-value is significant at the adjusted cutoff p-value level.

Multiple Vehicle - large logging truck crashes in Louisiana (2010-2018)

Table 2.4: Driver variables and crash severity for multiple vehicle crashes involving large logging truck in Louisiana (2010-2018)

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Large Truck Driver Demographics					
Age (years)					
25 and younger	7 (5.9%)	13 (2.5%)	0.042	26	0.018
26-35	15 (12.7%)	101 (19.5%)			
36-45	23 (19.5%)	112 (21.6%)			
46-55	46 (39.0%)	153 (29.5%)			
56-65	24 (20.3%)	105 (20.3%)			
66 & older	3 (2.5%)	34 (6.6%)			
Gender					
Male	117 (99.2%)	510 (98.5%)	1.000	69	0.047
Female	1 (0.9%)	8 (1.5%)			
Large Truck Driver Behaviors					
Distraction					
Yes	30 (25.4%)	195 (37.6%)	0.007*	18	0.012
No	86 (72.9%)	298 (57.5%)			
Unknown	2 (1.7%)	25 (4.8%)			
Fatigue					
Yes	0 (0.0%)	0 (0.0%)	0.593	53	0.036
No	117 (99.2%)	513 (99.0%)			
Unknown	1 (0.9%)	5 (1.0%)			
Occupant Seatbelt Use					
Used	107 (90.7%)	479 (92.5%)	0.319	42	0.028
Not Used	6 (5.1%)	13 (2.5%)			
Unknown	5 (4.2%)	26 (5.0%)			
Large Truck Driver Violations					
Failure to Yield					
Yes	10 (8.5%)	39 (7.5%)	0.728	59	0.040
No	108 (91.5%)	479 (92.5%)			
Following Too Closely					
Yes	3 (2.5%)	43 (8.3%)	0.029	24	0.016
No	115 (97.5%)	475 (91.7%)			
Driving Left of Center					
Yes	6 (5.1%)	17 (3.3%)	0.344	44	0.030
No	112 (94.9%)	501 (96.7%)			

Table 2.4 Continued

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Speeding					
Yes	0 (0.0%)	1 (0.2%)	1.000	70	0.047
No	118 (100.0%)	517 (99.8%)			
Cutting In, Improper Passing					
Yes	2 (1.7%)	16 (3.1%)	0.549	51	0.035
No	116 (98.3%)	502 (96.9%)			
Careless Operation					
Yes	10 (8.5%)	57 (11.0%)	0.419	47	0.032
No	108 (91.5%)	461 (89.0%)			
Other Vehicle Driver Demographics					
Age (years)					
25 and younger	14 (11.9%)	95 (18.3%)	0.050	28	0.019
26-35	38 (32.2%)	108 (20.9%)			
36-45	17 (14.4%)	95 (18.3%)			
46-55	12 (10.2%)	77 (14.9%)			
56-65	18 (15.3%)	61 (11.8%)			
66 & older	19 (16.1%)	82 (15.8%)			
Gender					
Male	70 (59.3%)	337 (65.1%)	0.241	39	0.026
Female	48 (40.7%)	181 (34.9%)			
Other Vehicle Driver Behaviors					
Distraction					
Yes	55 (46.6%)	174 (33.6%)	0.000*	1	0.001
No	39 (33.1%)	310 (59.9%)			
Unknown	24 (20.3%)	34 (6.6%)			
Fatigue					
Yes	1 (0.9%)	2 (0.4%)	0.000*	2	0.001
No	99 (83.9%)	512 (98.8%)			
Unknown	18 (15.3%)	4 (0.8%)			
Occupant Seatbelt Use					
Used	87 (73.7%)	482 (93.1%)	0.000*	3	0.002
Not Used	24 (20.3%)	11 (2.1%)			
Unknown	7 (5.9%)	25 (4.8%)			
Other Vehicle Driver Violations					
Failure to Yield					
Yes	18 (15.3%)	79 (15.3%)	0.999	68	0.046
No	100 (84.8%)	439 (84.8%)			

Table 2.4 Continued

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Following Too Closely					
Yes	3 (2.5%)	17 (3.3%)	1.000	73	0.049
No	115 (97.5%)	501 (96.7%)			
Driving Left of Center					
Yes	23 (19.5%)	14 (2.7%)	0.000*	4	0.003
No	95 (80.5%)	504 (97.3%)			
Speeding					
Yes	2 (1.7%)	0 (0.0%)	0.034	25	0.017
No	116 (98.3%)	518 (100.0%)			
Cutting In, Improper Passing					
Yes	2 (1.7%)	15 (2.9%)	0.751	60	0.041
No	116 (98.3%)	503 (97.1%)			
Careless Operation					
Yes	29 (24.6%)	67 (12.9%)	0.001*	12	0.008
No	89 (75.4%)	451 (87.1%)			

Notes: (1) Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Here, multiple vehicle crashes are only two-vehicle crashes; (3) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (4) a Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (5) b Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =d*i/n (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). i is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (6) *P-value is significant at the adjusted cutoff p-value level.

Table 2.5: Vehicle variables and crash severity for multiple vehicle crashes involving large logging truck in Louisiana (2010-2018)

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Large Truck Characteristics					
Vehicle Defects Observed					
Yes	5 (4.2%)	36 (7.0%)	0.344	45	0.030
No	109 (92.4%)	472 (91.1%)			
Unknown	4 (3.4%)	10 (1.9%)			
Vehicle Lighting Condition					
Headlights on or Daytime Running Lights	56 (47.5%)	190 (36.7%)	0.093	34	0.023
Headlights off	48 (40.7%)	258 (49.8%)			
Unknown	14 (11.9%)	70 (13.5%)			
Vehicle Age					
Less than 10 years	25 (21.2%)	104 (20.1%)	0.787	63	0.043
More than 10 years	93 (78.8%)	414 (79.8%)			
Large Truck Movement-Harmful Events					
Vehicle Overturn/Rollover					
Yes	11 (9.3%)	15 (2.9%)	0.001*	11	0.007
No	107 (90.7%)	503 (97.1%)			
Cargo/Equipment Loss or Shift					
Yes	2 (1.7%)	12 (2.3%)	1.000	71	0.048
No	116 (98.3%)	506 (97.7%)			
Ran Off Road Right					
Yes	14 (11.9%)	25 (4.8%)	0.008*	19	0.013
No	104 (88.1%)	493 (95.2%)			
Ran Off Road Left					
Yes	11 (9.3%)	16 (3.1%)	0.002*	15	0.010
No	107 (90.7%)	502 (96.9%)			
Hit Standing Tree					
Yes	1 (0.9%)	7 (1.4%)	1.000	72	0.049
No	117 (99.2%)	511 (98.7%)			
Crossed Median/Centerline					
Yes	18 (15.3%)	49 (9.5%)	0.064	31	0.021
No	100 (84.8%)	469 (90.5%)			
Hit Pedestrian					
Yes	0 (0.0%)	0 (0.0%)	N/A		
No	118 (100.0%)	518 (100.0%)			

Table 2.5 Continued

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Large Truck Movement-Prior Movement					
Ran Off Road					
Yes	6 (5.1%)	13 (2.5%)	0.211	38	0.026
No	111 (94.1%)	502 (96.9%)			
Unknown	1 (0.9%)	3 (0.6%)			
Making Left Turn					
Yes	6 (5.1%)	46 (8.9%)	0.297	41	0.028
No	111 (94.1%)	469 (90.5%)			
Unknown	1 (0.9%)	3 (0.6%)			
Crossed Median or Center Line into Opposite Lane					
Yes	15 (12.7%)	36 (7.0%)	0.080	32	0.022
No	102 (86.4%)	479 (92.5%)			
Unknown	1 (0.9%)	3 (0.6%)			
Large Truck Movement-Reason for Movement					
To Avoid Other Vehicle					
Yes	16 (13.6%)	39 (7.5%)	0.013*	21	0.014
No	101 (85.6%)	479 (92.5%)			
Unknown	1 (0.9%)	0 (0.0%)			
Vehicle Out of Control, Not Passing					
Yes	1 (0.9%)	1 (0.2%)	0.090	33	0.022
No	116 (98.3%)	517 (99.8%)			
Unknown	1 (0.9%)	0 (0.0%)			
Large Truck Movement-Traffic Control					
Stop Sign					
Yes	7 (5.9%)	36 (7.0%)	0.691	56	0.038
No	111 (94.1%)	482 (93.1%)			
Yellow No Passing Line					
Yes	39 (33.1%)	175 (33.8%)	0.879	65	0.044
No	79 (67.0%)	343 (66.2%)			
White Dashed Line					
Yes	25 (21.2%)	107 (20.7%)	0.898	66	0.045
No	93 (78.8%)	411 (79.3%)			
Yellow Dashed Line					
Yes	27 (22.9%)	81 (15.6%)	0.059	30	0.020
No	91 (77.1%)	437 (84.4%)			

Table 2.5 Continued

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
No Control					
Yes	8 (6.8%)	29 (5.6%)	0.621	55	0.037
No	110 (93.2%)	489 (94.4%)			
Other Vehicle Characteristics					
Vehicle Defects Observed					
Yes	0 (0.0%)	2 (0.4%)	1.000	74	0.050
No	109 (92.4%)	472 (91.1%)			
Unknown	0 (0.0%)	0 (0.0%)			
Vehicle Lighting Condition					
Headlights on or Daytime Running Lights	57 (48.3%)	204 (39.4%)	0.044	27	0.018
Headlights off	40 (33.9%)	241 (46.5%)			
Unknown	21 (17.8%)	73 (14.1%)			
Other Vehicle Movement-Harmful Events					
Vehicle Overturn/Rollover					
Yes	9 (7.6%)	7 (1.4%)	0.000*	5	0.003
No	109 (92.4%)	511 (98.7%)			
Cargo/Equipment Loss or Shift					
Yes	2 (1.7%)	5 (1.0%)	0.619	54	0.037
No	116 (98.3%)	513 (99.0%)			
Ran Off Road Right					
Yes	15 (12.7%)	25 (4.8%)	0.001*	13	0.009
No	103 (87.3%)	493 (95.2%)			
Ran Off Road Left					
Yes	9 (7.6%)	28 (5.4%)	0.352	46	0.031
No	109 (92.4%)	490 (94.6%)			
Hit Standing Tree					
Yes	3 (2.5%)	5 (1.0%)	0.171	37	0.025
No	115 (97.5%)	513 (99.0%)			
Crossed Median/Centerline					
Yes	30 (25.4%)	64 (12.4%)	0.000*	6	0.004
No	88 (74.6%)	454 (87.6%)			
Hit Pedestrian					
Yes	0 (0.0%)	0 (0.0%)	N/A		
No	118 (100.0%)	518 (100.0%)			

Table 2.5 Continued

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Other Vehicle Movement-Prior Movement					
Vehicle Ran Off Road					
Yes	3 (2.5%)	10 (1.9%)	0.769	61	0.041
No	114 (96.6%)	498 (96.1%)			
Unknown	1 (0.9%)	10 (1.9%)			
Making Left Turn					
Yes	10 (8.5%)	64 (12.4%)	0.431	48	0.032
No	107 (90.7%)	444 (85.7%)			
Unknown	1 (0.9%)	10 (1.9%)			
Crossed Median or Center Line into Opposite Lane					
Yes	28 (23.7%)	30 (5.8%)	0.000*	7	0.005
No	89 (75.4%)	478 (92.3%)			
Unknown	1 (0.9%)	10 (1.9%)			
Other Vehicle Movement-Reason for Movement					
To Avoid Other Vehicle					
Yes	5 (4.2%)	30 (5.8%)	0.004*	17	0.012
No	107 (90.7%)	485 (93.6%)			
Unknown	6 (5.1%)	3 (0.6%)			
Vehicle Out of Control, Not Passing					
Yes	1 (0.8%)	1 (0.2%)	0.001*	14	0.010
No	111 (94.1%)	514 (99.2%)			
Unknown	6 (5.1%)	3 (0.6%)			
Other Vehicle Movement-Traffic Control					
Stop Sign					
Yes	12 (10.2%)	47 (9.1%)	0.711	58	0.039
No	106 (89.8%)	471 (90.9%)			
Yellow No Passing Line					
Yes	39 (33.1%)	144 (27.8%)	0.255	40	0.027
No	79 (67.0%)	374 (72.2%)			
White Dashed Line					
Yes	23 (19.5%)	113 (21.8%)	0.579	52	0.035
No	95 (80.5%)	405 (78.2%)			

Table 2.5 Continued

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Yellow Dashed Line					
Yes	23 (19.5%)	82 (15.8%)	0.334	43	0.029
No	95 (80.5%)	436 (84.2%)			
No Control					
Yes	10 (8.5%)	40 (7.7%)	0.784	62	0.042
No	108 (91.5%)	478 (92.3%)			

Notes: (1) Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Here, multiple vehicle crashes are only two-vehicle crashes; (3) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (4) a Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (5) b Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =d*i/n (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). i is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (6) *P-value is significant at the adjusted cutoff p-value level; (7) N/A Not compared because of zero cell size.

Table 2.6: Crash variables and crash severity for multiple vehicle crashes involving large logging truck in Louisiana (2010-2018)

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Crash Time					
Morning	24 (20.3%)	153 (29.5%)	0.027	23	0.016
Afternoon	30 (25.4%)	148 (28.6%)			
Evening/ Night	21 (17.8%)	51 (9.9%)			
Unknown	43 (36.4%)	166 (32.1%)			
Crash Year					
2010	14 (11.9%)	69 (13.3%)	0.695	57	0.039
2011	14 (11.9%)	61 (11.8%)			
2012	9 (7.6%)	46 (8.9%)			
2013	11 (9.3%)	54 (10.4%)			
2014	8 (6.8%)	61 (11.8%)			
2015	17 (14.4%)	56 (10.8%)			
2016	19 (16.1%)	61 (11.8%)			
2017	14 (11.9%)	52 (10.0%)			
2018	12 (10.2%)	58 (11.2%)			
Day of the Week					
Weekday	111 (94.1%)	488 (94.2%)	0.953	67	0.045
Weekend	7 (5.9%)	30 (5.8%)			
Clear Weather Conditions					
Yes	85 (72.0%)	415 (80.1%)	0.053	29	0.020
No	33 (28.0%)	103 (19.9%)			
Daylight					
Yes	80 (67.8%)	443 (85.5%)	0.000*	8	0.005
No	38 (32.2%)	75 (14.5%)			
Road Surface Condition-Dry					
Yes	102 (86.4%)	470 (90.7%)	0.162	36	0.024
No	16 (13.6%)	48 (9.3%)			
Road Surface Type-Blacktop					
Yes	99 (83.9%)	419 (80.9%)	0.448	49	0.033
No	19 (16.1%)	99 (19.1%)			
Road Alignment					
Straight	91 (77.1%)	448 (86.5%)	0.011*	20	0.014
Curved	27 (22.9%)	70 (13.5%)			

Table 2.6 Continued

Independent Variable	Logging truck crashes (n=636)				
	Higher Severity Crash n (Col%) (n=118)	Lower Severity Crash n (Col%) (n=518)	P-value	I[a]	Adjusted cutoff P-value Significance Level [b]
Manner of Collision					
Rear End	34 (28.8%)	142 (27.4%)	0.000*	9	0.006
Head On	16 (13.6%)	1 (0.2%)			
Angle	31 (26.3%)	93 (18.0%)			
Opposite Direction	19 (16.1%)	75 (14.5%)			
Same Direction	12 (10.2%)	139 (26.8%)			
Other or Unknown	6 (5.1%)	68 (13.1%)			
Road Type No Physical Barrier					
Yes	89 (75.4%)	376 (72.6%)	0.530	50	0.034
No	29 (24.6%)	142 (27.4%)			
Location Type					
Manufacturing or Industrial or business area	45 (38.1%)	152 (29.3%)	0.017	22	0.015
Residential related area	33 (28.0%)	218 (42.1%)			
Open country	40 (33.9%)	148 (28.6%)			
Intersection					
Yes	30 (25.4%)	168 (32.4%)	0.138	35	0.024
No	88 (74.6%)	350 (67.6%)			
Highway Type					
Interstate or US highway	44 (37.3%)	195 (37.6%)	0.834	64	0.043
State highway	65 (55.1%)	275 (53.1%)			
Other (Parish Road, City Street)	9 (7.6%)	48 (9.3%)			
Impairment- Alcohol Estimates					
Yes	6 (5.1%)	4 (0.8%)	0.004*	16	0.011
No	112 (94.9%)	514 (99.2%)			
Driver at-Fault					
Large truck driver	23 (19.5%)	205 (39.6%)	0.000*	10	0.007
Other vehicle driver	55 (46.6%)	192 (37.1%)			
Both drivers or Unclear	40 (33.9%)	121 (23.4%)			

Notes: (1) Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Here, multiple vehicle crashes are only two-vehicle crashes; (3) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (4) a Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (5) b Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =d*i/n (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). i is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (6) *P-value is significant at the adjusted cutoff p-value level.

CHAPTER III

SPECIFC AIM 1B: THE ASSOCIATION OF DRIVER, VEHICLE, AND CRASH FACTORS WITH CRASH SEVERITY (HIGHER SEVERITY VERSUS LOWER SEVERITY) IN LARGE NON-LOGGING TRUCK CRASHES

Introduction

The literature on occupationally-related roadway crashes comparing the logging and the non-logging trucking industry is limited. Only a few studies have compared crash characteristics related to logging, and non-logging truck crashes by crash severity. None of these have compared crash characteristics and severity associations between non-logging truck crashes and logging truck crashes. This study determined statistically significant relationships between driver, vehicle, and crash variables and crash severity (higher severity versus lower severity) in large non-logging truck crashes stratified by crash type (single and multiple vehicle crashes). This analysis adds to the baseline information for further analysis and how crash patterns differ between higher and lower severity crashes involving non-logging trucks.

Occupant fatalities are rising for large truck crashes. Large truck occupant fatalities increased by 25% from 2015 to 2018 (NHTSA, 2020). Overall, long-haul drivers are at greater risk of being involved in serious crashes. More than 1 in 3 long-haul truck drivers reported being involved in a severe truck crash during their driving career (CDC, 2015). However, data and research on transportation-related injuries in the logging industry in the United States and Louisiana are limited. Therefore, it is difficult to compare the crash factors in large logging truck crashes with large non-logging truck crashes.

Cole (2018) compared frequencies and proportions of fatal logging truck crashes to other large trucks using FARS in the United States from 2011 to 2015 but did not include other crash severities in the comparison. Logging truck crashes followed the national trend of rising heavy truck crashes, but the frequency increased faster than heavy truck crashes. The overall increase in fatal crashes was higher in logging truck crashes (increased by more than 33%) than large truck crashes (increased by 16%). Crash characteristics contributing to logging and other non-logging tractor-trailer fatal crashes had similar trends from 2010 to 2015 (Cole, 2018). Logging trucks (average age 13.0 years) were older than all trucks (average age 7.6 years).

Greene et al. (1996) compared the cause of logging vehicle crashes with other heavy truck crashes with a focus on mechanical failures. Mechanical failure-related crashes dropped from 10.9% to 5.5% for logging tractor-trailers, 12.9% to 3.2% for logging trucks, and 3.8% to 2.3% for other heavy trucks from 1988-1991 to 2005-2008 (Greene, 1996). Scant literature has focused on the crash characteristics of specific types of large trucks or cargo types that affect drivers' maneuvers to the surrounding environment and other drivers' actions (Cole, 2018).

The average age of logging truck drivers involved in fatal crashes was slightly higher than other truck drivers. Cole (2018) analyzed the five-year national fatal crash database. He estimated the average age of logging truck drivers was 48.7 years old.

Mason (2008) found the average age of logging truck drivers who participated in a statewide survey of the log truck industry was 55 years in Washington State. Most previous studies have focused on heavy truck crash trends (McKnight 2009, Knipling et al. 2008, Braver et al. 1996). An analysis of the FMCSA data between 2010 and 2015 indicated that logging truck crashes were more severe than other types of crashes (Baker & Tyson, 2017).

Logging vehicles are often large and designated as heavyweight, overweight, and oversized more often than large non-logging trucks. Depending on the log loads, logging trucks' weight distribution can vary from other types of trucks, making logging trucks prone to rollover more often. About 12% of all large trucks involved in fatal crashes experienced rollovers, and the rollover proportion was much higher for logging trucks involved in fatal crashes (21%) (Cole 2018).

Cole (2018) found that the most common pre-crash event for fatal crashes was another vehicle entering the trucks' travel lane from the opposite direction over the left lane. This pre-crash event was more prevalent in logging truck crashes (29.1%) than all other large truck crashes (20.5%). Running off the road was more frequent in logging truck crashes (9.6%) than other tractor-trailers (7.9%), whereas the prevalence of pedestrian-related crashes was higher in heavy truck crashes (5.3%) than logging truck crashes (3.1%). However, Cole (2018) only analyzed fatal crashes and did not explain how various factors affected crash severity.

Besides crashes, the logging transportation industry is facing more challenges than other commercial trucking industries. One difficulty retaining truck drivers could be lower wages for logging truck drivers than drivers in other industries (Baker, Shawn, & Mendell, 2016). An analysis of logging truck registration data from the Washington State Department of Licensing (WSDOL) indicated a 36% decline in the number of logging trucks registered from 1998 to 2006 (Mason et al., 2008).

Another primary concern for the logging industry is qualifying for truck insurance due to the hazardous nature of transporting logs. Logging truck drivers must have two to three years of driving experience after getting a Commercial Driver's License (CDL) to qualify for insurance coverage (Baker, Shawn, & Tyson, 2017; Costello & Suarez, 2015). The average insurance premium for logging trucks increased by 53% from 2011 to 2016, whereas, for other heavy vehicles, it increased by 12% for the same period in Georgia (Conrad, 2018). Covering logging trucks is riskier than providing other commercial auto insurance for insurance companies because logging trucks tend to be more expensive than other heavy vehicles (Conrad, 2018). The average cost per claim of logging trucks has increased by approximately 40% since 2008 for a subset of carriers that offer logging truck insurance (Baker & Tyson, 2017; Conrad, 2018).

This current study's findings can be compared with associated crash characteristics in higher severe crashes involving large logging and non-logging trucks. The findings would help provide targeted safety training programs for the logging transportation industry and understand the differences in crash characteristics between large logging and non-logging truck crashes.

Methods

Hypothesis

The null hypothesis is that no statistically significant associations exist between driver, vehicle, and crash variables and crash severity (higher severity versus lower severity) in large non-logging truck crashes for single-vehicle crashes or multi-vehicle crashes in Louisiana from 2010-2018. The hypothesis was that statistically significant associations existed between driver, vehicle, crash variables, and crash severity (higher severity versus lower severity) in large non-logging truck crashes for single-vehicle crashes or multi-vehicle crashes in Louisiana from 2010-2018.

Data Source

A crash database from the Louisiana Department of Transportation and Development from 2010-2018 was analyzed to determine the associations between driver, vehicle, crash variables and crash severity (higher severity versus lower severity), and crash type (single and multiple vehicle crash) involving large non-logging trucks. The Louisiana Department of Transportation and Development (LaDOTD) Highway Safety database from 2010 to 2018 includes fatal, non-fatal, or property damage greater than $500 crashes and information on the person, vehicle, and crash factors. The severity level of fatal crashes is updated within 30 days. The police officers who respond to the scene collect the crash data and complete the reports based on the evidence at the scene and interviews with the victims and witnesses.

Variables

Large non-logging truck crashes were identified as those that were not flagged as "H" (logging truck) or "K" (pole-trailer) in cargo body type with vehicle configuration type of single-unit 2 axle (L), single-unit 3 axel (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), truck double (R) in Louisiana crash data 2010-2018.

A crash type variable was created using the number of vehicles involved in crashes. A crash type "single large non-logging truck crash" was defined as a situation where only one large non-logging truck was involved in a crash. A multi-vehicle crash was defined as more than one vehicle involved in a crash. For this dissertation, a "multi-vehicle crash" was defined as a crash type involving at least one large non-logging truck and at least one other vehicle in a collision.

The LaDOTD codes crash severity is based on the KABCO Injury Classification Scale (U.S. Department of Transportation, Federal Highway Administration, 2017). The dependent variable is binary, and classified crashes as higher crash severity (KAB) crashes. The higher crash severity (KAB) crash category (1) includes fatal (K), severe (A), and moderate (B) injuries. The lower crash severity (CO) crash category (0) includes complaints or possible injury (C) and no injury or property damage only (O) as coded by responding law enforcement officer.

The dependent variable was created from the crash severity variable (see Chapter 1, Data Description Section). Independent variables were the driver, vehicle, and crash factors. The driver factors included driver's demographics (age and gender) and behavioral characteristics (seatbelt use, distraction, and impairment variables and traffic violations variables). Vehicle factors included vehicle type, vehicle condition, vehicle light conditions, prior movement of the vehicle, the reason for the movement of the vehicle, and harmful events. Crash factors included the year of the crash, time of day or year, day of the week, weather, lighting conditions, intersection flag, highway type, road type, road condition, crash location type, traffic control factors, and manner of collision. For detailed information about the dependent and independent variables and the categorization, see Chapter 1, Data Description Section and Appendix Table A-2.

Analysis

Cross-tabulations were performed to estimate the frequency and proportions of crash severity (higher severity versus lower severity) among independent variables (driver, vehicle, and crash factors) in large non-logging truck crashes, stratified by crash type (single and multiple vehicle crash). Pearson chi-square tests were performed to determine whether a statistically significant relationship was present between crash characteristics (all variables are either binary or categorical) and crash severity (higher severity versus lower severity), stratified by crash type (single versus multiple vehicle crashes) in large non-logging truck crashes.

The following Pearson chi-square test formula was used for this method:

$$X^2 = \sum_{i=1}^{S} \frac{(O_i - E_i)^2}{E_i}$$

O = observed frequency

E = expected frequency

If the expected frequency for one or more of the cells was five or less for independent variables by the dependent variable, Fisher's exact test was conducted in place of the Pearson chi-square test. STATA 16 (StataCorp LP, College Station, TX) was used to analyze the descriptive statistics and Pearson chi-square or Fisher's exact test. An alpha level of 0.05 was used to define statistical significance.

False discovery rate post hoc analysis was conducted to examine the issue of multiple comparisons between crash characteristics and crash severity (KAB versus CO crash severity) by crash type (single versus multiple vehicle crashes) in large non-logging truck crashes (Benjamini and Hochberg, 1995; Glickman et al. 2014). Conducting multiple comparisons or hypothesis tests can result in obtaining statistically significant findings just by chance. The false discovery rate control method (also known as Benjamini–Hochberg procedure) was used to address and correct potential problems from conducting multiple comparisons.

The adjusted p-values were computed using a false discovery rate control method. The number of hypotheses was denoted by n tests with a maximum false discovery rate d (here, α=0.05). The p-value was calculated from the Pearson Chi-square or Fisher's exact tests. These p-values were sorted in ascending order (p1, p2, ..., pn). These n hypotheses tests were ranked in ascending order based on the p-value smallest to largest. The pi was calculated d*i/n for all tests (p1, p2, ..., pk), and the largest index value was indicated by k. Based on the calculated p-values (p1, p2, ..., pk), the significance of the tests was interpreted.

Results

Overview

The analyzed sample included 43,927 large non-logging truck crashes from the Louisiana crash database from 2010 to 2018. The analyzed sample included 7,913 SV crashes involving a large non-logging truck and 36,014 MV crashes involving at least one large non-logging truck in Louisiana. Overall, 6.7% (531 of 7,913) of SV large non-logging truck crashes and 6.9% (2,490 of 36,014) of MV large non-logging truck crashes were fatal or severe crashes. Tables 3.1 to 3.6 show the frequency of driver characteristics and behaviors, vehicle movement, and crash characteristics stratified by crash severity (higher severity versus lower severity) and for SV and MV large non-logging truck crashes separately.

Driver's Characteristics and behaviors

The average age of truck drivers involved in SV crashes was 44 years (range 16 to 82 years). The average age of truck drivers involved in MV crashes was 45 years (range 15 to 88 years), and other vehicle drivers involved in MV crashes was 42 years (range 11 to 98 years). The truck drivers from the age group 46-55 were more prevalently involved in higher severity SV crashes (27.3%) than lower severity crashes (25.2%). Truck drivers aged 56-65 were more prevalently involved in higher severity SV crashes (16.2%) than lower severity crashes (15.6%). Younger truck drivers (below age 25 years) were more prevalently involved in higher severity SV crashes (8.3%) than lower severity crashes (6.8%). There was no statistically significant difference in the distribution of age groups by crash severity in SV crashes. The middle age group (36-45 years) of large non-logging trucks was more prevalently involved in higher severity MV crashes (28.4%) than lower severity crashes (25.4%). Crash severity had a statistically significant difference among non-logging truck drivers' age groups involved in MV crashes (p=0.000).

More than 96.0% of SV and MV crashes involved large non-logging truck drivers who were male drivers. About 58.4% of other vehicles involved in MV crashes were male drivers. Male drivers were less prevalently involved in higher severity SV crashes (95.1%) than lower severity SV crashes (96.5%). Female drivers were more prevalently involved in higher severity SV crashes (4.9%) than lower severity SV crashes (3.5%). Male drivers of large non-logging trucks were less prevalently involved in higher severity MV crashes (96.3%) than lower severity MV crashes (96.5%). Female drivers of large non-logging trucks were more prevalently involved in higher severity MV crashes (3.7%) than lower severity MV crashes (3.5%). There was no statistically significant difference in the distribution of gender of large non-logging truck drivers by crash severity and crash type (SV and MV).

Distracted driving was a behavioral factor more often assigned to large non-logging trucks involved in SV crashes (52.5%) than MV crashes (37.4%). About 52.5%

of truck drivers involved in SV crashes were distracted at the time of the crash. Distracted driving was less prevalent in high severity SV crashes (43.3%) than lower severity crashes (53.1%), and the distribution of distracted drivers was significantly different by crash severity (p=0.000). About 37.4% of truck drivers involved in MV crashes were assigned as distracted at the time of a crash. Distracted driving was less prevalent for truck drivers among higher severity MV crashes (24.0%) than lower severity MV crashes (38.4%), and the distribution of distracted drivers was significantly different by crash severity (p=0.000).

About 3.1% of truck drivers involved in SV crashes failed to wear a seat belt at the time of the crash. Higher severity SV crashes (13.9%) had more significant proportions of the drivers who were not wearing a seat belt than lower severity SV crashes (2.4%). The difference in its distribution was statistically significant by crash severity (p=0.000). A lower proportion of truck drivers (0.7%) involved in MV crashes were not wearing a seat belt at the time of the crash. Higher severity MV crashes (1.7%) had higher proportions of the truck drivers who were not wearing a seat belt than lower severity MV crashes (0.7%). The difference in its distribution was statistically significant by crash severity (p=0.000).

A small proportion of SV crashes (0.8%) involved fatigued truck drivers. However, the frequency of fatigued truck drivers differed significantly between higher severity (1.3%) and lower severity (0.8%) SV crashes (p=0.000). Similarly, a lower proportion of MV crashes involving large non-logging truck drivers (0.1%) and other vehicle drivers (0.5%) happened due to fatigue. The frequency of fatigued truck drivers differed significantly among higher (0.2%) versus lower severity (0.1%) MV crashes (p=0.000).

About 1.0% of SV crashes and 2.0% of MV crashes involved impaired drivers. Impaired driving was more prevalent in higher severity SV crashes (5.5%) than among lower severity SV crashes (0.7%), and the frequency of impaired drivers differed significantly among SV crashes by crash severity (p=0.000). Impaired driving was more prevalent in higher severity MV crashes (9.5%) than among lower severity MV crashes (1.4%), and the frequency significantly varied by crash severity (p=0.000).

The careless operation was the most common citation assigned to drivers involved in SV large non-logging truck crashes (45.2%) (data not shown in tables). Careless operation violation was assigned to 11.4% of truck drivers and 14.1% of other vehicle drivers involved in MV crashes. Careless driving was more prevalent in higher severity SV crashes (55.9%) than lower severity SV crashes (44.4%), and its frequency varied significantly by crash severity (p=0.000). Careless driving assigned to truck drivers was less prevalent in higher severity MV crashes (9.8%) than lower severity MV crashes (11.5%), and its frequency significantly varied by crash severity (p=0.013).

A speeding violation was assigned to a small proportion of truck drivers involved in SV crashes (1.5%). The proportion among higher severity (2.8%) versus lower severity (1.4%) SV crashes was significantly different (p=0.009). The speeding violation was assigned to a small proportion of truck drivers (0.1%) and other vehicle drivers (0.4%)

involved in MV crashes. The proportions of truck drivers who received a speeding violation among higher severity (0.2%) versus lower severity (0.1%) MV crashes were not significantly different (p=0.141).

Vehicle Characteristics and Movement

Most of the SV and MV crashes happened when the truck's headlights were off, and there was no daylight (34.2% for SV and 36.8% for MV) (data not shown in tables). The truck headlights-off at the time of a crash was less prevalent in higher severity SV crashes (33.0%) than lower severity crashes (34.3%) in SV crashes, and its frequencies were not significantly different by crash severity (p=0.817). The truck headlights-off at the time of a crash was less prevalent in higher severity crashes (28.6%) than lower severity crashes (37.4%) in MV crashes, and its distribution did not significantly vary by crash severity (p=0.000).

Vehicle defects include defective brakes, headlights, rear lights, signal lights, steering, suspension, all lights out, tire failure, worn or smooth tires, and engine failure. About 7.5% of SV crashes and 3.5% of MV crashes involved large non-logging trucks with vehicle defects at the time of the crash. Trucks having vehicle defects at the time of a crash were less prevalent in higher severity crashes (6.0%) than lower severity crashes (7.6%) in SV crashes, and it did not significantly vary by crash severity (p=0.173). The frequency of vehicle defects in trucks differed significantly by crash severity in MV crashes (p=0.001).

The majority of SV (64.8%) and MV (65.1%) crashes involved large non-logging truck models older than ten years (data not shown in tables). The older trucks were more prevalently involved in higher severity SV crashes than lower severity SV crashes (68.2% higher versus 64.6% lower severity). However, the frequency of older trucks involved in SV crashes was not significantly different by crash severity (p=0.092). Older trucks were more prevalently involved in higher severity MV crashes (68.9%) than lower severity MV crashes (64.8%). The frequency of older trucks involved in MV crashes was significantly different by crash severity (p=0.000).

The most harmful events are the sequence of events that resulted in a more severe injury or, if no injury, the greatest property damage involving a vehicle. The following harmful events were more prevalent in higher severity SV crashes than lower severity SV crashes in respective harmful events:

- The truck ran off the road to the right side (43.5% higher versus 27.6% lower severity, p=0.000).
- Truck overturns or rollover (49.4% higher versus 23.3% lower severity p=0.000).
- The truck ran off the road to the left side (22.2% higher versus 13.7% lower severity, p=0.000).
- The truck hit a standing tree (15.3% higher versus 7.6% lower severity, p=0.000).
- The truck crossed the median, or centerline (12.6% higher versus 6.3% lower severity, p=0.000), the cargo shift or loss of cargo or equipment (5.7% higher versus 3.8% lower severity, p=0.029).

- The truck hit a pedestrian (10.4% higher versus 0.3% lower severity, p=0.000).
- The frequency of these harmful events in SV crashes significantly differed by crash severity.

The following harmful events assigned to large non-logging trucks in MV crashes were more prevalent in higher severity crashes than lower severity crashes: vehicle overturn or rollover (4.2% higher versus 0.5% lower severity, p=0.000), the vehicle ran off the road to the right side (6.6% higher versus 1.1% lower severity, p=0.001), the vehicle ran off the road to left side (4.4% higher versus 0.8% lower severity, p=0.000), the vehicle hit a standing tree (1.1% higher versus 0.2% lower severity, p=0.000), and the vehicle crossed median or centerline (5.5% higher versus 3.3% lower severity, p=0.000). Harmful event cargo or equipment loss or shift was less prevalent in higher severity MV crashes than lower severity crashes (0.6% higher versus 1.5% lower severity, p=0.000). The frequency of older trucks involved in MV crashes was significantly different by crash severity (p=0.000).

"Prior movement" is defined as the vehicle maneuver immediately prior to the crash. The most common prior movements in SV crashes were vehicle ran off the road (28.3%), the vehicle was making a left turn (7.0%), and the vehicle crossed median or center line into the opposite lane (1.6%). Truck running off the road before the crash was more prevalent in higher severity SV crashes (48.4%) than lower severity SV crashes (26.9%), and its distribution was significantly different by crash severity (p=0.000). Truck making left turn prior to the crash was less prevalent in higher severity SV crashes

(2.3%) than lower severity SV crashes (7.4%), and its distribution was significantly different by crash severity (p=0.000). The truck that crossed the median or center line into the opposite lane before the crash was more prevalent in higher severity SV crashes (2.8%) than lower severity SV crashes (1.5%), and its distribution was significantly different by crash severity (p=0.024).

About 0.6% of large non-logging trucks involved in MV crashes ROR prior to a crash. Truck ROR crash event prior to the crash was more prevalent in higher severity SV crashes (1.6%) than lower severity SV crashes (0.5%), and its distribution was significantly different by crash severity (p=0.000). About 1.9% of the large non-logging trucks involved in the MV crash crossed the median or center line into the opposite lane prior to the crash. Prior movement crossing the median or center line into the opposite lane in other the vehicle was more prevalent in higher severity MV crashes (2.7%) than lower severity MV crashes (1.8%), and its distribution was significantly different by crash severity (p=0.013).

The reason for movement describes the driver's action or the reason for the driver’s maneuver made the prior movement to crash. The large non-logging truck involved in SV crashes being out of control or not passing led was more frequent in higher severity crashes (4.5%) than lower severity crashes (1.4%), and the distribution was significantly different by crash severity (p=0.000). About 3.1% of MV large non-logging truck crashes involved large non-logging trucks trying to avoid other vehicles at the time of a crash. The large non-logging trucks trying to avoid other vehicles at the time of the crash were more prevalent in higher severity MV crashes (5.5%) than lower severity MV crashes (2.9%), and the distribution was significantly different by crash severity (p=0.000).

Traffic control is described as the type of traffic control present at the crash location. The distribution of these traffic controls in SV crashes was significantly different by crash severity. SV non-logging crashes were more prevalent in higher severity crashes than lower severity crashes for crashes assigned yellow no-passing line (26.9% higher severity versus 19.0% lower severity, p=0.000), white dashed line (32.4% higher severity versus 25.2% lower severity, p=0.000), and yellow dashed line (17.3% higher severity versus 11.2% lower severity, p=0.000). The stop sign (1.9% higher severity versus 7.1% lower severity, p=0.000) and no traffic control present (11.3% higher severity versus 21.4% lower severity, p=0.000) assigned to SV non-logging crashes were less prevalent in higher severity crashes than lower severity crashes.

The following traffic controls assigned to large non-logging trucks involved in MV crashes were more prevalent in higher severity crashes than lower severity crashes: yellow no-passing line present (14.8% higher severity versus 10.1% lower severity, p=0.000) and yellow dashed line (10.8% higher severity versus 6.5% lower severity, p=0.000). The white dashed line assigned to large non-logging trucks involved in MV crashes was a less prevalent crash factor in higher severity crashes (44.1%) than lower severity crashes (47.4%), and its distribution was significantly different by crash severity (p=0.002).

Crash Characteristics

A greater proportion of angle, head-on, opposite-direction, and rear-end MV crashes were higher severity crashes than lower severity crashes. Angle collisions were more prevalent in higher severity MV crashes (22.9%) than lower severity MV crashes (11.4%). Head-on collisions were more prevalent in higher severity MV crashes (7.4%) than lower severity MV crashes (1.2%). Opposite-direction collisions were more prevalent in higher severity MV crashes (9.8%) than lower severity MV crashes (6.4%). Rear-end MV collisions were more prevalent in higher severity crashes (39.1%) than lower severity crashes (30.2%). The frequency of collision types had statistically significant differences in MV crashes by crash severity (p=0.000).

Most of the SV large non-logging truck crashes (72.5%) and MV non-logging truck crashes (74.7%) happened in daylight. However, SV crashes in no daylight were more prevalent in higher severity crashes (33.7%) than lower severity crashes (27.1%). The distribution of daylight conditions was significantly different by crash severity (p=0.000). The MV large non-logging truck crashes that happened in the evening or night (6:00 PM to 5:59 AM) were more prevalent in higher severity crashes (20.1%) than lower severity crashes (10.2%), and its distribution was significantly different by crash severity (p=0.000).

About 21.2% of SV large non-logging truck crashes happened at the intersections. The SV large non-logging truck crashes were less frequent in higher severity crashes (13.2%) than lower severity crashes (21.8%), and the distribution was significantly different by crash severity (p=0.000). The distribution of intersection-related MV crashes was not significantly different by crash severity (p=0.797).

Most SV crashes happened in clear weather (70.8%), dry road surface conditions (84.2%), blacktop road surface type (68.2%), and straight road alignment (80.3%). The following general crash factors were more prevalent in higher severity crashes than lower severity crashes: clear weather condition (77.0% higher severity versus 70.4% lower severity, p=0.001), dry road surface conditions (88.5% higher severity versus 83.9% lower severity, p=0.005), blacktop road surface type (76.7% higher severity versus 67.6% lower severity, p=0.000), and curve road alignment (28.8% higher severity versus 19.0% lower severity, p=0.000). The distribution of these crash factors significantly varied by crash severity in SV crashes.

The majority of the MV crashes happened in clear weather (75.3%), dry road surface conditions (88.4%), blacktop road surface type (60.6%), straight road alignment (92.9%), and weekdays (89.0%). The distribution of these crash factors significantly varied by crash severity in MV crashes. The following crash-related factors in the MV crashes were more prevalent in higher severity crashes than lower severity crashes: the crashes happened on weekends (14.1% higher severity versus 10.7% lower severity, p=0.000), the impaired driver of any vehicle involved in the crash (9.5% higher severity versus 1.4% lower severity, p=0.004), on blacktop road surface type (66.4% higher severity versus 60.2% lower severity, p=0.000), and curve road alignment (8.4% higher severity versus 7.0% lower severity, p=0.006).

At-fault was assigned to 41.2% of large non-logging truck drivers, 35.1% of other vehicle drivers, and 23.7% of both vehicle drivers or unclear in MV crashes. A higher proportion of other vehicle drivers who were at fault for MV crashes were involved in higher severity crashes (44.9%) than lower severity crashes (34.4%), and the distribution was significantly different by crash severity (p=0.000).

Discussion

This study identified the crash characteristics by crash severity and crash type in large non-logging truck crashes in Louisiana from 2010 to 2018. Minimal literature is available to compare crash factors for different types of cargo configurations. The drivers' interactions with the surrounding environment and other drivers may vary by cargo type (Cole, 2018). The comparison of crash characteristics and crash severity by cargo types could help to design targeted safety programs.

Several studies have analyzed trends of all types of heavy truck crashes (McKnight, 2009, Knipling et al., 2008, Braver et al., 1996). FMCSA conducted the Large Truck Causation Study (LTCS) to determine the trend of large truck crashes in the United States from 2001 to 2003. The present study estimated that large non-logging truck crashes increased by 21.4%, with 3,863 crashes in 2010 increasing to 4,913 crashes in 2018 in Louisiana. Cole (2018) found a 16.0% increase in other large truck crashes in the United States from 2011 to 2015, whereas the present study found an 18.4% increase in large non-logging truck crashes in Louisiana from 2011 to 2015 (data not shown in tables).

Heavy trucks are at higher risk of rollover or overturn and leading to higher severity crashes. McKnight & Bahouth (2008) analyzed rollover large truck crashes from LTCCS sample data and stated that the large truck's high center of gravity increases the likelihood of vehicle rollovers. The majority of 239 rollover large truck crashes were SV crashes (77.0%), and 23% of large truck crashes were MV crashes (McKnight & Bahouth, 2008). The present study estimated that 5.1% of all large non-logging truck crashes had rollover in Louisiana from 2010 to 2018. About 25.0% of SV and only 0.7% of MV non-logging truck crashes had rollover.

Overall, older truck configuration models were involved in a higher proportion of logging truck crashes than non-logging truck crashes. About 64.8% of SV crashes, and 65.1% of MV crashes involved more than 10-year-old large non-logging truck models. To contrast, 88.2% of SV crashes and 79.7% of MV crashes involved more than 10-year-old large logging truck models. The average age of logging trucks was 13 years, and the overall average age of all trucks was 7.6 years in the United States from 2010 to 2015 (Cole, 2018). Conrad (2018) indicated that the average age of logging trucks involved in crashes was 14 years, seven years older than other heavy vehicles on the road at the time. Cole (2018) reported a significant difference between logging trucks and all other types of trucks in the United States from 2010 to 2015 (except for pole trailers and concrete mixers). A higher proportion of older large non-logging truck models was involved in higher severity SV and MV crashes. Older trucks often lack the proper maintenance and safety technologies, making them less safe on the road (Greene et al., 1996).

Several studies have found an association between impaired driving and increased fatality risk in all types of vehicle crashes (Noland & Quddus 2004: Dong et al. 2015). Impaired drivers could have poor vision, more risk-taking behavior, a lack of proper judgment, and slower reaction times. These factors increase the risk of impaired drivers being involved in higher severity crashes. The present study estimated that small proportions of impaired drivers were involved in SV and MV crashes. Impaired driving is significantly associated with higher severity crashes in SV and MV non-logging large truck crashes.

The National Transportation Safety Board indicated that fatigue is the most common cause of fatal-to-the-driver truck crashes (31%) (National Transportation Safety Board, 1990, 1995). A substantial literature has suggested a significant association between fatigue and increased risk of crashes. A research synthesis of the Transportation Research Board (TRB) publications concluded that sleep deficits, night driving, reduced sleep, and fatigue were associated with dangerous driving, reduced performance, and falling asleep while driving (Orris, 2005). The present study found that a small proportion of large non-logging truck SV and MV crashes involved fatigued drivers. A higher proportion of fatigued drivers involved in higher severity crashes than lower severity crashes in SV and MV crashes.

The proper use of a seatbelt in a vehicle has proven to be a protective measure. No seatbelt use is a leading risk factor and leads to higher injury severities sustained by vehicle occupants (Abdel-Aty, 2003; Boufous et al., 2008; Khattak et al., 2003; and

Gkritza and Mannering, 2008). The present study reported no seatbelt use in 3.1% of SV and 0.8% of MV crashes. Failing to wear a seat belt was significantly associated with higher severity crashes than lower severity crashes in SV and MV crashes. Large trucks involved in high-speed crashes may lead to greater injury severity due to larger kinetic forces (Duncan et al., 1998; Khattak et al., 2003; Islam and Hernandez, 2013). The present study estimated that a small proportion of SV and MV crashes involved truck drivers who received a speeding violation. Speeding citations assigned to truck drivers had a significant association with higher severity SV crashes. Azimi et al. (2020) found that careless driving or negligent maneuvers could increase crash injury severity in Florida from 2007 and 2016. Dissanayake and Kotikalapudi (2012) estimated that large trucks were at a 1.40 times higher risk of being involved in more severe crashes when the driver was careless (aggressive, reckless, or antagonistic) driving. The present study found similar findings that careless truck driving was significantly associated with higher severity SV crashes.

FMCSA (2007) reported that rollover was the most prevalent non-crash harmful event for trucks. Rollover could be due to drivers' misjudgment of speed on curved roads, reckless driving, failure to adjust the speed based on cargo load, distracted driving, and fatigue (McKnight 2009). McKnight (2009) analyzed 239 rollover crashes from 1,000 large truck fatal and injury crashes were investigated from 2001 to 2003 at 24 sites in 17 states in the United States. McKnight (2009) found that only 10% of large truck crashes experienced rollovers on curved roads. The present study found that about 25.0% of SV crashes and 0.8% of MV crashes involving large non-logging trucks experienced rollover, and 76.0% of SV crashes and 4.1% of MV crashes involving large logging trucks experienced rollover in Louisiana from 2010 to 2018. Different from the present finding, Khattak et al. (2002) estimated that 30% of all truck SV crashes experienced rollovers, and 43% of truck SV crashes occurred on curve roads in North Carolina from 1996-1998.

Running off the roadway increases the vehicle occupants' risk of sustaining more severe injuries (Yamamoto & Shankar,2004). Cole (2018) found that logging trucks had more occurrences of ROR (9.6%) than other tractor-trailers (7.9%) in fatal crashes in the United States from 2010 to 2015. The present study estimated that large logging trucks had a greater proportion of ROR to the right or left side than large non-logging trucks in SV and MV crashes in Louisiana from 2010 to 2018.

Dissanayake and Kotikalapudi (2012) estimated that falling cargo contributed to 33.7% of truck-related causes of truck crashes. A large truck crash causation study analyzed 963 crashes in the LTCCS sample from 24 sites in 17 States, and 4.0% of the crashes happened due to cargo shift (FMCSA, 2007). The present study indicates that large logging trucks experienced more cargo shifts than large non-logging trucks in higher severity SV and MV crashes.

Due to the center of gravity and speed, drivers of large trucks, which are often heavy, oversized, and overweight, might have difficulty controlling trucks on curved roads. SV crashes that happened on curved roads were more likely to experience rollovers, and the likelihood of higher injury severity was increased in those crashes in

North Carolina from 1996 to 1998 (Khattak, Schneider, & Targa, 2002). The present study concludes that large logging trucks were more often involved in higher severity crashes on curved roads than large non-logging trucks in SV and MV crashes. Overall, the present study found that the crash severity associated with crash factors varied between large logging and non-logging truck crashes. Thus, more in-depth research is needed to identify the crash characteristics to determine the difference between crash characteristics in higher severity crashes by cargo body type.

Conclusion

Limited literature is available comparing crash characteristics between large logging and non-logging truck crashes by crash severity. The present study provides valuable information on the crash characteristics, indicating that crash characteristics differ significantly by crash severity and crash type in large non-logging truck crashes in Louisiana from 2010 to 2018.

Single large non-logging truck crashes have different crash characteristics in higher severity crashes than MV crashes. Factors include a higher proportion of impaired driving, driving while fatigued, no seatbelt use, careless driving, and speeding in higher severity SV crashes. These behavioral factors are associated with higher severity SV crashes. Other crash factors with a higher proportion of higher severity SV crashes were truck rollover, cargo shift, ROR to the right or left, hitting a stationary tree, crossing median or centerline, and hitting pedestrians. A more significant proportion of higher severity SV crashes happened in clear weather, on dry road surfaces, on blacktop roads, and Interstate and U.S. highways compared to lower severity crashes.

Driver fatigue and not wearing a seatbelt at the time of the crash led to a greater proportion of higher severity MV crashes than lower severity crashes. A higher proportion of older large non-logging trucks were involved in higher severity MV crashes than lower severity MV crashes. MV crashes that experienced rollover, ROR to the right or left, hitting a stationary tree, crossing median or centerline, and hitting pedestrians could be associated with higher severity crashes. MV crashes on weekends, curved roads, blacktop roads, and Interstate and U.S. highways could be related to higher severity crashes. A small proportion of impaired drivers were involved in MV crashes, but most sustained higher severity injuries. Rear-end, head-on, opposite direction, and angle collisions could be associated with higher severity MV crashes. This study provides baseline information for future in-depth research to compare the crash characteristics in higher severity crashes in large logging and non-logging truck crashes.

Single Vehicle large non-logging truck crashes in Louisiana (2010-2018)

Table 3.1: Driver variables and crash severity for single large non-logging truck crashes in Louisiana (2010-2018)

Independent Variable	Non-logging truck crashes (n=7,913)				
	Higher Severity Crash n (Col%) (n=531)	Lower Severity Crash n (Col%) (n=7,382)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Driver's Demographics					
Age (years)					
25 and younger	44 (8.3%)	503 (6.8%)	0.495	40	0.045
26-35	110 (20.7%)	1703 (23.1%)			
36-45	125 (23.5%)	1869 (25.3%)			
46-55	145 (27.3%)	1859 (25.2%)			
56-65	86 (16.2%)	1150 (15.6%)			
66 & older	21 (4.0%)	298 (4.0%)			
Gender					
Male	505 (95.1%)	7123 (96.5%)	0.097	34	0.039
Female	26 (4.9%)	259 (3.5%)			
Driver's Behaviors					
Impairment- Alcohol Estimates					
Yes	29 (5.5%)	52 (0.7%)	0.000*	1	0.001
No	502 (94.5%)	7330 (99.3%)			
Distraction					
Yes	230 (43.3%)	3922 (53.1%)	0.000*	2	0.002
No	224 (42.2%)	3049 (41.3%)			
Unknown	77 (14.5%)	411 (5.6%)			
Fatigue					
Yes	7 (1.3%)	56 (0.8%)	0.000*	3	0.003
No	476 (89.6%)	7242 (98.1%)			
Unknown	48 (9.0%)	84 (1.1%)			
Occupant Seatbelt Use					
Used	403 (75.9%)	6505 (88.1%)	0.000*	4	0.005
Not Used	74 (13.9%)	174 (2.4%)			
Unknown	54 (10.2%)	703 (9.5%)			
Driver Violations					
Failure to Yield					
Yes	7 (1.3%)	50 (0.7%)	0.092	32	0.036
No	524 (98.7%)	7332 (99.3%)			
Following Too Closely					
Yes	6 (1.1%)	67 (0.9%)	0.605	42	0.048
No	525 (98.9%)	7315 (99.1%)			

Table 3.1 Continued

Independent Variable	Non-logging truck crashes (n=7,913)				
	Higher Severity Crash n (Col%) (n=531)	Lower Severity Crash n (Col%) (n=7,382)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Driving Left of Center					
Yes	1 (0.19%)	19 (0.26%)	1.000	44	0.05
No	530 (99.8%)	7363 (99.7%)			
Speeding					
Yes	15 (2.8%)	103 (1.4%)	0.009*	29	0.033
No	516 (97.2%)	7279 (98.6%)			
Careless Operation					
Yes	297 (55.9%)	3278 (44.4%)	0.000*	5	0.006
No	234 (44.1%)	4104 (55.6%)			

Notes: (1) KAB severity includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; CO severity includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (3) [a] Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (4) [b] Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =$d*i/n$ (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). *i* is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (5) *P-value is significant at the adjusted cutoff p-value level.

Table 3.2: Vehicle variables and crash severity for single large non-logging truck crashes in Louisiana (2010-2018)

Independent Variable	Non-logging truck crashes (n=7,913)				
	Higher Severity Crash n (Col%) (n=531)	Lower Severity Crash n (Col%) (n=7,382)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Vehicle Defects Observed					
Yes	32 (6.0%)	564 (7.6%)	0.173	36	0.041
No	499 (94.0%)	6818 (92.4%)			
Vehicle Lighting Condition			0.817	43	0.049
Headlights on or Daytime Running Lights	280 (52.7%)	3812 (51.6%)			
Headlights off	175 (33.0%)	2533 (34.3%)			
Unknown	76 (14.3%)	1037 (14.1%)			

Table 3.2 Continued

Independent Variable	Non-logging truck crashes (n=7,913)				
	Higher Severity Crash n (Col%) (n=531)	Lower Severity Crash n (Col%) (n=7,382)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Vehicle Age					
Less than 10 years	169 (31.8%)	2616 (35.4%)	0.092	33	0.038
More than 10 years	362 (68.2%)	4766 (64.6%)			
Vehicle Movement-Harmful Events					
Vehicle Overturn/Rollover					
Yes	262 (49.4%)	1716 (23.3%)	0.000*	6	0.007
No	269 (50.7%)	5666 (76.8%)			
Cargo/Equipment Loss or Shift					
Yes	30 (5.7%)	277 (3.8%)	0.029*	31	0.035
No	501 (94.4%)	7105 (96.3%)			
Ran Off Road Right					
Yes	231 (43.5%)	2038 (27.6%)	0.000*	7	0.008
No	300 (56.5%)	5344 (72.4%)			
Ran Off Road Left					
Yes	118 (22.2%)	1014 (13.7%)	0.000*	8	0.009
No	413 (77.8%)	6368 (86.3%)			
Hit Standing Tree					
Yes	81 (15.3%)	562 (7.6%)	0.000*	9	0.010
No	450 (84.8%)	6820 (92.4%)			
Crossed Median/Centerline					
Yes	67 (12.6%)	466 (6.3%)	0.000*	10	0.011
No	464 (87.4%)	6916 (93.7%)			
Hit Pedestrian					
Yes	55 (10.4%)	25 (0.3%)	0.000*	11	0.013
No	476 (89.6%)	7357 (99.7%)			
Vehicle Movement-Prior Movement					
Vehicle Ran Off Road					
Yes	257 (48.4%)	1984 (26.9%)	0.000*	12	0.014
No	274 (51.6%)	5398 (73.1%)			
Making Left Turn					
Yes	12 (2.3%)	542 (7.4%)	0.000*	13	0.015
No	519 (97.7%)	6840 (92.7%)			
Crossed Median or Center Line into Opposite Lane					
Yes	15 (2.8%)	114 (1.5%)	0.024*	30	0.034
No	516 (97.2%)	7268 (98.5%)			

Table 3.2 Continued

Independent Variable	Non-logging truck crashes (n=7,913)				
	Higher Severity Crash n (Col%) (n=531)	Lower Severity Crash n (Col%) (n=7,382)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Vehicle Movement-Reason for Movement					
To Avoid Other Vehicle					
Yes	17 (3.2%)	339 (4.6%)	0.135	35	0.040
No	514 (96.8%)	7043 (95.4%)			
Vehicle Out of Control, Not Passing					
Yes	24 (4.5%)	105 (1.4%)	0.000*	14	0.016
No	507 (95.5%)	7277 (98.6%)			
Vehicle Movement-Traffic Control					
Stop Sign					
Yes	10 (1.9%)	521 (7.1%)	0.000*	15	0.017
No	521 (98.1%)	6861 (92.9%)			
Yellow No Passing Line					
Yes	143 (26.9%)	1403 (19.0%)	0.000*	16	0.018
No	388 (73.1%)	5979 (81.0%)			
White Dashed Line					
Yes	172 (32.4%)	1860 (25.2%)	0.000*	17	0.019
No	359 (67.6%)	5522 (74.8%)			
Yellow Dashed Line					
Yes	92 (17.3%)	828 (11.2%)	0.000*	18	0.020
No	439 (82.7%)	6554 (88.8%)			
No Control					
Yes	60 (11.3%)	1575 (21.4%)	0.000*	19	0.022
No	471 (88.7%)	5807 (78.7%)			

Notes: (1) KAB severity includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; CO severity includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (3) [a] Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (4) [b] Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =$d*i/n$ (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). *i* is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (5) *P-value is significant at the adjusted cutoff p-value level.

Table 3.3: Crash variables and crash severity for single large non-logging truck crashes in Louisiana (2010-2018)

Independent Variable	Non-logging truck crashes (n=7,913)				
	Higher Severity Crash n (Col%) (n=531)	Lower Severity Crash n (Col%) (n=7,382)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Crash Time					
Morning	112 (21.1%)	1843 (25.0%)	0.206	37	0.042
Afternoon	129 (24.3%)	1656 (22.4%)			
Evening/Night	100 (18.8%)	1268 (17.2%)			
Unknown	190 (35.8%)	2615 (35.4%)			
Crash Year					
2010	63 (11.9%)	748 (10.1%)	0.551	41	0.047
2011	62 (11.7%)	860 (11.7%)			
2012	52 (9.8%)	808 (11.0%)			
2013	56 (10.6%)	765 (10.4%)			
2014	53 (10.0%)	790 (10.7%)			
2015	50 (9.4%)	857 (11.6%)			
2016	55 (10.4%)	796 (10.8%)			
2017	73 (13.8%)	841 (11.4%)			
2018	67 (12.6%)	917 (12.4%)			
Day of the Week					
Weekday	452 (85.1%)	6378 (86.4%)	0.408	38	0.043
Weekend	79 (14.9%)	1004 (13.6%)			
Clear Weather Conditions					
Yes	409 (77.0%)	5196 (70.4%)	0.001*	26	0.03
No	122 (23.0%)	2186 (29.6%)			
Daylight					
Yes	352 (66.3%)	5384 (72.9%)	0.001*	27	0.031
No	179 (33.7%)	1998 (27.1%)			
Road Surface Condition-Dry					
Yes	470 (88.5%)	6192 (83.9%)	0.005*	28	0.032
No	61 (11.5%)	1190 (16.1%)			
Road Surface Type-Blacktop					
Yes	407 (76.7%)	4991 (67.6%)	0.000*	20	0.023
No	124 (23.4%)	2391 (32.4%)			
Road Alignment					
Straight	378 (71.2%)	5978 (81.0%)	0.000*	21	0.024
Curved	153 (28.8%)	1404 (19.0%)			
Manner of Collision					
Non-Collision with Motor Vehicle	451 (84.9%)	5408 (73.3%)	0.000*	22	0.025
Other or Unknown	80 (15.1%)	1947 (26.7%)			
Road Type No Physical Barrier					
Yes	314 (59.1%)	4488 (60.8%)	0.449	39	0.044
No	217 (40.9%)	2894 (39.2%)			

Table 3.3 Continued

Independent Variable	Non-logging truck crashes (n=7,913)				
	Higher Severity Crash n (Col%) (n=531)	Lower Severity Crash n (Col%) (n=7,382)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Location Type					
Manufacturing or Industrial or business area	143 (26.9%)	2746 (37.2%)	0.000*	23	0.026
Residential related area	149 (28.1%)	2421 (32.8%)			
Open country	239 (45.0%)	2215 (30.0%)			
Intersection					
Yes	70 (13.2%)	1610 (21.8%)	0.000*	24	0.027
No	461 (86.8%)	5772 (78.2%)			
Highway Type					
Interstate and US highway	222 (41.8%)	2400 (32.5%)	0.000*	25	0.028
State highway	210 (39.6%)	2235 (30.3%)			
Other (Parish Road, City Street)	99 (18.6%)	2747 (37.2%)			

Notes: (1) KAB severity includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; CO severity includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (3) a Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (4) b Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =d*i/n (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). i is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (5) *P-value is significant at the adjusted cutoff p-value level.

Multiple Vehicle - large non-logging truck crashes in Louisiana (2010-2018)

Table 3.4: Driver variables and crash severity for multiple vehicle crashes involving non-logging trucks in Louisiana (2010-2018)

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Large Truck Driver Demographics					
Age (years)					
25 and younger	108 (4.4%)	1913 (5.7%)	0.000*	1	0.001
26-35	447 (18.0%)	6819 (20.3%)			
36-45	708 (28.4%)	8520 (25.4%)			
46-55	675 (27.1%)	9138 (27.3%)			
56-65	432 (17.4%)	5766 (17.2%)			
66 & older	120 (4.8%)	1368 (4.1%)			
Gender					
Male	2398 (96.3%)	32339 (96.5%)	0.677	73	0.048
Female	92 (3.7%)	1185 (3.5%)			
Large Truck Driver Behaviors					
Distraction					
Yes	597 (24.0%)	12859 (38.4%)	0.000*	3	0.002
No	1740 (69.9%)	18982 (56.6%)			
Unknown	153 (6.1%)	1683 (5.0%)			
Fatigue					
Yes	6 (0.2%)	41 (0.1%)	0.000*	4	0.003
No	2429 (97.6%)	33157 (98.9%)			
Unknown	55 (2.2%)	326 (1.0%)			
Occupant Seatbelt Use					
Used	2223 (89.3%)	30148 (89.9%)	0.000*	5	0.003
Not Used	42 (1.7%)	238 (0.7%)			
Unknown	225 (9.0%)	3138 (9.4%)			
Large Truck Driver Violations					
Failure to Yield					
Yes	214 (8.6%)	2562 (7.6%)	0.086	64	0.042
No	2276 (91.4%)	30962 (92.36%)			
Following Too Closely					
Yes	120 (4.8%)	2582 (7.7%)	0.000*	6	0.004
No	2370 (95.2%)	30942 (92.3%)			
Driving Left of Center					
Yes	28 (1.1%)	430 (1.3%)	0.497	72	0.047
No	2462 (98.9%)	33094 (98.7%)			

Table 3.4 Continued

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Speeding					
Yes	6 (0.2%)	43 (0.1%)	0.141	67	0.044
No	2484 (99.8%)	33481 (99.9%)			
Cutting In, Improper Passing					
Yes	39 (1.6%)	1358 (4.0%)	0.000*	7	0.005
No	2451 (98.4%)	32166 (96.0%)			
Careless Operation					
Yes	245 (9.8%)	3846 (11.5%)	0.013*	55	0.036
No	2245 (90.2%)	29678 (88.5%)			
Other Vehicle Driver Demographics					
Age (years)					
25 and younger	557 (22.4%)	6704 (20.0%)	0.000*	20	0.013
26-35	624 (25.1%)	7582 (22.6%)			
36-45	414 (16.6%)	5985 (17.9%)			
46-55	381 (15.3%)	5628 (16.8%)			
56-65	286 (11.5%)	4251 (12.7%)			
66 & older	228 (9.2%)	3374 (10.1%)			
Gender					
Male	1570 (63.1%)	19459 (58.0%)	0.000*	21	0.014
Female	920 (37.0%)	14065 (42.0%)			
Other Vehicle Driver Behaviors					
Distraction					
Yes	853 (34.3%)	10497 (31.3%)	0.000*	22	0.014
No	1134 (45.5%)	20996 (62.6%)			
Unknown	503 (20.2%)	2031 (6.1%)			
Fatigue					
Yes	23 (0.9%)	155 (0.5%)	0.000*	23	0.015
No	2160 (86.8%)	32985 (98.4%)			
Unknown	307 (12.3%)	384 (1.2%)			
Occupant Seatbelt Use					
Used	1961 (78.8%)	30124 (89.9%)	0.000*	24	0.016
Not Used	277 (11.1%)	341 (1.0%)			
Unknown	252 (10.1%)	3059 (9.1%)			
Other Vehicle Driver Violations					
Failure to Yield					
Yes	246 (9.9%)	2857 (8.5%)	0.020*	57	0.038
No	2244 (90.1%)	30667 (91.5%)			

Table 3.4 Continued

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Following Too Closely					
Yes	112 (4.5%)	1321 (3.9%)	0.170	70	0.046
No	2378 (95.5%)	32203 (96.1%)			
Driving Left of Center					
Yes	122 (4.9%)	322 (1.0%)	0.000*	25	0.016
No	2368 (95.1%)	33202 (99.0%)			
Speeding					
Yes	31 (1.2%)	118 (0.4%)	0.000*	27	0.017
No	2459 (98.8%)	33406 (99.7%)			
Cutting In, Improper Passing					
Yes	38 (1.5%)	1710 (5.1%)	0.000*	26	0.018
No	2452 (98.5%)	31814 (94.9%)			
Careless Operation					
Yes	649 (26.1%)	4425 (13.2%)	0.000*	28	0.018
No	1841 (73.9%)	29099 (86.8%)			

Notes: (1) KAB severity includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; CO severity includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Here, multiple vehicle crashes are only two-vehicle crashes; (3) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (4) a Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (5) b Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =d*i/n (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). i is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (6) *P-value is significant at the adjusted cutoff p-value level.

Table 3.5: Vehicle variables and crash severity for multiple vehicle crashes involving non-logging truck crashes in Louisiana (2010-2018)

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Large Truck Characteristics					
Vehicle Defects Observed					
Yes	88 (3.5%)	1160 (3.5%)	0.001*	49	0.032
No	2329 (93.5%)	31747 (94.7%)			
Unknown	73 (2.9%)	617 (1.8%)			
Vehicle Lighting Condition					
Headlights on or Daytime Running Lights	1341 (53.9%)	14831 (44.2%)	0.000*	8	0.005
Headlights off	712 (28.6%)	12538 (37.4%)			
Unknown	437 (17.6%)	6155 (18.4%)			
Vehicle Age					
Less than 10 years	774 (31.1%)	11810 (35.2%)	0.000*	9	0.006
More than 10 years	1716 (68.9%)	21714 (64.8%)			
Large Truck Movement-Harmful Events					
Vehicle Overturn/Rollover					
Yes	105 (4.2%)	166 (0.5%)	0.000*	10	0.007
No	2385 (95.8%)	33358 (99.5%)			
Cargo/Equipment Loss or Shift					
Yes	16 (0.6%)	516 (1.5%)	0.000*	11	0.007
No	2474 (99.4%)	33008 (98.5%)			
Ran Off Road Right					
Yes	164 (6.6%)	383 (1.1%)	0.000*	12	0.008
No	2326 (93.4%)	33141 (98.9%)			
Ran Off Road Left					
Yes	109 (4.4%)	281 (0.8%)	0.000*	13	0.009
No	2381 (95.6%)	33243 (99.2%)			
Hit Standing Tree					
Yes	27 (1.1%)	54 (0.2%)	0.000*	14	0.009
No	2463 (98.9%)	33470 (99.8%)			
Crossed Median/Centerline					
Yes	138 (5.5%)	1116 (3.3%)	0.000*	15	0.010
No	2352 (94.5%)	32408 (96.7%)			
Hit Pedestrian					
Yes	1 (0.0%)	0 (0.0%)	0.069	63	0.041
No	2489 (100.0%)	33524 (100.0%)			

Table 3.5 Continued

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Large Truck Movement-Prior Movement					
Ran Off Road					
Yes	39 (1.6%)	179 (0.5%)	0.000*	16	0.011
No	2426 (97.4%)	32989 (98.4%)			
Unknown	25 (1.0%)	356 (1.1%)			
Making Left Turn					
Yes	205 (8.2%)	3090 (9.2%)	0.247	71	0.047
No	2260 (90.8%)	30079 (89.7%)			
Unknown	25 (1.0%)	355 (1.1%)			
Crossed Median or Center Line into Opposite Lane					
Yes	66 (2.7%)	610 (1.8%)	0.013*	56	0.037
No	2399 (96.4%)	32559 (97.1%)			
Unknown	25 (1.0%)	355 (1.1%)			
Large Truck Movement-Reason for Movement					
To Avoid Other Vehicle					
Yes	137 (5.5%)	983 (2.9%)	0.000*	17	0.011
No	2338 (93.9%)	32334 (96.5%)			
Unknown	15 (0.6%)	207 (0.6%)			
Vehicle Out of Control, Not Passing					
Yes	7 (0.3%)	38 (0.1%)	0.068	62	0.041
No	2466 (99.0%)	33278 (99.3%)			
Unknown	17 (0.7%)	208 (0.6%)			
Large Truck Movement-Traffic Control					
Stop Sign					
Yes	117 (4.7%)	1789 (5.3%)	0.170	69	0.045
No	2373 (95.3%)	31735 (94.7%)			
Yellow No Passing Line					
Yes	369 (14.8%)	3372 (10.1%)	0.000*	18	0.012
No	2121 (85.2%)	30152 (89.9%)			
White Dashed Line					
Yes	1098 (44.1%)	15876 (47.4%)	0.002*	50	0.033
No	1392 (55.9%)	17648 (52.6%)			

Table 3.5 Continued

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Yellow Dashed Line					
Yes	269 (10.8%)	2175 (6.5%)	0.000*	19	0.013
No	2221 (89.2%)	31349 (93.5%)			
No Control					
Yes	200 (8.0%)	3067 (9.2%)	0.061	61	0.040
No	2290 (92.0%)	30457 (90.9%)			
Other Vehicle Characteristics					
Vehicle Defects Observed					
Yes	9 (0.4%)	124 (0.4%)	1.000	76	0.050
No	2481 (99.6%)	33389 (99.6%)			
Unknown	0 (0.0%)	11 (0.03%)			
Vehicle Lighting Condition					
Headlights on or Daytime Running Lights	1218 (48.9%)	13969 (41.7%)	0.000*	29	0.019
Headlights off	750 (30.1%)	13362 (39.9%)			
Unknown	522 (21.0%)	6193 (18.5%)			
Other Vehicle Movement-Harmful Events					
Vehicle Overturn/Rollover					
Yes	122 (4.9%)	226 (0.7%)	0.000*	30	0.020
No	2368 (95.1%)	33298 (99.3%)			
Cargo/Equipment Loss or Shift					
Yes	1 (0.0%)	197 (0.6%)	0.000*	31	0.020
No	2489 (100.0%)	33327 (99.4%)			
Ran Off Road Right					
Yes	235 (9.4%)	913 (2.7%)	0.000*	32	0.021
No	2255 (90.6%)	32611 (97.3%)			
Ran Off Road Left					
Yes	177 (7.1%)	928 (2.8%)	0.000*	33	0.022
No	2313 (92.9%)	32596 (97.2%)			
Hit Standing Tree					
Yes	46 (1.9%)	138 (0.4%)	0.000*	34	0.022
No	2444 (98.2%)	33386 (99.6%)			
Crossed Median/Centerline					
Yes	279 (11.2%)	1348 (4.0%)	0.000*	35	0.023
No	2211 (88.8%)	32176 (95.98%)			

Table 3.5 Continued

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Hit Pedestrian					
Yes	1 (0.0%)	1 (0.0%)	0.134	65	0.043
No	2489 (99.96%)	33523 (100%)			
Other Vehicle Movement-Prior Movement					
Vehicle Ran Off Road					
Yes	46 (1.9%)	396 (1.2%)	0.003*	52	0.034
No	2418 (97.1%)	32625 (97.3%)			
Unknown	26 (1.0%)	503 (1.5%)			
Making Left Turn					
Yes	160 (6.4%)	1849 (5.5%)	0.034*	59	0.039
No	2304 (92.5%)	31172 (93.0%)			
Unknown	26 (1.0%)	503 (1.5%)			
Crossed Median or Center Line into Opposite Lane					
Yes	245 (9.8%)	804 (2.4%)	0.000*	36	0.024
No	2219 (89.1%)	32217 (96.1%)			
Unknown	26 (1.0%)	503 (1.5%)			
Other Vehicle Movement-Reason for Movement					
To Avoid Other Vehicle					
Yes	82 (3.3%)	1091 (3.3%)	0.000*	37	0.024
No	2269 (91.1%)	32179 (96.0%)			
Unknown	139 (5.6%)	254 (0.8%)			
Vehicle Out of Control, Not Passing					
Yes	21 (0.8%)	89 (0.3%)	0.000*	38	0.025
No	2330 (93.6%)	33181 (99.0%)			
Unknown	139 (5.6%)	254 (0.8%)			
Other Vehicle Movement-Traffic Control					
Stop Sign					
Yes	171 (6.9%)	1991 (5.9%)	0.060	60	0.039
No	2319 (93.1%)	31533 (94.1%)			
Yellow No Passing Line					
Yes	336 (13.5%)	3175 (9.5%)	0.000*	39	0.026
No	2154 (86.5%)	30349 (90.5%)			

Table 3.5 Continued

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
White Dashed Line					
Yes	1094 (43.9%)	15473 (46.2%)	0.032*	58	0.038
No	1396 (56.1%)	18051 (53.9%)			
Yellow Dashed Line					
Yes	270 (10.8%)	2113 (6.3%)	0.000*	40	0.026
No	2220 (89.2%)	31411 (93.7%)			
No Control					
Yes	187 (7.5%)	3132 (9.3%)	0.002*	51	0.034
No	2303 (92.5%)	30392 (90.7%)			

Notes: (1) KAB severity includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; CO severity includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Here, multiple vehicle crashes are only two-vehicle crashes; (3) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (4) a Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (5) b Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =d*i/n (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). i is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (6) *P-value is significant at the adjusted cutoff p-value level; (7) N/A Not compared because of zero cell size.

Table 3.6: Crash variables and crash severity for multiple vehicle crashes involving non-logging trucks in Louisiana (2010-2018)

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Crash Time					
Morning	559 (22.5%)	8575 (25.6%)	0.000*	41	0.027
Afternoon	576 (23.1%)	9405 (28.1%)			
Evening/ Night	500 (20.1%)	3431 (10.2%)			
Unknown	855 (34.3%)	12113 (36.1%)			
Crash Year					
2010	262 (10.5%)	3264 (9.7%)	0.007*	54	0.036
2011	283 (11.4%)	3431 (10.2%)			
2012	276 (11.1%)	3494 (10.4%)			
2013	275 (11.0%)	3524 (10.5%)			
2014	279 (11.2%)	3680 (11.0%)			
2015	303 (12.2%)	3833 (11.4%)			
2016	260 (10.4%)	4018 (12.0%)			
2017	253 (10.2%)	4128 (12.3%)			
2018	299 (12.1%)	4152 (12.4%)			
Day of the Week					
Weekday	2140 (85.9%)	29922 (89.3%)	0.000*	42	0.028
Weekend	350 (14.1%)	3602 (10.7%)			
Clear Weather Conditions					
Yes	1905 (76.5%)	25219 (75.2%)	0.153	68	0.045
No	585 (23.5%)	8305 (24.8%)			
Daylight					
Yes	1670 (67.1%)	27781 (82.9%)	0.000*	43	0.028
No	820 (32.9%)	5743 (17.1%)			
Road Surface Condition-Dry					
Yes	2206 (88.6%)	29645 (88.4%)	0.804	75	0.049
No	284 (11.4%)	3879 (11.6%)			
Road Surface Type-Blacktop					
Yes	1653 (66.4%)	20167 (60.2%)	0.000*	44	0.029
No	837 (33.6%)	13357 (39.8%)			
Road Alignment					
Straight	2280 (91.6%)	31184 (93.0%)	0.006*	53	0.035
Curved	210 (8.4%)	2340 (7.0%)			

Table 3.6 Continued

Independent Variable	Non-logging truck crashes (n=36014)				
	Higher Severity Crash n (Col%) (n=2490)	Lower Severity Crash n (Col%) (n=33524)	P-value	I[a]	Adjusted cutoff P-value Significance Level[b]
Manner of Collision					
Rear End	974 (39.1%)	10119 (30.2%)	0.000*	45	0.030
Head On	184 (7.4%)	386 (1.2%)			
Angle	570 (22.9%)	3822 (11.4%)			
Opposite Direction	244 (9.8%)	2152 (6.4%)			
Same Direction	376 (15.1%)	12321 (36.8%)			
Other or Unknown	142 (5.7%)	4724 (14.1%)			
Road Type No Physical Barrier					
Yes	1027 (41.2%)	13323 (39.7%)	0.139	66	0.044
No	1463 (58.8%)	20201 (60.3%)			
Location Type					
Manufacturing or Industrial or business area	502 (20.2%)	5331 (15.9%)	0.000*	46	0.030
Residential related area	1237 (49.7%)	21049 (62.8%)			
Open country	751 (30.2%)	7144 (21.3%)			
Intersection					
Yes	682 (27.4%)	9262 (27.6%)	0.797	74	0.049
No	1808 (72.6%)	24262 (72.4%)			
Highway Type					
Interstate or US highway	1329 (53.4%)	16802 (50.1%)	0.000*	47	0.031
State highway	843 (33.9%)	9734 (29.0%)			
Other (Parish Road, City Street)	318 (12.8%)	6988 (20.8%)			
Impairment- Alcohol Estimates					
Yes	237 (9.5%)	473 (1.4%)	0.000*	2	0.001
No	2253 (90.5%)	33051 (98.6%)			
Driver at-Fault					
Large truck driver	744 (29.9%)	14096 (42.1%)	0.000*	48	0.032
Other vehicle driver	1117 (44.9%)	11533 (34.4%)			
Both drivers or Unclear	629 (25.3%)	7895 (23.6%)			

Notes: (1) KAB severity includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; CO severity includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O); (2) Here, multiple vehicle crashes are only two-vehicle crashes; (3) Pearson Chi-2 test at 0.05 significance level was performed for all independent variables, and Fisher's Exact test at 0.05 significance level was performed for independent variables with cell size less than 5; (4) [a] Ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value; (5) [b] Adjusted cutoff p-value level calculated using a False Discovery Rate (FDR) method. The adjusted significance level (cutoff) =$d*i/n$ (n is the number of hypotheses tests with maximum false discovery rate d (here, α=0.05). *i* is ranking of ascending sorted Pearson Chi-square or Fisher exact test p-value. The significance of independent variables will be determined using a new adjusted significance level (cutoff)); (6) *P-value is significant at the adjusted cutoff p-value level.

CHAPTER IV

SPECIFIC AIM 2A: ESTIMATE OF THE ASSOCIATIONS BETWEEN DRIVER CHARACTERISTICS AND BEHAVIORS AND HIGHER CRASH SEVERITY IN SINGLE-VEHICLE CRASHES INVOLVING A LOGGING TRUCK WHILE ADJUSTING FOR VEHICLE AND CRASH VARIABLE

Introduction

Logging is considered one of the most hazardous industries in the United States. In 2018, logging workers were at the highest risk of fatal occupational injuries (National Institute for Occupational Safety and Health, 2012; U.S. Department of Labor, 2019). The fatal occupational injury rate among logging workers is higher than that of all American industries combined (97.6 per 100,000 FTEs compared to the fatal occupational rate of 3.5 per 100,000 FTEs for all industries combined in the United States in 2018) (BLS, 2018a to BLS, 2019). Unfortunately, this information is not readily accessible at the state level, which prevents a clear understanding of this issue.

Logging vehicles are the primary transportation mode to transport forestry products from remote locations to various processing facilities. The trucking industry is a vital part of the transportation of forestry products (Roberts, Shaffer, & Bush, 2005). More than half of the trucking industry's logging-related business expenses are incurred (Shaffer & Stuart, 2009). Almost 28% of the total fatal occupational injuries in the logging industry were due to transportation crashes (BLS, 2019). The logging industry is one of the most significant employers and major contributors to Louisiana’s economy.

The trend of logging-related roadway crashes shows that it has been rising in the United States since 2012 (Cole, 2018; Conrad, 2018). Cole (2018) estimated that fatal logging truck crashes increased by 41% in the United States between 2011 and 2015. Logging truck crashes doubled in the United States from 2010 to 2015 (Baker & Tyson, 2017), and this increasing trend continued due to recovery in the timber market after the recession (Conrad, 2018). Logging truck crashes on the roadways are expected to increase in the future due to the recovery of the forestry industry (Baker & Tyson, 2017). Unfortunately, limited literature is available on the details of logging truck crashes to understand the crash factors by crash severity and type. To address research gaps, the present analysis focused on identifying factors associated with single vehicle (SV) large logging truck crashes in Louisiana.

Methods

Hypothesis

The null hypothesis was that no association would be present between driver characteristics and behaviors and higher crash severity in single-vehicle crashes involving a logging truck on public roadways in Louisiana from 2010-2018, adjusting for vehicle and crash variables. The hypothesis was that there would be an association between driver characteristics and behaviors and higher crash severity in single-vehicle crashes involving a large logging truck on public roadways in Louisiana from 2010-2018, adjusting for the vehicle and crash variables.

Data Source

A crash database from the Louisiana Department of Transportation and Development (LaDOTD) from 2010-2018 was analyzed to estimate the associations between driver characteristics and behaviors and higher crash severity in single-vehicle crashes involving a logging truck, adjusting for vehicle and crash variables. The LaDOTD Highway Safety database from 2010 to 2018 included fatal, non-fatal, or property damage greater than $500 crashes and information on the person, vehicle, and crash factors. The severity level of fatal crashes is updated within 30 days. The police officers who respond to the scene collect the crash data and complete the reports based on evidence at the scene and interviews with the victims and witnesses.

Variables

A single large logging truck crash was defined as a crash involving only one vehicle, the logging truck. The dependent variable was binary with higher crash severity and lower crash severity categories. The dependent variable was created from the crash severity variable, with higher crash severity (KAB) and lower crash severity (CO) categories (Winston, Maheshri, & Mannering, 2006; Farmer, 2003). Higher crash severity (KAB) category (1) included fatal (K), severe (A), and moderate (B) crash injuries. Lower crash severity (CO) category (0) included complaint or possible injury (C) and no injury or property damage only (O) (see Chapter 1, Data Description Section for detailed information on crash severity). Independent variables were related to the driver and behavioral factors and adjusted for vehicle and crash-related factors (see appendix Table A-2 for detailed categorization information).

Independent variables were the driver (e.g., age) and behavioral factors (seat belt use, impairment, distraction, fatigue, and violations). They were adjusted for vehicle factors (vehicle condition, vehicle light condition, type of vehicle, most harmful event, the motion of the vehicle before the crash, and the reason for motion), and crash-related factors (crash year, the day of the week, time of the day, manner of collision, daylight conditions, weather conditions, traffic control conditions, road alignment, road surface conditions, road surface types, road type, roadway relation, road alignment, kind of location, intersection and highway type). (See Appendix Table A-2 for detailed information on categorization.)

Analysis

Single-vehicle and multi-vehicle crashes often need to be analyzed separately to identify crash characteristics accurately (Kockelman & Kweon, 2002; Savolainen & Mannering, 2007; Ulfarsson & Mannering, 2004). No gold standard approaches exist for modeling crash data. Conventional approaches include both binary logistic regression (Jones & Whitfield, 1988; Lui et al., 1988; Shibata & Fukuda, 1994; Simončič, 2001; Tay, Rifaat, & Chin, 2008; Tay, Barua, & Kattan, 2009; Valent et al., 2002; Zhang et al., 2000) and multinomial logistic regression (Chang & Mannering, 1999; Kim, S., Kim, Ulfarsson, & Porrello, 2007; Lee & Mannering, 2002; Neyens & Boyle, 2007; Savolainen & Mannering, 2007; Shankar & Mannering, 1996; Ulfarsson & Mannering, 2004).

Multinomial logistic regression is preferred when the data may be biased due to the underreporting of “property damage only” crashes. However, a limitation of multinomial logistic regression is that it requires a larger sample size. The Hausman test and suest-based Hausman test confirmed that the MNL specification was inappropriate for using the model.

Other modeling approaches include ordinal logistic regression and a probit model. The ordinal logistic model was not appropriate for this research question. According to Ulfarsson and Mannering’s study (2004), ordinal analysis restricts the effect of the independent variables on the dependent variable. The crash severity categories range from low to high severity. However, there was no compelling evidence that variables cannot increase the probability of mid-level crash severities and decrease the probability of no-injury, fatal or severe injury accidents (Ulfarsson & Mannering, 2004). The selection of the logistic model is recommended over the probit model unless the sample size is limited (Ye & Lord 2011). The current study sample size is large enough, and therefore, binary logistic regression was the initial approach.

STATA 16 (StataCorp LP, College Station, TX) was used to analyze aim 2A statistically. The descriptive statistics were calculated for all independent variables, stratified by the dependent variable. Pearson Correlation Coefficients were calculated for all independent variables to identify highly correlated independent variables to determine which independent variables should be considered during the modeling process. Before removing them from the final model, highly correlated independent variables were also examined during the model fit process. A binary logistic regression model was constructed to analyze single motor vehicle crashes involving a logging truck in Louisiana (2010-2018).

For the model building process, independent variables with cell sizes less than five were not included in the subsequent analysis. The first step was the variable selection process using the univariate analysis. Variables with a p-value of less than 0.25 in the univariate analysis were included in the model building procedure as part of an intermediate model. The forward selection method was performed for the model selection process. Model selection was based on the smallest p-value and Bayesian Information Criterion (BIC) values from the univariate analysis. Selected independent variables were then added to the model one by one until the final model contained all significant explanatory variables at 0.05 level and had the smallest BIC compared to another model. The effect of explanatory variables on parameter estimates was checked at each step of model building for confounding variables. The categorical variables with at least one significant category were included in the model. After exclusion from the model, the confounders were selected from non-significant explanatory variables at the 0.1 significance level that also affected parameter estimates (15% to 20% change).

The likelihood ratio test and Hosmer-Lemeshow Goodness-of-Fit test were used to check the goodness of fit at the 0.05 significance level. Multicollinearity in the final model was checked with Variance Inflation Factors (VIF). The VIF was calculated for each explanatory variable Xj. The tolerance for each variable was calculated using the regression model and calculating the coefficient of determination R2. The following equation was used for VIF calculation.

$$VIF_j = \frac{1}{Tolerance} = \frac{1}{1 - R_j^2}$$

The final model also was checked for the measure of influence. The measure of influence was verified if any observation(s) influenced the final model and whether any change in the summary measures observed after removing the particular observation(s) was present. The measure of influence was verified using the Pearson Residual diagnostics test.

Adjusted odds ratio and 95% confidence interval were used for the interpretation of the final model. The probability of KAB crash severity among single motor vehicle crashes involving a large logging truck driver (Y=1) was p. Xi were explanatory variables. βi was the vector for the slope parameter (regression coefficient) for the explanatory variable Xi. β0 was the intercept parameter. The number of explanatory variables in the logistic model was $\mathcal{S}$. The following logistic regression model was used.

$$Logit(p) = Log\left(\frac{p}{1-p}\right) = \beta_0 + \sum_{i=1}^{\mathcal{S}} \beta_i X_i$$

The odds ratio was obtained by exponentiating the value of the coefficient of the respective explanatory variable and 95% confidence interval by exponentiating the 95% confidence interval for the respective explanatory variable regression coefficient. The following equations were used to calculate the odds ratio and 95% confidence interval.

$$OR = e^{\beta_i}$$

$$95\%\ confidence\ interval_{lower\ limit} = e^{\beta_{lower\ limit}}$$

$$95\%\ confidence\ interval_{upper\ limit} = e^{\beta_{upper\ limit}}$$

Power Calculations

The power for the current sample size was calculated based on the proportions of driver characteristics or behavior in higher crash severity (n=71) and suspected injury or no injury (n=393) crashes, using standard parameters (i.e., alpha=0.05 and 2-sided test). A range of prevalence for independent variables in crashes with (6-80%) and without the outcome (0.3-64%) was selected for power calculation. Given these parameters, the estimated power ranged from 76 to 80%. Ranges were based on prior analyses in Texas and Louisiana (Shipp & Trueblood, personal communication, March 25, 2019).

Results

From 2010 to 2018 in Louisiana, 518 single-vehicle (SV) large logging truck crashes (a large logging truck and no other vehicle involved in a crash) were recorded. Six hit-and-run crashes were excluded from the analysis because hit-and-run crashes often have missing information for most variables. One crash coded as a parked vehicle hit by a non-moving vehicle at the time crash was excluded from the analysis because this is logically not possible. Twenty-seven (5.2%) crashes were excluded from the analysis due to missing values for most variables. The remaining 484 SV crashes were analyzed and are described in the sections below.

Of 484 SV crashes, 68 (14.1%) resulted in higher severity injuries, and 416 (86.0%) resulted in possible or no injury. Overall, 1.2% were fatal, 0.2% incapacitating, 12.6% non-incapacitating, 36.2% possible, and 49.8% were property damage only. With respect to crash year, 66 (13.6%) occurred in 2010, 64 (13.2%) occurred in 2011, 53 (11.0%) occurred in 2012, 43 (8.9%) occurred in 2013, 56 (11.6%) occurred in 2014, 66 (13.6%) occurred in 2015, 51 (10.5%) occurred in 2016, 41 (8.5%) occurred in 2017, and 44 (9.1%) occurred in 2018 (data not shown).

Tables 4.1-4.3 show the frequency and proportion of independent variables by crash severity (i.e., higher versus lower severity). Most drivers were 36 to 45 years of age (29.6%), followed by 46 to 55 (26.2%). The median age was 44 years (range16 to 80 years). Almost all drivers were male. More than 65.0% of drivers in large logging truck crashes were Caucasian (data not shown in tables).

About 62.2% of the large logging truck drivers were coded as distracted or inattentive. In truck drivers, impairment due to drugs or alcohol was higher among higher severity crashes than in no injury crashes (2.9% versus 0.2%). Approximately 11.2% of truck drivers were not wearing their seat belts at the time of the crash. The proportion of seat belt use differed significantly by crash severity. A greater percentage of drivers sustained higher severity injuries in a collision classified as not wearing their seat belts than non-injury crashes, 22.1%, and 9.4%, respectively. Most drivers received a citation for the careless operation of their vehicle (67.0%). A higher proportion of drivers who received a citation for the careless operation of their vehicle sustained a higher severity injury (82.4%) than drivers who sustained no injuries (64.9%). Very few drivers received citations for other types of violations.

About 14.9% of large logging trucks had a defect contributing to the crash, including a tire, braking, steering, suspension, or other defects. About one-third (35.1%) had headlights on at the time of the crash. Almost 88% of the SV large logging trucks were older than ten years. The three most common reported movements before a crash were running off-road (50.2%), crossing the median or centerline into the opposite lane (9.3%), and making a left turn (8.3%). Overturned or rollover (76.0%) was the most common harmful event, followed by run-off-road to the right (47.9%), cargo or equipment loss or shift (21.3%), crossed the median, or centerline (20.0%), and run-off-road to the left (16.7%).

Most crashes occurred on two-way roadways without a physical separation (88.4%), state highways (70.3%), relation to roadway classified as other (e.g., off the roadway versus on the roadway) (54.3%), not at or related to an intersection (84.7%), and with a traffic control present (e.g., stop sign, traffic light) (89.7%). Most crashes occurred in daylight (84.9%), under clear weather conditions (76.5%), and with a dry road surface (91.7%).

The unadjusted odds ratio was statistically significant (OR = 12.7; 95% CI = 1.1–142.0) for impaired drivers compared to no impairment drivers, but the overall frequency of impairment-related crashes was small. Only three SV large logging truck crashes involved impaired drivers. No seat belt use was associated with higher severity SV crashes. The unadjusted odds ratio was statistically significant for not wearing a seat belt compared to wearing a seat belt (OR = 3.15; 95% CI = 1.61–6.15). Careless driving was associated with higher severity SV crashes. The unadjusted odds ratio was statistically significant for careless driving compared to no careless driving (OR = 2.52; 95% CI = 1.31–4.56). The most harmful event-vehicle ran off to the left side was more common in higher severity crashes than no injury crashes (OR = 2.43; 95% CI = 1.35–4.37). The vehicle that ran off the road prior to the crash was more common in higher severity crashes than no injury crashes (OR = 1.86; 95% CI = 1.09–3.15).

Table 4.4 shows the final multiple logistic regression model. For the model fit, the forward variable selection method was performed. In the final model, three variables were found to be statistically associated with higher severity crashes. These variables included not wearing a seat belt (OR = 3.21; 95% CI = 1.62–6.38), a violation of careless operation of their vehicle (OR = 2.64; 95% CI = 1.33–5.24), and a harmful event of run off the road to left (OR = 2.27; 95% CI = 1.21–4.25). First-order interaction terms were also included in the model but were not statistically significant. There was no multicollinearity issue observed. None of the independent variables in the model had a VIF of more than 10. The Hosmer Lemeshow Goodness-of-Fit test statistic was 0.363, suggesting that the final model fit the data well. The diagnostic test to measure the influence indicated that no single observation was highly influential.

Discussion

In Louisiana between 2010 and 2018, about 38% of logging truck crashes were SV crashes, and 68 of these single large logging truck crashes were higher severity crashes. The present study found that 11.2% of SV logging truck drivers were not wearing seat belts at the time of the crash and had a greater proportion of higher severity of crashes. The use of a seatbelt is mandatory for all vehicle drivers, but only 56% of logging truck drivers responded that they always wore a seat belt in a survey conducted at driving safety courses in logging truck drivers from Alabama, Georgia, and Mississippi (Carnahan, 2004). Carnahan (2004) is the only study examining this behavioral factor in logging truck drivers. The reporting of seat belt use could be subjective in severe crashes. Seatbelt use in non-fatal crashes could be overestimated, as police often collect this information from vehicle occupants (Farmers, 2003; Yamamoto, Hashiji, & Shankar, 2008), who may not be telling the truth to avoid penalties.

The most common violation assigned to logging truck drivers in SV crashes was careless operation (67% of citations issued). Careless operation was more prevalent among higher severity SV crashes (82.4%) than lower severity SV crashes (64.9%). None of the previous studies analyzed the association between behavioral characteristics and crash severity in SV crashes involving large logging trucks, apart from the analysis of previous AgFF projects. This study found that no seatbelt use and careless driving were associated with higher severity SV crashes in Louisiana from 2010 to 2015 (Shipp et al., 2019).

Among SV crashes, a greater proportion of the harmful event run off road (ROR) to the left side of the road happened in higher severity crashes (29.4%) than lower severity crashes (14.7%). A ROR to the left side event might lead to over-corrective evasive action due to fear of entering the opposite direction on-coming traffic lane. FMCSA and NHTSA conducted the LTCCS to identify the causes of severe crashes involving large trucks using crash data samples (n= 963) between April 2001 and December 2003. The major critical events assigned to at-fault truck crashes include running out of the travel lane or off the road (32%), loss of control due to speed, cargo shift, vehicle failure or other problem (29%), and colliding with the rear end of another vehicle (22%) (FMCSA, 2007). Additionally, log trucks have higher occurrences of running off the road (9.6 %) than tractor-trailers (7.9%) in the United States from 2010 to 2015 (Cole 2018). Shipp et al. (2019) is the only study that found that the harmful event ROR to the left side of the road was associated with higher severity SV crashes in Louisiana from 2010 to 2015.

Harmful event overturn or rollover of the truck was common in SV crashes (76.0%) and was assigned more often in higher severity crashes (85.3%) than lower severity crashes (74.5%). Logging trucks are often heavier than other trucks and have a higher center of gravity, which increases the likelihood of rollover. (McKnight & Bahouth, 2008). Cole (2018) estimated that 32.4% of 68 fatal SV logging truck crashes experienced rollover. The present study data show that 67.2% of higher severity crashes in rollover events happened on curved roads (data not shown in tables). More research is needed to determine why logging trucks have more rollover occurrences, but a failure to keep control around curves on rural roads where log trucks often navigate coupled with a higher center of gravity may contribute to these crashes.

The American trucking industry is facing several related challenges. First, due to drivers aging out of the workforce, there is a continuing truck driver shortage with insufficient replacement and increasing demand for truck drivers across industries. Second, the truck driver shortage makes it difficult to ensure a qualified and experienced truck driver workforce in the logging industry (Costello, 2017). The truck driver shortage further highlights the need to prevent crashes and ensure the health and safety of this workforce.

Insurance coverage for logging trucks can be costly as well as complicated. Logging truck drivers must have two to three years of driving experience after getting a Commercial Driver's License (CDL) to qualify for insurance coverage (Baker, Shawn, & Tyson, 2017; Costello & Suarez, 2015). Insurance companies can deny coverage if logging truck drivers have serious traffic violations, such as speeding and DUI (Baker & Tyson, 2017). The average insurance premium for logging trucks increased by 53% from 2011 to 2016, whereas, for other heavy vehicles, it increased by 12% for the same period in Georgia (Conrad, 2018).

Covering logging trucks is riskier than providing other commercial auto insurance for insurance companies because logging trucks tend to have more crashes and are more expensive than other heavy vehicles (Conrad, 2018). The average cost of logging truck accidents per claim increased by approximately 40% since 2008 for a subset of carriers that offer log truck insurance (Baker & Tyson, 2017; Conrad, 2018). Reducing logging truck crashes could lead to lower insurance premiums and better coverage for forestry industry drivers. One way to reduce the insurance premium could be to offer targeted training and enhanced safety measures for logging truck drivers.

Several limitations are associated with reporting of behavioral factors. Information about driver distraction is complicated to collect, and the data often are unknown or missing. In general, driver distraction and inattention are likely to be underreported (Stutts & Hunter, 2003), as these factors are difficult to verify and measure (National Highway Traffic Safety Administration, 2010). Police officers have to choose from a list of different types of distractions (e.g., cell phones, other distractions inside or outside the vehicle) and may be inconsistent or mistaken in their choice. Misclassification of fatigue is common due to the difficulty of observing and identifying this behavior (Filtness, Armstrong, Watson, & Smith, 2017; Radun, Radun, Ohisalo, Wahde, & Kecklund, 2013). The impairment from alcohol and drugs is often misclassified as alcohol-only impairment. Drug-only impairment often is mistaken for driving without attention (Mercer & Jeffery, 1995). Kim (1999) compared police crash reports and hospital records and found that police crash records underreported the alcohol involvement rate. This underreporting can lead to differential misclassification bias, causing the odds ratios to be towards the null value.

Conclusion

Logging trucks are the primary transport mode for forestry products to various processing facilities, and crashes are frequent. More than 40% of the large logging truck crashes in Louisiana from 2010 to 2018 were SV. No seatbelt use, careless driving, and harmful event running off the road to the left side were associated with higher severity SV crashes. Providing targeted safety training programs to logging truck drivers to reduce crashes related to behavioral characteristics like careless driving and proper seatbelt use is needed. This study identifies behavioral factors associated with higher severity crashes in Louisiana and could help design targeted safety training programs for logging truck drivers.

Table 4.1: Unadjusted associations between driver variables and higher crash severity for single large logging truck crashes in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (Single Vehicle) (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	Unadjusted OR	95% CI	P-Value
Driver's Demographics					
Driver Age (years)					
35 & younger	13 (19.1%)	108 (26.0%)	1.00	Ref.	
36-45	21 (30.9%)	122 (29.3%)	1.43	0.68-2.99	0.343
45-55	17 (25.0%)	110 (26.4%)	1.28	0.60-2.77	0.524
56 & older	17 (25.0%)	76 (18.3%)	1.86	0.85-4.05	0.119
Driver Gender [a]					
Male	66 (97.1%)	410 (98.6%)	1.00	Ref.	
Female	2 (2.9%)	6 (1.4%)	2.07	0.41-10.48	0.380
Driver's Behaviors					
Driver Impairment- Alcohol Estimates [a]					
Yes	2 (2.9%)	1 (0.2%)	12.58	1.12-140.64	0.040
No	66 (97.1%)	415 (99.8%)	1.00	Ref.	

Table 4.1 Continued

Independent Variable	Large logging truck crashes (Single Vehicle) (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	Unadjusted OR	95% CI	P-Value
Driver Distraction					
Yes	45 (66.2%)	257 (61.8%)	1.62	0.88-2.97	0.120
No	16 (23.5%)	148 (35.6%)	1.00	Ref.	
Unknown	7 (10.3%)	11 (2.6%)	5.89	2.00-17.32	0.000
Driver Fatigue [a]					
Yes	1 (1.5%)	2 (0.5%)	3.28	0.29-36.68	0.290
No	63 (92.7%)	413 (99.3%)	1.00	Ref.	
Unknown	4 (5.9%)	1 (0.2%)	26.22	2.88-238.39	0.000
Driver Seatbelt Use					
Used	45 (66.2%)	368 (88.5%)	1.00	Ref.	
Not Used	15 (22.1%)	39 (9.4%)	3.15	1.61-6.15	0.000
Unknown	8 (11.8%)	9 (2.2%)	7.27	2.67-19.79	0.000
Driver Violations					
Failure to Yield [b]					
Yes	0 (0.0%)	2 (0.5%)	N/A		
No	68 (100.0%)	414 (99.5%)			
Following Too Closely [b]					
Yes	0 (0.0%)	6 (1.4%)	N/A		
No	68 (100.0%)	410 (98.6%)			
Driving Left of Center [b]					
Yes	0 (0.0%)	2 (0.5%)	N/A		
No	68 (100.0%)	414 (99.5%)			
Speeding [a]					
Yes	1 (1.5%)	10 (2.4%)	0.61	0.08-4.81	0.636
No	67 (98.5%)	406 (97.6%)	1.00	Ref.	
Careless Operation					
Yes	56 (82.4%)	270 (64.9%)	2.52	1.31-4.56	0.006
No	12 (17.7%)	146 (35.1%)	1.00	Ref.	

Notes: (1) Abbreviation: Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI). (2) [a] Insufficient sample size to compute additional statistics (if the cell size is less than 5). (3) [b] and N/A = Odds ratio not calculated because zero cell size. (4) Table 4.1 is adapted from Shipp et al. (2019).

Table 4.2: Unadjusted associations between vehicle variables and higher crash severity for single large logging truck crashes in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (Single Vehicle) (n=484)				
	Higher Severity Crash n (Col%) (N=68)	Lower Severity Crash n (Col%) (N=416)	Unadjusted OR	95% CI	P-Value
Vehicle Characteristics					
Vehicle Defects Observed					
Yes	6 (8.8%)	66 (15.9%)	0.51	0.21-1.24	0.137
No	62 (91.2%)	350 (84.1%)	1.00	Ref.	
Vehicle Lighting Condition					
Headlights on or Daytime Running Lights	17 (25.0%)	161 (38.7%)	1.00	Ref.	
Headlights off	42 (61.8%)	236 (56.7%)	1.69	0.93-3.07	0.087
Unknown	9 (13.2%)	19 (4.6%)	4.49	1.76-11.46	0.002
Vehicle Age					
Less than 10 years	10 (14.7%)	47 (11.3%)	1.00	Ref.	0.420
More than 10 years	58 (85.3%)	369 (88.7%)	0.74	0.35-1.54	
Vehicle Movement-Harmful Events					
Vehicle Overturn/Rollover					
Yes	58 (85.3%)	310 (74.5%)	1.98	0.98-4.02	0.057
No	10 (14.7%)	106 (25.5%)	1.00	Ref.	
Cargo/Equipment Loss or Shift					
Yes	20 (29.4%)	83 (19.9%)	1.67	0.97-2.97	0.080
No	48 (70.6%)	333 (80.1%)	1.00	Ref.	
Ran Off Road Right					
Yes	35 (51.5%)	197 (47.4%)	1.18	0.71-1.97	0.529
No	33 (48.5%)	219 (52.6%)	1.00	Ref.	
Ran Off Road Left					
Yes	20 (29.4%)	61 (14.7%)	2.43	1.35-4.37	0.003
No	48 (70.6%)	355 (85.3%)	1.00	Ref.	
Hit Standing Tree					
Yes	8 (11.8%)	39 (9.4%)	1.29	0.58-2.90	0.538
No	60 (88.2%)	377 (90.6%)	1.00	Ref.	
Crossed Median/Centerline					
Yes	17 (25.0%)	80 (19.2%)	1.40	0.77-2.55	0.272
No	51 (75.0%)	336 (80.8%)	1.00	Ref.	
Hit Pedestrian [a]					
Yes	2 (2.9%)	2 (0.5%)	6.27	0.87-45.30	0.069
No	66 (97.1%)	414 (99.5%)	1.00	Ref.	

Table 4.2 Continued

Independent Variable	Large logging truck crashes (Single Vehicle) (n=484)				
	Higher Severity Crash n (Col%) (N=68)	Lower Severity Crash n (Col%) (N=416)	Unadjusted OR	95% CI	P-Value
Vehicle Movement-Prior Movement					
Vehicle Ran Off Road					
Yes	43 (63.2%)	200 (48.1%)	1.86	1.09-3.15	0.022
No	25 (36.8%)	216 (51.9%)	1.00	Ref.	
Making Left Turn [a]					
Yes	3 (4.4%)	37 (8.9%)	0.47	0.14-1.58	0.223
No	65 (95.6%)	379 (91.1%)	1.00	Ref.	
Crossed Median or Center Line into Opposite Lane					
Yes	9 (13.2%)	36 (8.7%)	1.61	0.74-3.51	0.231
No	59 (86.8%)	380 (91.4%)	1.00	Ref.	
Vehicle Movement-Reason For Movement					
To Avoid Other Vehicle [a]					
Yes	3 (4.4%)	16 (3.9%)	1.15	0.33-4.07	0.824
No	65 (95.6%)	400 (96.2%)	1.00	Ref.	
Vehicle Out of Control, Not Passing [a]					
Yes	4 (5.9%)	27 (6.5%)	0.90	0.31-2.66	0.849
No	64 (94.2%)	389 (93.5%)	1.00	Ref.	
Vehicle Movement-Traffic Control					
Stop Sign [a]					
Yes	3 (4.4%)	22 (5.3%)	1.00	Ref.	
No	65 (95.6%)	394 (94.7%)	1.21	0.35-4.16	0.762
Yellow No Passing Line					
Yes	44 (64.7%)	234 (56.2%)	1.00	Ref.	
No	24 (35.3%)	182 (43.8%)	0.70	0.41-1.20	0.193
White Dashed Line [a]					
Yes	3 (4.4%)	37 (8.9%)	1.00	Ref.	
No	65 (95.6%)	379 (91.1%)	2.12	0.63-7.06	0.223
Yellow Dashed Line					
Yes	7 (10.3%)	61 (14.7%)	1.00	Ref.	
No	61 (89.7%)	355 (85.3%)	1.50	0.65-3.43	0.339
No Control					
Yes	9 (13.2%)	41 (9.9%)	1.00	Ref.	
No	59 (86.8%)	375 (90.1%)	0.72	0.33-1.55	0.398

Notes: (1) Abbreviation: Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI) (2) [a] Insufficient sample size to compute additional statistics (if the cell size is less than 5). (4) Table 4.2 is adapted from Shipp et al. (2019).

Table 4.3: Unadjusted associations between crash variables and higher crash severity for single large logging truck crashes in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (Single Vehicle) (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	Unadjusted OR	95% CI	P-value
Crash Time [b]					
Morning	24 (35.3%)	128 (30.8%)	N/A		
Afternoon	24 (35.3%)	115 (27.6%)			
Evening	4 (5.9%)	13 (3.1%)			
Night	0 (0.0%)	25 (6.0%)			
Unknown	16 (23.5%)	135 (32.5%)			
Crash Year [a]					
2010	10 (14.7%)	56 (13.5%)	1.00	Ref.	
2011	7 (10.3%)	57 (13.7%)	0.69	0.24-1.93	0.478
2012	7 (10.3%)	46 (11.1%)	0.85	0.30-2.41	0.763
2013	3 (4.4%)	40 (9.6%)	0.42	0.11-1.62	0.209
2014	13 (19.1%)	43 (10.3%)	1.69	0.68-4.23	0.259
2015	5 (7.4%)	61 (14.7%)	0.46	0.15-1.43	0.178
2016	12 (17.7%)	39 (9.4%)	1.72	0.68-4.38	0.253
2017	6 (8.8%)	35 (8.4%)	0.96	0.32-2.87	0.942
2018	5 (7.4%)	39 (9.4%)	0.72	0.23-2.26	0.572
Day of the Week					
Weekday	62 (91.2%)	378 (90.9%)	1.00	Ref.	
Weekend	6 (8.8%)	38 (9.1%)	0.96	0.39-2.37	0.934
Clear Weather Conditions					
Yes	57 (83.8%)	313 (75.2%)	1.00	Ref.	
No	11 (16.2%)	103 (24.8%)	0.59	0.30-1.16	0.126
Daylight [a]					
Yes	66 (97.1%)	345 (82.9%)	1.00	Ref.	
No	2 (2.9%)	71 (17.1%)	0.15	0.04-0.62	0.009
Road Surface Condition-Dry [a]					
Yes	67 (98.5%)	377 (90.6%)	1.00	Ref.	
No	1 (1.5%)	39 (9.4%)	0.14	0.02-1.07	0.058
Road Surface Type-Blacktop					
Yes	63 (92.7%)	380 (91.4%)	1.00	Ref.	
No	5 (7.4%)	36 (8.7%)	0.84	0.32-2.22	0.721
Road Alignment					
Straight	29 (42.7%)	213 (51.2%)	1.00	Ref.	
Curved	39 (57.4%)	203 (48.8%)	1.41	0.84-2.37	0.192
Manner of Collision [a]					
Non-Collision with Motor Vehicle	64 (94.1%)	404 (97.1%)	1.00	Ref.	
Other or Unknown	4 (5.8%)	12 (2.9%)	2.10	0.66-6.73	0.210

Table 4.3 Continued

Independent Variable	Large logging truck crashes (Single Vehicle) (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	Unadjusted OR	95% CI	P-value
Road Type No Physical Barrier					
Yes	63 (92.7%)	365 (87.7%)	1.00	Ref.	
No	5 (7.4%)	51 (12.3%)	1.76	0.68-4.58	0.247
Location Type [a]					
Manufacturing or Industrial or business area	29 (42.7%)	153 (36.8%)	0.39	0.13-1.16	0.091
Residential related area	4 (5.9%)	54 (13.0%)	1.00	Ref.	
Open country	35 (51.5%)	209 (50.2%)	0.88	0.52-1.51	0.650
Intersection [a]					
Yes	3 (4.4%)	71 (17.1%)	0.22	0.07-0.73	0.010
No	65 (95.6%)	345 (82.9%)	1.00	Ref.	
Highway Type					
Interstate and US highway	10 (14.7%)	79 (19.0%)	1.00	Ref.	
State highway	49 (72.1%)	291 (70.0%)	1.33	0.64-2.74	0.440
Other (Parish Road, City Street)	9 (13.2%)	46 (11.1%)	1.55	0.59-4.08	0.379

Notes: (1) Abbreviation: Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI) .(2) [a] Insufficient sample size to compute additional statistics (if the cell size is less than 5). (3) [b] and N/A = Odds ratio not calculated because zero cell size. (4) Table 4.3 is adapted from Shipp et al. (2019).

Table 4.4: Adjusted associations between driver and vehicle variables and higher crash severity for single large logging truck crashes in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (Single Vehicle) (n=484)				
	Higher Severity Crash n (Col%) (n=68)	Lower Severity Crash n (Col%) (n=416)	Adjusted OR	95% CI	P-value
Driver Seatbelt Use					
Used	45 (66.2%)	368 (88.5%)	1.00	Ref.	
Not Used	15 (22.1%)	39 (9.4%)	3.21	1.62-6.38	0.001
Unknown	8 (11.8%)	9 (2.2%)	7.94	2.66-23.69	0.000
Driver Violations -Careless Operation					
Yes	56 (82.4%)	270 (64.9%)	2.64	1.33-5.24	0.006
No	12 (17.7%)	146 (35.1%)	1.00	Ref.	
Harmful Events- Ran Off Road Left					
Yes	20 (29.4%)	61 (14.7%)	2.27	1.21-4.25	0.010
No	48 (70.6%)	355 (85.3%)	1.00	Ref.	

Notes: (1) Abbreviation: Higher severity crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Lower severity crash includes crash severities classified as complaints or possible injury (C) and no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI). (4) Table 4.4 is adapted from Shipp et al. (2019).

CHAPTER V

SPECIFIC AIM 2B: ASSOCIATIONS BETWEEN DRIVER CHARACTERISTICS AND BEHAVIORS AND HIGHER SEVERITY CRASHES IN MULTI-VEHICLE CRASHES INVOLVING A LOGGING TRUCK WHILE ADJUSTING FOR VEHICLE AND CRASH VARIABLES

Introduction

Logging is considered one of the most dangerous industries in the United States, and logging workers were at the highest risk of fatal occupational injuries in 2018 (National Institute for Occupational Safety and Health, 2012; U.S. Department of Labor, 2019). The fatal occupational injury rate in logging workers is higher than for workers from all American industries combined (BLS, 2019). Limited information is not readily available at the state level, obstructing a clear understanding of this issue.

Logging vehicles are the only transportation method for transporting forestry products from remote locations to various processing facilities. The trucking industry plays a crucial role in transporting forestry products (Roberts, Shaffer, & Bush, 2005). The trucking industry also plays a vital role in the economy of logging-related businesses and accounts for almost 50% of the total expenses (Shaffer & Stuart, 2009). Almost one-fourth of the total fatal occupational injuries in the logging industry were due to transportation crashes (BLS, 2019). Louisiana's economy is dependent on the logging industry because they are one of the most significant employers and major contributors.

Nationally, logging-related roadway crashes have increased in the United States since 2012 (Cole, 2018; Conrad, 2018), and fatal logging truck crashes increased by 41% in the United States between 2011 and 2015 (Cole, 2018). An analysis of FMCSA indicated that logging truck crashes doubled in the United States from 2010 to 2015 (Baker & Tyson, 2017). Logging truck crashes on the roadways are expected to increase in the future due to the recovery of the forestry industry (Baker & Tyson, 2017). Limited information is available on the associated crash factors in logging truck crashes by crash severity and type. The lack of information hinders the development of countermeasures and other preventive measures.

Methods

Hypothesis

The null hypothesis was that there is no association between driver and behavioral crash characteristics and higher severity crashes in multi-vehicle crashes involving a logging truck on public roadways in Louisiana from 2010-2018, adjusting for vehicle and crash variables. The hypothesis was there would be an association between driver and behavioral crash characteristics and higher severity crashes in multi-vehicle crashes involving a logging truck on public roadways in Louisiana from 2010-2018, adjusting for the vehicle and crash variables.

Data Source

A crash database from the Louisiana Department of Transportation and Development (LaDOTD) from 2010-2018 was analyzed to estimate the associations between driver characteristics and behaviors and higher crash severity in multi-vehicle crashes involving a logging truck while adjusting for vehicle and crash variables. The LaDOTD Highway Safety database from 2010 to 2018 included fatal, non-fatal, or property damage greater than $500 crashes and information on the person, vehicle, and crash factors. The severity level of fatal crashes is updated within 30 days. The police officers who respond to the scene collect the crash data and complete the reports based on evidence at the scene and interviews with the victims and witnesses.

Variables

A multi-vehicle crash is often defined as an event with more than one vehicle involved in a crash. However, for this dissertation, a multi-vehicle crash was defined as a crash involving only two vehicles, one being a large logging truck (cargo body type “H”), in Louisiana between 2010 and 2018. The dependent variable was crash severity with discrete categories. The dependent variable was coded as higher severity (1), minor severity (2), and no injury or property damage only (0) (reference category) categories (see Chapter 1, Data Description Section for detailed information on crash severity).

Independent variables were the driver (driver’s age and gender) and behavioral factors (seatbelt use, impairment, distraction, fatigue, and violations). They were adjusted for vehicle factors (vehicle condition, vehicle light condition, type of vehicle, most harmful event, the motion of the vehicle prior to the crash, and the reason for motion), and crash-related factors (crash year, the day of the week, time of the day, manner of collision, daylight conditions, weather conditions, traffic control conditions, road alignment, road surface conditions, road surface types, road type, roadway relation, road alignment, kind of location, intersection and highway type and at-fault status) (see Appendix Table A-2 for detail information on categorization).

Analysis

Previous literature suggests that single vehicle (SV) and multiple vehicle (MV) crashes have different crash factors by crash severity and need to be analyzed separately (Kockelman & Kweon, 2002; Savolainen & Mannering, 2007; Ulfarsson & Mannering, 2004). For specific aim 2B, multinomial logistic regression (MNL) was performed. The modeling approach was based on Shankar and Mannering (1996) and Ulfarsson and Mannering (2004). The MNL model follows the independence of irrelevant alternatives (IIA) assumption, which means that adding or removing an alternative will not affect the ratio between the probabilities of any pair of existing alternatives. The Hausman test and suest-based Hausman test were conducted to confirm that the MNL specification was appropriate for using the model.

The use of MNL for estimating multi-vehicle crash severity outcomes offered the flexibility of MNL over the ordered model and is commonly used (Cerwick, Gkritza, Shaheed, & Hans, 2014) because MNL accommodates unobserved heterogeneity in the crash data. In the multi-vehicle crash model, there were three categories of crash severity: no injury (property damage only) (O), possible injury (C), and fatal or severe injury (KAB).

Descriptive statistics were calculated for crash characteristics stratified by the dependent variable. Pearson Correlation Coefficients were calculated for all independent variables to identify highly correlated independent variables to determine which independent variables should be considered during the modeling process. Before removing them from the final model, highly correlated independent variables were also examined during the model fitting process.

The Independence of Irrelevant Alternatives (IIA) assumption was tested using the Hausman. Hausman's test results were negative values. Based on Hausman and McFadden (1984) and Freese and Long (2000), the negative statistics are very common and can be interpreted as evidence that IIA has not been violated. Hausman test results can vary depending on the base outcome category and could be inclusive. The suest test findings indicated that the null hypothesis could not be rejected. IIA was not violated, and the use of MNL for these data is appropriate. Therefore, using the suest-based Hausman test is recommended to evaluate the IIA assumption as an add-on test.

The multi-vehicle logging truck crashes were analyzed using MNL as described above to identify the associated driver, and behavioral crash characteristics in higher severity crashes involving only the logging truck after adjusting the model for vehicle and environmental factors. The MNL model is a discrete choice model that assumes a dependent variable with more than two levels without accounting for order between levels.

For the model building process, independent variables with less than five cell sizes were not included in further analysis. The first step in fitting the model was the variable selection process using the univariate analysis. Variables with a p-value of less than 0.25 in the univariate analysis were included in the model building procedure as part of an intermediate model. The forward selection method was used for the model selection process. Model selection was based on the smallest p-value and Bayesian Information Criterion (BIC) values from univariate analysis. Then selected explanatory variables were added to the model one by one until the final model contained all significant explanatory variables at 0.05 level and had the smallest BIC compared to other models. The effect of explanatory variables on parameter estimates was checked at each step of model building for confounding variables. The categorical variables with at least one significant category were included in the model. The confounders were selected from non-significant explanatory variables at the 0.1 significance level. These variables affect parameter estimates (15 to 20% change) after exclusion from the model.

Model fit was assessed by checking the goodness of fit using a likelihood ratio test and Hosmer-Lemeshow Goodness-of-Fit test at the 0.05 significance level. Multicollinearity in the final model was checked with the variance inflation factor (VIF). VIF was calculated for each explanatory variable Xj. The tolerance for each variable was calculated using the regression model and calculating the coefficient of determination R2. The following formula was used for VIF calculation:

$$VIF_j = \frac{1}{Tolerance} = \frac{1}{1 - R_j^2}$$

All the independent variables in the final model had a VIF less than 10, and no multicollinearity was observed. Additionally, the condition number was 13.6 and did not suggest a multicollinearity issue since it was less than 30.

The final model also was checked for the measure of influence. The measure of influence was verified if any observation(s) influenced the final model and whether there was any change in the summary measures observed after removing particular observation(s). The measure of influence was verified using the Pearson Residual diagnostics test.

Adjusted odds ratio and 95% confidence intervals were used for the interpretation of the final model. Pni was the probability of driver n sustaining an injury with a severe outcome i, (where i= 1, …, I) greater than or equal to the propensity of driver n towards all other injury-severity outcomes. βi denoted the vector parameter, and Xn was a vector of the observable characteristics that determine severity. The MNL model was derived using the following equation if εni (an unobserved random error) was assumed to be the generalized extreme value (GEV) distributed (based on McFadden, 1981):

$$P_{ni} = \frac{\exp\,[\beta_i' X_n]}{\sum_{i'=1}^{I} \exp\,[\beta_i' X_n]}$$

The coefficients were estimated using the maximum likelihood function. The explanatory variables are not injury-specific and do not vary across injuries, the equation for I − 1 log-odds ratio of the model outcomes was:

$$In\left(\frac{P_{ni}}{P_{nI}}\right) = (\beta_i' - \beta_I')x_n$$

For i = 1, 2, .., I-1.

The odds ratio can be obtained through the ratio between the probabilities of two specific categories and specifies the propensity of a driver falling into one category as opposed to the other. The odds ratio was obtained by exponentiating the value of the coefficient of the respective explanatory variable. The following equations were used to calculate the odds ratio and 95% confidence interval:

$$OR = e^{\beta_i}$$

$$95\%\ confidence\ interval_{lower\ limit} = e^{\beta_{lower\ limit}}$$

$$95\%\ confidence\ interval_{upper\ limit} = e^{\beta_{upper\ limit}}$$

MNL was performed and used to calculate unadjusted, adjusted odds ratios, 95% confidence intervals, and p-values using the statistical modeling software STATA 16. A total of 30 independent variables were included in the model fit: driver, vehicle, and crash factors. The collinearity between independent variables was checked before the model fit. Pearson Correlation Coefficients were calculated for all independent variables to identify highly correlated independent variables.

A strong correlation was found between both vehicles involved in a crash with traffic control yellow dash line (r=0.8), both vehicles involved in a crash with occupant seatbelt use (r=0.7), time of the day and crash year (0.7), and road condition and weather condition (r=0.6). Before removing them from the final model, highly correlated independent variables were also examined during the model fit process (data not shown).

Two logistic models were developed to measure the influence of observations on final model fit: 1) higher severity (KAB) versus no injury or property damage only (O) logistic regression model and 2) Minor severity (C) versus no injury or property damage only (O) logistic regression model. A diagnostic test was performed to measure influence by calculating Pearson Residuals for the higher severity (KAB) versus no injury or property damage (O) logistic regression model. It indicated that four observations could have a potential influence on the final model. Higher severity (KAB) versus no injury or property damage only (O) model was run with and without those four observations for possible influence on the final model fit. The direction of the association between dependent and independent variables did not change. The Pearson Residuals diagnostic test was also performed to measure influence for the minor severity (C) versus no injury or property damage only (O) logistic regression model. It indicated that no single observation was highly influential. The Hosmer Lemeshow Goodness-of-Fit test statistic was 0.953, suggesting that the final model fit the data well. Pearson Residuals were used to identify any observations with too much influence on the fitted model.

Power Calculations

The power for the current sample size was calculated based on the proportions of the driver characteristic or behavior in higher severity crash (n=127), minor severity (192), and no injury (n=413) crashes, using standard parameters (i.e., alpha=0.05 and 2-

sided test). A range of prevalence for independent variables in higher severity crashes with (5-60%), and minor severity (1.04-42%) was selected for power calculation. A range of prevalence for independent variables in higher severity crashes with (10-60%), and no injury (1.04-37%) was selected for power calculation. Ranges were based on preliminary analyses in Texas and Louisiana (Shipp & Trueblood, personal communication, March 25, 2019). Given these parameters, the estimated power ranged from 74% to 100%.

Results

There were 748 MV crashes involving at least one large logging truck in Louisiana from 2010 to 2018. The analysis excluded 54 hit-and-run crashes because hit-and-run crashes often have missing information for most variables. Two crashes were coded as the parked vehicle was hit by the non-moving vehicle at the time of the crash, which is not possible, so they were excluded from the analysis (refer to Flowchart 1). Fifty-six (8.0%) crashes were excluded from the analysis due to missing values for most variables.

Of the remaining 636 MV crashes, 118 (18.6%) resulted in higher severity injuries, 177 (27.8%) resulted in minor severity, and 341 (53.6%) resulted in no injury. Overall, 3.6% of crash severity were fatal, 1.3% incapacitating, 13.7% non-incapacitating, 27.8% possible, and 53.6% were non-injury. Of the MV logging-related large truck crashes, 83 (13.1%) occurred in 2010, 75 (11.8%) occurred in 2011, 55 (8.7%) occurred in 2012, 65 (10.2%) occurred in 2013, 69 (10.9%) occurred in 2014, 73 (11.5%) occurred in 2015, 80 (12.6%) occurred in 2016, 66 (10.4%) occurred in 2017, and 70 (11.0%) occurred in 2018 (data not shown in tables). Tables 5.1-5.3 show the frequency and proportion of independent variables by crash severity category (i.e., higher severity versus minor severity versus property damage only crashes).

Most large logging truck drivers involved in MV crashes were more than 45 years of age (57.4%), while other vehicle drivers were most often less than 35 years (40.1%). The median age of large logging truck drivers was 47 years (range 19 to 77 years), and other vehicle drivers were 45 years (range 15 to 91 years). About 98.6% of large logging truck crashes involved male drivers, while only 1.4% involved female truck drivers. About 64.0% of MV crashes involved male drivers of other vehicles, while 36.0% of MV crashes involved female drivers of other vehicles. Female drivers of other vehicles were involved in 40.7% of higher severity crashes, 45.8% of minor severity crashes, and 29.3% of no injury or property damage only crashes. More than 66.0% of large logging truck drivers involved in MV crashes were Caucasian, and more than 68.0% of other vehicle drivers involved in MV crashes were Caucasian (data not shown in tables).

About 35.4% of the large logging truck drivers and 36.0% of other vehicle drivers were coded as distracted or inattentive. Logging truck drivers were coded as distracted in 25.4% of higher severity crashes, 35.6% of minor severity crashes, and 38.7% of no injury or property damage only crashes. Other vehicle drivers were coded as distracted in 46.6% of higher severity crashes, 39.6% of minor severity crashes, and 30.5% of no injury or property damage only crashes. About 3.0% of truck drivers and 5.5% of other vehicle drivers failed to wear a seatbelt at the time of the crash. Logging truck drivers who failed to wear a seatbelt were involved in 5.1% of higher severity crashes, 4.5% of minor severity crashes, and 1.5% of no injury or property damage only crashes. The most common citations assigned to large logging truck drivers were careless operation (10.5%), failure to yield (7.7%), following other vehicles too closely (7.2%), driving left of center (3.6%), cutting-in or improper passing (2.8%), and speeding (0.2%). The most common citations assigned to other vehicle drivers involved in MV crashes were failure to yield (15.3%), careless operation (15.1%), driving left of center (5.8%), following other vehicles too closely (3.2%), cutting-in or improper passing (2.7%), and speeding (0.3%). Careless operation citations were assigned to logging truck drivers in 8.5% of higher severity crashes, 15.8% of minor severity crashes, and 8.5% of no injury or property damage only crashes. Careless operation citations were assigned to other vehicle drivers in 24.6% of higher severity crashes, 15.8% of minor severity crashes, and 11.4% of no injury or property damage only crashes. Driving to left side citations were assigned to other vehicle drivers in 19.5% of higher severity crashes, 4.0% of minor severity crashes, and 2.1% of no injury or property damage only crashes.

Most MV crashes involved trucks that had headlights on (41.0%). Headlights-on was assigned to the trucks 48.3% of higher severity crashes, 41.8% of minor severity crashes, and 38.1% of no injury or property damage only crashes. Vehicle defects that contributed to the crash included tire, braking, steering, suspension, or other defects. Vehicle defects in MV crashes were observed more in large logging trucks (6.5%) than in other vehicles (0.3%). Most large logging trucks involved in MV crashes had headlights off when there was no daylight (48.1%), and about 44.2% of other vehicles involved in

MV crashes had headlights off at the time of the crash when there was no daylight. About 79.7% of the MV large logging trucks were older than ten years.

Large logging trucks involved in MV crashes had the following most harmful events: crossed the median, or centerline (10.5%), run-off-road to the right (6.1%), run-off-road to the left (4.3%), overturned or rollover (4.1%), and cargo or equipment loss or shift (2.2%). Ran off the road to the right side was assigned to large logging truck drivers in 11.9% of higher severity crashes, 7.3% of minor severity crashes, and 3.5% of no injury or property damage only crashes. Ran off the road to the left side was assigned to large logging truck drivers in 9.3% of higher severity crashes, 4.5% of minor severity crashes, and 2.4% of no injury or property damage only crashes. The vehicle crossed the median or centerline was assigned to large logging truck drivers in 15.3% of higher severity crashes, 13.6% of minor severity crashes, and 7.3% of no injury or property damage only crashes.

The other vehicle involved in MV crashes had the following most harmful events: crossed the median, or centerline (14.8%), run-off-road to the right (6.3%), run-off-road to the left (5.8%), overturned or rollover (2.5%), and cargo or equipment loss or shift (1.1%). Ran off the road to the right side was assigned to other vehicle drivers in 12.7% of higher severity crashes, 6.8% of minor severity crashes, and 3.8% of no injury or property damage only crashes. Ran off the road to the left side was assigned to other vehicle drivers in 7.6% of higher severity crashes, 10.2% of minor severity crashes, and 2.9% of no injury or property damage only crashes. The vehicle crossed the median or centerline was assigned to other vehicle drivers in 25.4% of higher severity crashes, 15.3% of minor severity crashes, and 10.9% of no injury or property damage only crashes.

Before the crash, the vehicle ran off the road, was reported in 3.0% of large logging trucks and 2.0% of other vehicles involved in MV crashes. Before the crash, the vehicle making a left turn was reported in 8.2% of large logging trucks and 11.6% of other vehicles involved in MV crashes. The vehicle crossed the median or center line into the opposite lane before the crash was reported in 8.0% of large logging trucks and 9.1% of other vehicles involved in MV crashes. The vehicle crossed median or centerline into opposite line before the crash was assigned to large logging truck drivers in 23.7% of higher severity crashes, 7.9% of minor severity crashes, and 4.7% of no injury or property damage only crashes.

The common traffic controls assigned to large logging trucks were white dashed line (20.8%), no traffic control present (5.8%), yellow no-passing line (33.7%), yellow dashed line (17.0%), and stop sign (6.8%) in MV crashes. Traffic control-yellow dashed line was assigned to large logging truck drivers in 22.9% of higher severity crashes, 21.5% of minor severity crashes, and 12.6% of no injury or property damage only crashes.

The common traffic controls assigned to other vehicles were white dashed line (21.4%), no traffic control present (7.9%), yellow no-passing line (28.8%), yellow dashed line (16.5%), and stop sign (9.3%) in MV crashes. Traffic control-yellow dashed line was assigned to other vehicle drivers in 19.5% of higher severity crashes, 20.9% of minor severity crashes, and 13.2% of no injury or property damage only crashes.

The majority of MV large logging truck crashes occurred on two-way roadways without a physical separation (73.1%), state highways (53.5%), relation to roadway classified as on the roadway (94.3%), not at or related to an intersection (68.9%), and with a traffic control present (e.g., stop sign, traffic light) (93.2%). Most MV large logging truck crashes also occurred in daylight (82.2%), under clear weather conditions (78.6%), with a dry road surface (89.9%), on a blacktop road surface (81.5%), and on straight roads (84.8%).

About 11.3% of MV crashes happened at night. MV crashes happening at night were 17.8% of higher severity crashes, 9.0% of minor severity crashes, and 10.3% of no injury or property damage only crashes. MV crashes that happened in clear weather were 72.0% of higher severity crashes, 79.7% of minor severity crashes, and 80.4% of no injury or property damage only crashes. MV crashes in daylight were 67.8% of higher severity crashes, 85.3% of minor severity crashes, and 85.6% of no injury or property damage only crashes. MV crashes on curved roads were 22.9% of higher severity crashes, 15.3% of minor severity crashes, and 12.6% of no injury or property damage only crashes.

About 23.7% of MV large logging truck crashes were the same direction crashes, 17.5% were head-on or opposite direction crashes, 19.5% were angle crashes, 27.7% were rear-ended, and 11.6% were other or unknown type of crashes. Head-on or opposite direction crashes happened in 29.7% of higher severity crashes, 14.1% of minor severity crashes, and 15.0% of no injury or property damage only crashes. Angle crashes happened in 26.3% of higher severity crashes, 23.7% of minor severity crashes, and 15.0% of no injury or property damage only crashes. Rear-end crashes happened in 28.8% of higher severity crashes, 33.9% of minor severity crashes, and 24.1% of no injury or property damage only crashes. About 28.0% of higher severity crashes, 37.9% of minor severity crashes, and 44.3% of no injury or property damage only crashes happened in manufacturing, industrial or business area.

A small proportion of large logging truck MV crashes (n=10, 1.6%) involved impaired drivers. The impairment flag was assigned at the crash level and not at the driver level. Driver at-fault was assigned to 35.9% of large logging truck drivers, 38.8% other vehicle drivers, and 25.3% was assigned to both drivers, or at-fault was not unclear (25.3%). At-fault large logging truck drivers were involved in 19.5% of higher severity crashes, 35.6% of minor severity crashes, and 41.6% of no injury or property damage only crashes. At-fault other vehicle drivers were involved in 46.6% of higher severity crashes, 41.2% of minor severity crashes, and 34.9% of no injury or property damage only crashes.

The unadjusted odds ratio was statistically significant in large logging truck drivers who failed to use a seatbelt compared to those who wore a seatbelt in higher severity crashes (OR = 3.56; 95% CI = 1.06–11.88) and minor severity crashes (OR = 3.13; 95% CI = 1.01–9.72). Careless driving in large logging truck drivers was significantly associated with minor severity crashes (OR = 2.02; 95% CI = 1.16–3.52). A large truck crossing the median or centerline was significantly associated with higher severity crashes (OR = 2.28; 95% CI = 1.19–4.34) and also found to be significantly associated with minor severity crashes (OR = 1.98; 95% CI = 1.10–3.59). A large logging truck that ran-off-road to the left side was significantly associated with higher severity crashes (OR = 4.28; 95% CI = 1.68–10.92). A large logging truck that ran-off-road to the right side was significantly associated with higher severity crashes (OR = 3.69; 95% CI = 1.66–8.23). The unadjusted odds ratio was statistically significant for large logging trucks at the yellow dashed line at the time of the crash in higher severity crashes versus no injury crashes (OR = 20.6; 95% CI = 1.20–3.51) and minor severity versus no injury crashes (OR = 1.89; 95% CI = 1.17–3.06).

Distracted driving in other vehicle drivers was significantly associated with higher severity crashes (OR = 2.83; 95% CI = 1.77–4.55). Careless driving in other vehicle drivers was associated with minor severity crashes (OR = 2.52; 95% CI = 1.48–4.31). Other vehicle drivers who received a citation for driving left of center were significantly associated with higher severity crashes (OR = 11.55; 95% CI = 4.81–27.74). A harmful event of ROR to the right (OR = 3.67; 95% CI = 1.69–7.98), ROR to the left (OR = 2.73; 95% CI = 1.08–6.90) and crossed the median or centerline (OR = 2.80; 95% CI = 1.64–4.79) were significantly associated with higher severity crashes. The harmful event ROR to the left side was significantly associated with minor severity crashes in other vehicles (OR = 3.75; 95% CI = 1.69–8.30). The unadjusted odds ratio was statistically significant in other vehicles that were at the yellow dashed line at the time of crash compared to other vehicles that were not at the yellow dashed line at the time of the crash in minor severity injury versus no injury crashes (OR = 1.74; 95% CI = 1.08–2.81).

MV large logging truck crashes that happened at night were significantly associated with higher severity crashes versus no injury crashes (OR = 2.94; 95% CI = 1.38–6.27). The unadjusted odds ratio was statistically significant in higher severity crashes that happened with no daylight compared to crashes in daylight (OR = 2.83; 95% CI = 1.73–4.62). Large logging truck MV crashes that happened on curved roads were significantly associated with higher severity crashes versus no injury crashes (OR = 2.06; 95% CI = 1.20–3.51).

Head-on or opposite direction crashes were significantly associated with higher severity crashes versus no injury crashes (OR = 5.95; 95% CI = 2.85–12.42). Angle crashes were also significantly associated with higher severity crashes versus no injury crashes (OR = 5.27; 95% CI = 2.50–11.11). Angle crashes were also significantly associated with large logging truck MV crashes compared to the same direction crashes in minor severity crashes versus no injury crashes (OR = 2.45; 95% CI = 1.40–4.28). The unadjusted odds ratio was statistically significant in rear-end crashes in large logging truck MV crashes compared to the same direction crashes in higher severity crashes versus no injury crashes (OR = 3.59; 95% CI = 1.75–7.38) and minor severity crashes versus no injury crashes (OR = 2.17; 95% CI = 1.31–3.61). The unadjusted odds ratio was statistically significant in large logging truck MV crashes where other vehicles drivers were at-fault, compared to large logging truck MV crashes where large logging truck drivers were at-fault, in higher severity crashes versus no injury crashes (OR = 2.85; 95% CI = 1.66–4.92).

Higher Severity (KAB) crashes versus no injury (O) crashes model (Table 5.4)

This section summarizes the crash factors that had significantly higher severity (KAB) crashes relative to no injury (O) crashes, given that the other crash factors in the model are held constant. Higher severity crashes had higher odds of the large logging truck driver not wearing a seatbelt (adjusted OR = 5.68; 95% CI = 1.53–21.09) than lower severity crashes. Higher severity crashes had a higher odds of the large logging truck being assigned a harmful event of run off the road to the right (adjusted OR = 2.69; 95% CI = 1.03-7.00) than crashes where the large logging trucks were not assigned a harmful event of run off the road to the right side. Higher severity crashes had higher odds of the large logging truck being assigned a harmful event of crossing the median or centerline (adjusted OR = 2.91; 95% CI = 1.37-6.19) compared to crashes where the large logging trucks were not assigned a harmful event of crossing the median or centerline. Higher severity crashes had higher odds of female drivers of other vehicles or second logging trucks (adjusted OR = 2.27; 95% CI = 1.37-3.75) than crashes involved in male drivers of other vehicles. Higher severity crashes had a higher odds of the other vehicle driver being assigned a violation of failure to yield (adjusted OR = 2.48; 95% CI = 1.21-5.12) compared to other vehicle drivers who did not receive a violation of failure to yield. Higher severity crashes had higher odds of the other vehicle driver being assigned a violation of driving to the left of center (adjusted OR = 17.73; 95% CI = 5.95-52.80) than other vehicle drivers who did not get a violation of driving to the left of center. Higher severity crashes had a higher odds of the other vehicle driver being assigned a violation of careless operation (adjusted OR = 3.91; 95% CI = 2.00-7.65) than other vehicle drivers who did not get a violation of careless operation. Higher severity crashes had a higher odds of the other vehicle being assigned a harmful event of run off the road to the right (adjusted OR = 2.73; 95% CI = 1.10-6.78) than crashes where the other vehicle being assigned a harmful event of run off the road to the right. Higher severity crashes had higher odds of the crashes happening in no daylight (adjusted OR = 2.58; 95% CI = 1.44-4.61) than crashes that happened in daylight. Higher severity crashes had a higher odds of head-on or opposite direction crashes (adjusted OR = 2.93; 95% CI = 1.25-6.90) than same direction crashes. Higher severity crashes had a higher odds of angle crashes (adjusted OR = 4.94; 95% CI = 2.21-11.06) than the same direction crashes. Higher severity crashes had a higher odds of rear-end crashes (adjusted OR = 3.65; 95% CI = 1.66-8.01) than same direction crashes.

Minor severity (C) crashes versus no injury (O) crashes model (Table 5.4)

This section summarizes the crash factors with significantly higher odds for minor severity (C) crashes relative to no injury (O) crashes. The other crash factors in the model were held constant. Minor severity crashes (C) had higher odds of the large logging truck driver being assigned a violation of careless operation (adjusted OR = 2.37; 95% CI = 1.28-4.40) compared to large logging truck drivers who did not get a violation of careless operation given the other variables in the model are held constant. Minor severity crashes had higher odds of the large logging truck being assigned a harmful event of crossing the median or centerline (adjusted OR = 2.11; 95% CI = 1.09-4.08) than large logging trucks that were not assigned a harmful event of crossed the median or centerline. Minor severity crashes (C) had higher odds in female drivers of other vehicles (adjusted OR = 2.56; 95% CI = 1.70-3.85) than crashes involving male drivers of other vehicles. The minor severity crashes (C) had a higher odds of the other vehicle driver being assigned a violation of failure to yield (adjusted OR = 2.05; 95% CI = 1.70-3.62) than other vehicle drivers who did not get a violation of failure to yield. Minor severity crashes (C) had a higher odds of the other vehicles being assigned a harmful event of run off the road to the left (adjusted OR = 3.76; 95% CI = 1.57-3.97) than other vehicles that were not assigned a harmful event of run off the road to the left. The minor severity crashes (C) had a higher odds of angle crashes (adjusted OR = 2.12; 95% CI = 1.16-3.87) than same direction crashes. The minor severity crashes (C) had a higher odds of rear-end crashes (adjusted OR = 2.40; 95% CI = 1.38-4.17) than same direction crashes.

Discussion

In Louisiana, from 2010 to 2018, almost 50.0% of the large logging truck crashes were two-vehicle (MV) crashes involving at least one large logging truck. About 118 of the MV crashes were higher severity crashes, and 177 MV crashes were minor severity crashes. Cole (2018) estimated that 70.2% of fatal crashes involved two vehicles, and at least one logging truck was involved. None of the previous studies analyzed the association between behavioral characteristics and crash severity in MV crashes involving large logging trucks.

Almost 3.0% of the large logging truck drivers and 5.5% of the other vehicle drivers failed to wear a seatbelt. No seatbelt use in large logging truck crashes was significantly associated with higher severity crashes, and minor severity crashes compared to no injury crashes. However, the findings must be interpreted cautiously because the number of crashes is low. Similar to the present analysis, Shipp et al. (2019) found an association between no seatbelt use and higher severity crashes in SV crashes in Louisiana (2010-2017). Limited literature has stratified the logging truck crashes by crash type and studied the crash factors separately for SV and MV, so it is challenging to compare the findings with available literature. The vast literature available shows that seatbelt use has a protective effect. Even though seatbelt use is mandatory for all vehicle drivers, only 56.0% of the logging truck drivers reported in a survey that they always wore seatbelts while driving (Carnahan, 2004).

Careless driving was the most common citation that large truck drivers received (10.5%) in MV crashes. Careless driving in large logging truck drivers was significantly associated with minor severity crashes compared to no injury crashes. Large logging truck drivers received a citation for careless driving more in SV crashes than MV crashes. Other vehicle drivers most commonly received failure to yield (15.3%) and careless driving (15.1%) citations. Careless driving in other vehicle drivers was significantly associated with higher severity crashes compared to no injury crashes. Other vehicle drivers who received a driving left of center citation were also significantly associated with higher severity crashes than no injury crashes. Large logging trucks are most commonly involved in crashes with passenger cars. The driver of small vehicle often suffers more severe injuries than large vehicle drivers.

The harmful event run off the road to the right was the most prevalent in higher severity crashes (11.9%) and minor severity crashes (7.3%) than no injury crashes (3.5%). There is no research available to compare the association between the severity of crashes and ROR in logging-related crashes. The present study estimated the significant association between higher severity crashes and harmful event ROR to the right side of the road in large logging trucks involved in MV crashes. Extensive research has been conducted to identify the relationship between crash factors, crash severity, and ROR crashes in large truck crashes. The reason for ROR in large truck crashes could be speeding, speeding on curve roads, wet and icy road surfaces, younger drivers, impaired drivers, fatigued and drowsy drivers (Davis et al., 2006; McGinnis et al., 2001; Liu & Subramanian, 2009; Roy & Dissanayake, 2011). The present study's data were too small to conduct a detailed association between crash factors and crash severity in ROR logging-related crashes. Other vehicles involved in MV crashes also experienced ROR to the right side and ROR to the road's left side. Since the other vehicles are primarily small with less mass for protection, and running off the road and striking an object or rolling over could lead to more severe injuries to occupants. Other vehicle ROR to the right were significantly associated with higher severity crashes, and other vehicle ROR to the left were significantly associated with minor severity crashes compared to no injury crashes.

Large logging trucks crossing the median or centerline during the crash were significantly associated with higher severity crashes and minor severity crashes, compared to no injury crashes. Vehicle crossing the median did affect crash severity. The reasons for a vehicle to cross the median could be the loss of vehicle control, adverse weather conditions, and road conditions (Lu et al., 2010). Donnell and Mason (2004) analyzed cross-median crashes (CMC) on Pennsylvania Interstate highways. They concluded that impairment from drugs, curve road, wet road surface, and average daily traffic (ADT) volume increased the odds of fatal crashes compared to no injury. The present study's data are insufficient to conduct a detailed association between crash factors and crash severity in CMC crashes.

Female drivers of other vehicles involved in MV crashes sustained higher severity and minor severity injuries than male drivers. There was a significant association in higher severity crashes and minor severity crashes. Duncan et al. (1998) analyzed rear-end crashes between heavy trucks and passenger cars and found that female drivers sustained more severe injuries than male drivers. Abdel-Aty (2003) also concluded that female drivers had a higher probability of increased severity of injury. The behavioral and average physiological differences between males and females may affect accident-injury severity (Ulfarsson & Mannering, 2004). Male drivers have a higher probability of being involved in more risk-taking and dangerous driving than female drivers (Amarasingha & Dissanayake, 2014; Butters et al., 2012). The present study concludes that male drivers were involved in more crashes, but female drivers sustained more severe injuries than male drivers.

The majority of MV crashes happened in daylight (79.4%). Cole (2018) analyzed FARS data for fatal crashes involving a logging truck and reported that 76.0% of those crashes happened in daylight from 2011 to 2015. Analysis of Central Florida crash data (1996-1997) indicated that crashes that happened in daylight were less injurious (Abdel-Aty, 2003). No daylight included dark with no streetlights, dark with a continuous streetlight, dark with streetlight at an intersection only, dusk and dawn. About 20.6% of large truck crashes happened in no daylight. The MV crashes in no daylight were significantly associated with higher severity crashes than no injury crashes. Zhu and Srinivasan (2011) analyzed LTCC data between April 2001 and December 2003 and reported similar findings that dark but lighted conditions (7:30 p.m. to 5:30 a.m.) lead to more severe crashes. Another study found that no daylight is a significant contributor to severe rollover crashes (Islam et al., 2016). Several studies have indicated that dark or limited lighting conditions could increase the crashes' injury severity (Helai et al., 2008; Chimba and Sando, 2009; Xie et al., 2009).

Extensive research shows that head-on crashes were the most severe crashes (Kockelman, 2001; Zhu & Srinivasan, 2011). Kotikalapudi and Dissanayake (2013) analyzed large truck crashes from Kansas Accident Reporting System (KARS) database (2004-2008) and indicated that head-on crashes were more severe than other types of crashes. This study found that head-on crashes had 1.60 times higher odds of leading to a more severe truck crash than other crash types (Kotikalapudi and Dissanayake, 2013). The present study found that the head-on or opposite direction crashes have almost three times higher odds of higher severity crashes than same direction crashes. Mannila (2006) analyzed the car-truck crash database from the General Estimate System of the National Sampling System (NSS GES) and FARS databases (2000-2004); and found that angle crashes contributed to the highest proportion of car-truck crashes. The present study found that higher severity crashes had almost five times higher odds of angle collisions than same direction crashes, and minor severity crashes had almost two times higher odds of angle crashes than same direction crashes.

Duncan et al. (1998) analyzed rear-end crashes between heavy trucks and passenger cars from Highway Safety Information System (HSIS) data from North Carolina (1993–1995). The truck rear-ended the car was involved in more severe injuries than the truck being struck in the rear (Duncan et al., 1998). The present study estimated that higher severity crashes had 3.7 times higher odds of rear-end crashes than same direction crashes. The minor severity crashes had 2.4 times higher odds of Rear-end crashes than same direction crashes.

The underreporting of non-fatal and less severe crashes can be an issue because drivers may avoid reporting the crash to avoid the involvement of insurance companies and the possibility of getting traffic citations (Farmer, 2003; Savolainen, Mannering, Lord, & Quddus, 2011). This underreporting of non-fatal and less severe injuries could lead to overestimating the odds of higher injury severity crashes and underestimating the lower severity crashes (Ye & Lord, 2011).

Another limitation is the misclassification of injury severity because police officers are not clinicians. The police officers classify fatal injury and no injury reasonably correctly. Part of the reason for better reporting fatalities is that fatal crashes are updated within 30 days of the incident with detailed information about the death (LaDOTD, 2005). However, misclassification of the severity of non-fatal crashes is more common (Farmers, 2003), with the classification of severity improving as injury severity increases when compared to hospital records (Agran, Castillo, & Winn, 1990; Aptel et al., 1999; Cercarelli, Rosman, & Ryan, 1996; Harris, 1990; Rosman & Knuiman, 1994). Grouping higher severity crashes into a broader category helps to reduce the need to precisely classify crashes into more refined severity categories, thus reducing misclassification.

Behavioral factors are difficult to measure based on the severity of a crash, traffic congestion, and police officers' training. For example, the use of seatbelts often has been misreported in the crash data. Seatbelt use in non-fatal crashes is often collected from vehicle occupants and could be overestimated (Farmers, 2003; Yamamoto, Hashiji, & Shankar, 2008). Another example is driver distraction reporting, which is challenging to measure and verify (National Highway Traffic Safety Administration, 2010). Distracted driving is often reported as unknown or missing, which leads to underreporting (Stutts & Hunter, 2003). Similarly, the misclassification of fatigue and impairment from alcohol and drugs is often an issue (Filtness et al, 2017; Radun et al., 2013; Mercer & Jeffery, 1995). This underreporting can lead to differential misclassification bias, causing the odds ratios to be towards the null value.

Conclusion

This study identified the driver's and behavioral factors associated with increased severity while controlling for vehicle and crash factors in MV crashes involving large logging trucks. The crash database was obtained from the Louisiana Department of Transportation and Development for 2010-2018.

Almost 50.0% of the large logging truck crashes involved at least one large logging truck in MV crashes. About 18.6% of MV crashes resulted in higher severity injuries, 27.8% minor injuries, and 53.6% no injuries. No seatbelt use, a harmful event ROR to the right side of the road, and a harmful event crossed median/centerline were associated with higher severity MV crashes than no injury crashes. The harmful event of crossed median/centerline was associated with minor severity MV crashes compared to no injury crashes. Compared to same direction crashes, this study found that head-on or opposite direction, angle, and rear-ended crashes were significantly associated with higher severity crashes than no injury crashes. Compared to same direction crashes, this study found that angle and rear-ended crashes were significantly associated with minor severity crashes compared to no injury crashes. Careless driving assigned to large logging truck drivers was significantly associated with minor severity crashes compared to no injury crashes.

This study's analysis shows that the crash characteristics differ by crash type and severity in MV crashes. The findings add information to the current literature to improve the understanding of driver characteristics and behaviors associated with the higher severity of large logging truck crashes. The findings can help direct future research and design a more targeted safety program for large logging truck drivers. However, the present study is focused on Louisiana's crash database, so the findings of this dissertation may not be generalizable to other locations and timeframes.

Table 5.1: Unadjusted associations between driver variables and higher crash severity for multiple vehicle crashes involving large logging truck in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Large Truck Driver Demographics							
Age (years)							
Less than 35	22 (18.6%)	36 (20.3%)	78 (22.9%)	1 (Ref.)		1 (Ref.)	
36-45	23 (19.5%)	42 (23.7%)	70 (20.5%)	1.16 (0.6-2.27)	0.654	1.30 (0.75-2.25)	0.350
46-55	46 (39.0%)	53 (29.9%)	100 (29.3%)	1.63 (0.91-2.94)	0.103	1.15 (0.69-1.92)	0.600
56 & above	27 (22.9%)	46 (26.0%)	93 (27.3%)	1.03 (0.54-1.95)	0.929	1.07 (0.63-1.82)	0.798
Gender [a]							
Male	117 (99.2%)	174 (98.3%)	336 (98.5%)	1 (Ref.)		1 (Ref.)	
Female	1 (0.9%)	3 (1.7%)	5 (1.5%)	0.57 (0.07-4.97)	0.614	1.16 (0.27-4.90)	0.842
Large Truck Driver Behaviors							
Distraction [a]							
Yes	30 (25.4%)	63 (35.6%)	132 (38.7%)	0.51 (0.32-0.81)	0.005	0.86 (0.59-1.27)	0.456
No	86 (72.9%)	106 (59.9%)	192 (56.3%)	1 (Ref.)		1 (Ref.)	
Unknown	2 (1.7%)	8 (4.5%)	17 (5.0%)	0.26 (0.06-1.16)	0.078	0.85 (0.36-2.04)	0.720
Fatigue [b]							
Yes	0 (0.0%)	0 (0.0%)	0 (0.0%)	N/A		N/A	
No	117 (99.2%)	175 (98.9%)	338 (99.1%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	2 (1.1%)	3 (0.9%)	0.96 (0.1-9.35)	0.974	1.29 (0.21-7.78)	0.783
Driver Seatbelt Use							
Used	107 (90.7%)	162 (91.5%)	317 (93.0%)	1 (Ref.)		1 (Ref.)	
Not Used	6 (5.1%)	8 (4.5%)	5 (1.5%)	3.56 (1.06-11.88)	0.039	3.13 (1.01-9.72)	0.048
Unknown	5 (4.2%)	7 (4.0%)	19 (5.6%)	0.78 (0.28-2.14)	0.629	0.72 (0.3-1.75)	0.470
Large Truck Driver Violations							
Failure to Yield							
Yes	10 (8.5%)	14 (7.9%)	25 (7.3%)	1.17 (0.54-2.52)	0.687	1.09 (0.55-2.15)	0.813
No	108 (91.5%)	163 (92.1%)	316 (92.7%)	1 (Ref.)		1 (Ref.)	
Following Too Closely [a]							
Yes	3 (2.5%)	16 (9.04%)	27 (7.9%)	0.30 (0.09-1.02)	0.054	1.16 (0.61-2.21)	0.661
No	115 (97.5%)	161 (91.0%)	314 (92.1%)	1 (Ref.)		1 (Ref.)	

Table 5.1 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Driving Left of Center							
Yes	11 (9.3%)	8 (4.5%)	8 (2.4%)	1.35 (0.5-3.64)	0.551	0.58 (0.19-1.82)	0.352
No	107 (90.7%)	169 (95.5%)	333 (97.7%)	1 (Ref.)		1 (Ref.)	
Driving Cutting In, Improper Passing [a]							
Yes	2 (1.7%)	3 (1.7%)	13 (3.8%)	0.44 (0.1-1.96)	0.278	0.44 (0.12-1.55)	0.198
No	116 (98.3%)	174 (98.3%)	328 (96.2%)	1 (Ref.)		1 (Ref.)	
Speeding [b]							
Yes	0 (0.0%)	1 (0.6%)	0 (0.0%)	N/A		N/A	
No	118 (100.0%)	176 (99.4%)	341 (100.0%)	1 (Ref.)		1 (Ref.)	
Careless Operation							
Yes	10 (8.5%)	28 (15.8%)	29 (8.5%)	1.00 (0.47-2.11)	0.992	2.02 (1.16-3.52)	0.013
No	108 (91.5%)	149 (84.2%)	312 (91.5%)	1 (Ref.)		1 (Ref.)	
Other vehicle Driver Demographics							
Age (years)							
Less than 35	52 (44.1%)	79 (44.6%)	124 (36.4%)	1 (Ref.)		1 (Ref.)	
36-45	17 (14.4%)	25 (14.1%)	70 (20.5%)	0.58 (0.31-1.08)	0.085	0.56 (0.33-0.96)	0.035
46-55	12 (10.2%)	26 (14.7%)	51 (15.0%)	0.56 (0.28-1.14)	0.109	0.80 (0.46-1.39)	0.427
56 & above	37 (31.4%)	47 (26.6%)	96 (28.2%)	0.92 (0.56-1.51)	0.740	0.77 (0.49-1.2)	0.250
Gender							
Male	70 (59.3%)	96 (54.2%)	241 (70.7%)	1 (Ref.)		1 (Ref.)	
Female	48 (40.7%)	81 (45.8%)	100 (29.3%)	1.65 (1.07-2.55)	0.024	2.03 (1.4-2.96)	0.000
Other vehicle Driver Behaviors							
Distraction							
Yes	55 (46.6%)	70 (39.6%)	104 (30.5%)	2.83 (1.77-4.55)	0.000	1.39 (0.95-2.05)	0.092
No	39 (33.1%)	101 (57.1%)	209 (61.3%)	1 (Ref.)		1 (Ref.)	
Unknown	24 (20.3%)	6 (3.4%)	28 (8.2%)	4.59 (2.41-8.74)	0.000	0.44 (0.18-1.11)	0.081
Fatigue [b]							
Yes	1 (0.9%)	0 (0.0%)	2 (0.6%)	1.69 (0.15-18.84)	0.670	N/A	0.989
No	99 (83.9%)	177 (100.0%)	335 (98.2%)	1 (Ref.)		1 (Ref.)	
Unknown	18 (15.3%)	0 (0.0%)	4 (1.2%)	15.23 (5.04-46.06)	0.000	N/A	0.986

Table 5.1 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Driver Seatbelt Use [a]							
Used	87 (73.7%)	162 (91.5%)	320 (93.8%)	1 (Ref.)		1 (Ref.)	
Not Used	24 (20.3%)	8 (4.5%)	3 (0.9%)	29.43 (8.66-100.01)	0.000	5.27 (1.38-20.12)	0.015
Unknown	7 (5.9%)	7 (4.0%)	18 (5.3%)	1.43 (0.58-3.53)	0.438	0.77 (0.31-1.88)	0.563
Other vehicle Driver Violations							
Failure to Yield							
Yes	18 (15.3%)	33 (18.6%)	46 (13.5%)	1.15 (0.64-2.08)	0.634	1.47 (0.90-2.40)	0.123
No	100 (84.8%)	144 (81.4%)	295 (86.5%)	1 (Ref.)		1 (Ref.)	
Following Too Closely [a]							
Yes	3 (2.5%)	4 (2.3%)	13 (3.8%)	0.66 (0.18-2.35)	0.520	0.58 (0.19-1.82)	0.352
No	115 (97.5%)	173 (97.7%)	328 (96.2%)	1 (Ref.)		1 (Ref.)	
Driving Left of Center							
Yes	23 (19.5%)	7 (4.0%)	7 (2.1%)	11.55 (4.81-27.74)	0.000	1.96 (0.68-5.69)	0.213
No	95 (80.5%)	170 (96.1%)	334 (98.0%)	1 (Ref.)		1 (Ref.)	
Driving Cutting In, Improper Passing [a]							
Yes	2 (1.7%)	4 (2.3%)	11 (3.2%)	0.52 (0.11-2.37)	0.396	0.69 (0.22-2.21)	0.536
No	116 (98.3%)	173 (97.7%)	330 (96.8%)	1 (Ref.)		1 (Ref.)	
Speeding [b]							
Yes	2 (1.7%)	0 (0.0%)	0 (0.0%)	N/A		N/A	
No	116 (98.3%)	177 (100.0%)	341 (100.0%)	1 (Ref.)		1 (Ref.)	
Careless Operation							
Yes	29 (24.6%)	28 (15.8%)	39 (11.4%)	2.52 (1.48-4.31)	0.001	1.46 (0.86-2.46)	0.160
No	89 (75.4%)	149 (84.2%)	302 (88.6%)	1 (Ref.)		1 (Ref.)	

Notes: (1) Abbreviation: Higher severity (KAB) crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Minor severity (C) crash includes crash severities classified as complaints or possible injury (C) and O injury includes no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI) .(2)[a] Insufficient sample size to compute additional statistics (if the cell size is less than 5). (3) [b] N/A = Odds ratio not calculated because zero cell size.

Table 5.2: Unadjusted associations between vehicle variables and higher crash severity for multiple vehicle crashes involving large logging truck in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Large Truck Characteristics							
Vehicle Defects Observed [a]							
Yes	5 (4.2%)	13 (7.3%)	23 (6.7%)	0.62 (0.23-1.67)	0.342	1.08 (0.53-2.19)	0.828
No	109 (92.4%)	162 (91.5%)	310 (90.9%)	1 (Ref.)		1 (Ref.)	
Unknown	4 (3.4%)	2 (1.1%)	8 (2.4%)	1.42 (0.42-4.82)	0.572	0.48 (0.1-2.28)	0.355
Vehicle Lighting Condition							
Headlights on or Daytime Running Lights	56 (47.5%)	62 (35.0%)	128 (37.5%)	1 (Ref.)		1 (Ref.)	
Headlights off	48 (40.7%)	100 (56.5%)	158 (46.3%)	0.69 (0.44-1.09)	0.113	1.31 (0.88-1.94)	0.183
Unknown	14 (11.9%)	15 (8.5%)	55 (16.1%)	0.58 (0.3-1.13)	0.111	0.56 (0.29-1.07)	0.082
Vehicle Age							
Less than 10 years	25 (21.2%)	34 (19.2%)	70 (20.5%)	1 (Ref.)		1 (Ref.)	
More than 10 years	93 (78.8%)	143 (80.8%)	271 (79.5%)	1.24 (0.57-2.69)	0.584	1.04 (0.54-1.98)	0.913
Large Truck Movement-Harmful Events							
Vehicle Overturn/Rollover [a]							
Yes	11 (9.3%)	11 (6.2%)	4 (1.2%)	8.66 (2.7-27.76)	0.000	5.58 (1.75-17.8)	0.004
No	107 (90.7%)	166 (93.8%)	337 (98.8%)	1 (Ref.)		1 (Ref.)	
Cargo/Equipment Loss or Shift [a]							
Yes	2 (1.7%)	4 (2.3%)	8 (2.4%)	0.72 (0.15-3.43)	0.678	0.96 (0.29-3.24)	0.951
No	116 (98.3%)	173 (97.7%)	333 (97.7%)	1 (Ref.)		1 (Ref.)	
Ran Off Road Right							
Yes	14 (11.9%)	13 (7.3%)	12 (3.5%)	3.69 (1.66-8.23)	0.001	2.17 (0.97-4.87)	0.059
No	104 (88.1%)	164 (92.7%)	329 (96.5%)	1 (Ref.)		1 (Ref.)	
Ran Off Road Left							
Yes	11 (9.3%)	8 (4.5%)	8 (2.4%)	4.28 (1.68-10.92)	0.002	1.97 (0.73-5.34)	0.183
No	107 (90.7%)	169 (95.5%)	333 (97.7%)	1 (Ref.)		1 (Ref.)	
Hit Standing Tree [a]							
Yes	1 (0.9%)	3 (1.7%)	4 (1.2%)	0.72 (0.08-6.51)	0.770	1.45 (0.32-6.56)	0.628
No	117 (99.2%)	174 (98.3%)	337 (98.8%)	1 (Ref.)		1 (Ref.)	

Table 5.2 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Crossed Median/Centerline							
Yes	18 (15.3%)	24 (13.6%)	25 (7.3%)	2.28 (1.19-4.34)	0.013	1.98 (1.10-3.59)	0.024
No	100 (84.8%)	153 (86.4%)	316 (92.7%)	1 (Ref.)		1 (Ref.)	
Large Truck Movement-Prior Movement							
Vehicle Ran Off Road [b]							
Yes	6 (5.1%)	5 (2.8%)	8 (2.4%)	2.23 (0.76-6.56)	0.146	1.20 (0.39-3.72)	0.753
No	111 (94.1%)	172 (97.2%)	330 (96.8%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	0 (0.0%)	3 (0.9%)	0.99 (0.10-9.63)	0.994	N/A	
Making Left Turn [b]							
Yes	6 (5.1%)	14 (7.9%)	32 (9.4%)	0.52 (0.21-1.27)	0.150	0.82 (0.43-1.58)	0.557
No	111 (94.1%)	163 (92.1%)	306 (89.7%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	0 (0.0%)	3 (0.9%)	0.92 (0.09-8.93)	0.942	N/A	
Crossed Median or Center Line into Opposite Lane [b]							
Yes	15 (12.7%)	13 (7.3%)	23 (6.7%)	2.01 (1.01-4)	0.046	1.09 (0.54-2.2)	0.819
No	102 (86.4%)	164 (92.7%)	315 (92.4%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	0 (0.0%)	3 (0.9%)	1.03 (0.11-10.01)	0.980	N/A	
Large Truck Movement-Reason for Movement							
To Avoid Other Vehicle [b]							
Yes	16 (13.6%)	10 (5.7%)	29 (8.5%)	1.7 (0.89-3.27)	0.108	0.64 (0.31-1.35)	0.246
No	101 (85.6%)	167 (94.4%)	312 (91.5%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	0 (0.0%)	0 (0.0%)	N/A		N/A	
Vehicle Out of Control, Not Passing [b]							
Yes	1 (0.9%)	1 (0.6%)	0 (0.0%)	N/A		N/A	
No	116 (98.3%)	176 (99.4%)	341 (100.0%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	0 (0.0%)	0 (0.0%)	N/A		N/A	

Table 5.2 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Large Truck Movement-Traffic Control							
Stop Sign							
Yes	7 (5.9%)	13 (7.3%)	23 (6.7%)	0.87 (0.36-2.09)	0.758	1.10 (0.54-2.22)	0.799
No	111 (94.1%)	164 (92.7%)	318 (93.3%)	1 (Ref.)		1 (Ref.)	
Yellow No Passing Line							
Yes	39 (33.1%)	59 (33.3%)	116 (34.0%)	0.96 (0.61-1.49)	0.848	0.97 (0.66-1.42)	0.876
No	79 (67.0%)	118 (66.7%)	225 (66.0%)	1 (Ref.)		1 (Ref.)	
White Dashed Line							
Yes	25 (21.2%)	35 (19.8%)	72 (21.1%)	1.00 (0.60-1.68)	0.987	0.92 (0.59-1.45)	0.721
No	93 (78.8%)	142 (80.2%)	269 (78.9%)	1 (Ref.)		1 (Ref.)	
Yellow Dashed Line							
Yes	27 (22.9%)	38 (21.5%)	43 (12.6%)	2.06 (1.2-3.51)	0.008	1.89 (1.17-3.06)	0.009
No	91 (77.1%)	139 (78.5%)	298 (87.4%)	1 (Ref.)		1 (Ref.)	
No Control							
Yes	8 (6.8%)	11 (6.2%)	18 (5.3%)	1.31 (0.55-3.09)	0.544	1.19 (0.55-2.58)	0.661
No	110 (93.2%)	166 (93.8%)	323 (94.7%)	1 (Ref.)		1 (Ref.)	
Other vehicle Characteristics							
Vehicle Defects Observed [b]							
Yes	0 (0.0%)	2 (1.1%)	0 (0.0%)	N/A		N/A	
No	118 (100.0%)	175 (98.9%)	341 (100.0%)	1 (Ref.)		1 (Ref.)	
Unknown	0 (0.0%)	0 (0.0%)	0 (0.0%)	N/A		N/A	
Vehicle Lighting Condition							
Headlights on or Daytime Running Lights	57 (48.3%)	74 (41.8%)	130 (38.1%)	1 (Ref.)		1 (Ref.)	
Headlights off	40 (33.9%)	86 (48.6%)	155 (45.5%)	0.59 (0.37-0.94)	0.026	0.97 (0.66-1.44)	0.897
Unknown	21 (17.8%)	17 (9.6%)	56 (16.4%)	0.86 (0.47-1.54)	0.604	0.53 (0.29-0.98)	0.044
Other vehicle Movement-Harmful Events							
Vehicle Overturn/Rollover [a]							
Yes	9 (7.6%)	6 (3.4%)	1 (0.3%)	28.07 (3.52-224.08)	0.002	11.93 (1.42-99.88)	0.022
No	109 (92.4%)	171 (96.6%)	340 (99.7%)	1 (Ref.)		1 (Ref.)	

Table 5.2 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Cargo/Equipment Loss or Shift [b]							
Yes	2 (1.7%)	0 (0.0%)	5 (1.5%)	1.16 (0.22-6.05)	0.862	N/A	
No	116 (98.3%)	177 (100.0%)	336 (98.5%)	1 (Ref.)		1 (Ref.)	
Ran Off Road Right							
Yes	15 (12.7%)	12 (6.8%)	13 (3.8%)	3.67 (1.69-7.98)	0.001	1.83 (0.82-4.11)	0.140
No	103 (87.3%)	165 (93.2%)	328 (96.2%)	1 (Ref.)		1 (Ref.)	
Ran Off Road Left							
Yes	9 (7.6%)	18 (10.2%)	10 (2.9%)	2.73 (1.08-6.90)	0.033	3.75 (1.69-8.30)	0.001
No	109 (92.4%)	159 (89.8%)	331 (97.1%)	1 (Ref.)		1 (Ref.)	
Hit Standing Tree [a]							
Yes	3 (2.5%)	2 (1.1%)	3 (0.9%)	2.94 (0.59-14.77)	0.191	1.29 (0.21-7.78)	0.783
No	115 (97.5%)	175 (98.9%)	338 (99.1%)	1 (Ref.)		1 (Ref.)	
Crossed Median/Centerline							
Yes	30 (25.4%)	27 (15.3%)	37 (10.9%)	2.80 (1.64-4.79)	0.000	1.48 (0.87-2.52)	0.150
No	88 (74.6%)	150 (84.8%)	304 (89.2%)	1 (Ref.)		1 (Ref.)	
Other vehicle Movement-Prior Movement							
Vehicle Ran Off Road [a]							
Yes	3 (2.5%)	7 (4.0%)	3 (0.9%)	2.90 (0.58-14.59)	0.196	4.62 (1.18-18.11)	0.028
No	114 (96.6%)	167 (94.4%)	331 (97.1%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	3 (1.7%)	7 (2.1%)	0.41 (0.05-3.41)	0.413	0.85 (0.22-3.33)	0.815
Making Left Turn [a]							
Yes	10 (8.5%)	27 (15.3%)	37 (10.9%)	0.75 (0.36-1.56)	0.442	1.47 (0.86-2.51)	0.154
No	107 (90.7%)	147 (83.1%)	297 (87.1%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	3 (1.7%)	7 (2.1%)	0.40 (0.05-3.26)	0.390	0.87 (0.22-3.40)	0.836
Crossed Median or Center Line into Opposite Lane [a]							
Yes	28 (23.7%)	14 (7.9%)	16 (4.7%)	6.25 (3.24-12.07)	0.000	1.74 (0.83-3.65)	0.144
No	89 (75.4%)	160 (90.4%)	318 (93.3%)	1 (Ref.)		1 (Ref.)	
Unknown	1 (0.9%)	3 (1.7%)	7 (2.1%)	0.51 (0.06-4.20)	0.532	0.85 (0.22-3.34)	0.818

Table 5.2 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Other vehicle Movement-Reason for Movement							
To Avoid Other Vehicle [b]							
Yes	5 (4.2%)	12 (6.8%)	18 (5.3%)	0.83 (0.30-2.29)	0.720	1.29 (0.61-2.75)	0.504
No	107 (90.7%)	165 (93.2%)	320 (93.8%)	1 (Ref.)		1 (Ref.)	
Unknown	6 (5.1%)	0 (0.0%)	3 (0.9%)	5.97 (1.47-24.29)	0.013	N/A	
Vehicle Out of Control, Not Passing [b]							
Yes	1 (0.9%)	0 (0.0%)	1 (0.3%)	3.04 (0.19-48.95)	0.434	NA	
No	111 (94.1%)	177 (100.0%)	337 (98.8%)	1 (Ref.)		1 (Ref.)	
Unknown	6 (5.1%)	0 (0.0%)	3 (0.9%)	6.08 (1.49-24.7)	0.012	N/A	
Other vehicle Movement-Traffic Control							
Stop Sign							
Yes	12 (10.2%)	18 (10.2%)	29 (8.5%)	1.22 (0.6-2.47)	0.585	1.22 (0.66-2.26)	0.532
No	106 (89.8%)	159 (89.8%)	312 (91.5%)	1 (Ref.)		1 (Ref.)	
Yellow No Passing Line							
Yes	39 (33.1%)	46 (26.0%)	98 (28.7%)	1.22 (0.78-1.92)	0.378	0.87 (0.58-1.31)	0.508
No	79 (67.0%)	131 (74.0%)	243 (71.3%)	1 (Ref.)		1 (Ref.)	
White Dashed Line							
Yes	23 (19.5%)	39 (22.0%)	74 (21.7%)	0.87 (0.52-1.47)	0.613	1.02 (0.66-1.58)	0.931
No	95 (80.5%)	138 (78.0%)	267 (78.3%)	1 (Ref.)		1 (Ref.)	
Yellow Dashed Line							
Yes	23 (19.5%)	37 (20.9%)	45 (13.2%)	1.59 (0.92-2.77)	0.099	1.74 (1.08-2.81)	0.024
No	95 (80.5%)	140 (79.1%)	296 (86.8%)	1 (Ref.)		1 (Ref.)	
No Control							
Yes	10 (8.5%)	16 (9.04%)	24 (7.04%)	1.22 (0.57-2.64)	0.608	1.31 (0.68-2.54)	0.419
No	108 (91.5%)	161 (91.0%)	317 (93.0%)	1 (Ref.)		1 (Ref.)	

Notes: (1) Abbreviation: Higher severity (KAB) crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Minor severity (C) crash includes crash severities classified as complaints or possible injury (C) and O injury includes no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI). (2)[a] Insufficient sample size to compute additional statistics (if the cell size is less than 5). (3) [b] N/A = Odds ratio not calculated because zero cell size.

Table 5.3: Unadjusted associations between crash variables and higher crash severity for multiple vehicle crashes involving large logging truck in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Crash Time							
Morning	24 (20.3%)	59 (33.3%)	94 (27.6%)	1 (Ref.)		1 (Ref.)	
Afternoon	27 (22.9%)	39 (22.0%)	89 (26.1%)	1.19 (0.64-2.21)	0.587	0.70 (0.42-1.15)	0.157
Evening	6 (5.1%)	11 (6.2%)	26 (7.6%)	0.90 (0.33-2.44)	0.842	0.67 (0.31-1.47)	0.319
Night	18 (15.3%)	10 (5.7%)	24 (7.0%)	2.94 (1.38-6.27)	0.005	0.66 (0.30-1.49)	0.319
Unknown	43 (36.4%)	58 (32.8%)	108 (31.7%)	1.56 (0.88-2.76)	0.127	0.86 (0.54-1.35)	0.503
Crash Year							
2010	14 (11.9%)	23 (13.0%)	46 (13.5%)	1 (Ref.)		1 (Ref.)	
2011	14 (11.9%)	15 (8.5%)	46 (13.5%)	1.00 (0.43-2.33)	1.000	0.65 (0.3-1.41)	0.275
2012	9 (7.6%)	19 (10.7%)	27 (7.9%)	1.10 (0.42-2.87)	0.853	1.41 (0.65-3.04)	0.385
2013	11 (9.3%)	19 (10.7%)	35 (10.3%)	1.03 (0.42-2.55)	0.944	1.09 (0.51-2.3)	0.830
2014	8 (6.8%)	19 (10.7%)	42 (12.3%)	0.63 (0.24-1.64)	0.341	0.90 (0.43-1.89)	0.790
2015	17 (14.4%)	20 (11.3%)	36 (10.6%)	1.55 (0.68-3.56)	0.300	1.11 (0.53-2.33)	0.781
2016	19 (16.1%)	24 (13.6%)	37 (10.9%)	1.69 (0.75-3.81)	0.208	1.30 (0.63-2.66)	0.477
2017	14 (11.9%)	19 (10.7%)	33 (9.7%)	1.39 (0.59-3.31)	0.452	1.15 (0.54-2.45)	0.714
2018	12 (10.2%)	19 (10.7%)	39 (11.4%)	1.01 (0.42-2.44)	0.981	0.97 (0.46-2.05)	0.945
Day of the Week							
Weekday	111 (94.1%)	171 (96.6%)	317 (93.0%)	1.20 (0.50-2.86)	0.680	2.16 (0.87-5.38)	0.099
Weekend	7 (5.9%)	6 (3.4%)	24 (7.04%)	1 (Ref.)		1 (Ref.)	
Clear Weather Conditions							
Yes	85 (72.0%)	141 (79.7%)	274 (80.4%)	1 (Ref.)		1 (Ref.)	
No	33 (28.0%)	36 (20.3%)	67 (19.7%)	1.59 (0.98-2.57)	0.06	1.04 (0.66-1.64)	0.852
Daylight							
Yes	80 (67.8%)	151 (85.3%)	292 (85.6%)	1 (Ref.)		1 (Ref.)	
No	38 (32.2%)	26 (14.7%)	49 (14.4%)	2.83 (1.73-4.62)	0.000	1.03 (0.61-1.72)	0.922
Road Surface Condition-Dry							
Yes	102 (86.4%)	161 (91.0%)	309 (90.6%)	1 (Ref.)		1 (Ref.)	
No	16 (13.6%)	16 (9.04%)	32 (9.4%)	1.51 (0.8-2.87)	0.204	0.96 (0.51-1.8)	0.898
Road Surface Type-Blacktop							
Yes	99 (83.9%)	147 (83.1%)	272 (79.8%)	1 (Ref.)		1 (Ref.)	
No	19 (16.1%)	30 (17.0%)	69 (20.2%)	1.32 (0.76-2.31)	0.327	1.24 (0.77-2)	0.368

Table 5.3 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636)						
	Higher severity (KAB) Crash n (Col%) (n=118)	Minor Severity (C) Crash n (Col%) (n=177)	No injury or property damage only (O) Crash n (Col%) (n=341) (Base outcome)	Higher Severity (KAB) Crash		Minor Severity (C) Crash	
				Unadjusted OR (95% CI)	P-value	Unadjusted OR (95% CI)	P-value
Road Alignment							
Straight	91 (77.1%)	150 (84.8%)	298 (87.4%)	1 (Ref.)		1 (Ref.)	
Curved	27 (22.9%)	27 (15.3%)	43 (12.6%)	2.06 (1.20-3.51)	0.008	1.25 (0.74-2.1)	0.404
Manner Of Collision							
Same direction	12 (10.2%)	35 (19.8%)	104 (30.5%)	1 (Ref.)		1 (Ref.)	
Head-on or opposite direction	35 (29.7%)	25 (14.1%)	51 (15.0%)	5.95 (2.85-12.42)	0.000	1.46 (0.79-2.69)	0.229
Angle	31 (26.3%)	42 (23.7%)	51 (15.0%)	5.27 (2.50-11.11)	0. 000	2.45 (1.40-4.28)	0.002
Rear-end	34 (28.8%)	60 (33.9%)	82 (24.1%)	3.59 (1.75-7.38)	0. 000	2.17 (1.31-3.61)	0.003
Other or Unknown	6 (5.1%)	15 (8.5%)	53 (15.5%)	0.98 (0.35-2.76)	0.971	0.84 (0.42-1.68)	0.622
Road Type No Physical Barrier							
Yes	29 (24.6%)	50 (28.3%)	92 (27.0%)	1.13 (0.7-1.84)	0.610	0.94 (0.63-1.41)	0.759
No	89 (75.4%)	127 (71.8%)	249 (73.0%)	1 (Ref.)		1 (Ref.)	
Location Type							
Manufacturing or Industrial or business area	33 (28.0%)	67 (37.9%)	151 (44.3%)	0.46 (0.28-0.77)	0.003	0.74 (0.48-1.14)	0.176
Residential related area	45 (38.1%)	57 (32.2%)	95 (27.9%)	1 (Ref.)		1 (Ref.)	
Open country	40 (33.9%)	53 (29.9%)	95 (27.9%)	0.89 (0.53-1.48)	0.652	0.93 (0.58-1.49)	0.761
Intersection							
Yes	30 (25.4%)	49 (27.7%)	119 (34.9%)	0.64 (0.4-1.02)	0.059	0.71 (0.48-1.06)	0.097
No	88 (74.6%)	128 (72.3%)	222 (65.1%)	1 (Ref.)		1 (Ref.)	
Highway Type							
Interstate and US highway	44 (37.3%)	67 (37.9%)	128 (37.5%)	1 (Ref.)		1 (Ref.)	
State highway	65 (55.1%)	100 (56.5%)	175 (51.3%)	1.08 (0.69-1.69)	0.733	1.09 (0.74-1.6)	0.655
Other (Parish Road, City Street)	9 (7.6%)	10 (5.7%)	38 (11.1%)	0.69 (0.31-1.54)	0.363	0.5 (0.24-1.07)	0.075
Impairment- Alcohol Estimates [b]							
Yes	6 (5.1%)	0 (0.0%)	4 (1.2%)	4.52 (1.25-16.30)	0.021	N/A	
No	112 (94.9%)	177 (100.0%)	337 (98.8%)	1 (Ref.)		1 (Ref.)	
At Fault							
1st Logging truck driver	23 (19.5%)	63 (35.6%)	142 (41.6%)	1 (Ref.)		1 (Ref.)	
2nd logging or Other vehicle driver	55 (46.6%)	73 (41.2%)	119 (34.9%)	2.85 (1.66-4.92)	0.000	1.38 (0.91-2.1)	0.127
Both or Unclear	40 (33.9%)	41 (23.2%)	80 (23.5%)	3.09 (1.73-5.52)	0.000	1.16 (0.72-1.87)	0.555

Notes: (1) Abbreviation: Higher severity (KAB) crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Minor severity (C) crash includes crash severities classified as complaints or possible injury (C) and O injury includes no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI) . (2) [b] N/A = Odds ratio not calculated because zero cell size.

Table 5.4: Adjusted associations between driver variables and higher crash severity for multiple vehicle crashes involving large logging truck in Louisiana (2010-2018)

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636) No injury or property damage only (O) (Base outcome)			
	Higher severity (KAB) Crash n (Col%) (n=118)		Minor Severity (C) Crash n (Col%) (n=177)	
	Adjusted OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Large Truck Driver Behaviors				
Driver Seatbelt Use				
Used	1 (Ref.)		1 (Ref.)	
Not Used	5.68 (1.53-21.09)	0.009	3.18 (0.96-10.54)	0.058
Unknown	1.36 (0.44-4.16)	0.593	0.83 (0.33-2.12)	0.625
Large Truck Driver Violations				
Careless Operation				
Yes	1.95 (0.83-4.57)	0.123	2.37 (1.28-4.40)	0.006
No	1 (Ref.)		1 (Ref.)	
Large Truck Movement-Harmful Events				
Ran Off Road Right				
Yes	2.69 (1.03-7.00)	0.043	2.08 (0.87-4.96)	0.099
No	1 (Ref.)		1 (Ref.)	
Crossed Median/Centerline				
Yes	2.91 (1.37-6.19)	0.006	2.11 (1.09-4.08)	0.027
No	1 (Ref.)		1 (Ref.)	
Other vehicle Driver Demographics				
Gender				
Male	1 (Ref.)		1 (Ref.)	
Female	2.27 (1.37-3.75)	0.001	2.56 (1.70-3.85)	0.000
Other vehicle Driver Violations				
Failure to Yield				
Yes	2.48 (1.21-5.12)	0.014	2.05 (1.70-3.62)	0.013
No	1 (Ref.)		1 (Ref.)	
Driving Left of Center				
Yes	17.73 (5.95-52.80)	0.000	2.97 (0.91-9.68)	0.072
No	1 (Ref.)		1 (Ref.)	
Careless Operation				
Yes	3.91 (2.00-7.65)	0.000	1.74 (0.96-3.17)	0.072
No	1 (Ref.)		1 (Ref.)	
Other vehicle Movement-Harmful Events				
Ran Off Road Right				
Yes	2.73 (1.10-6.78)	0.030	1.66 (0.70-3.97)	0.251
No	1 (Ref.)		1 (Ref.)	
Ran Off Road Left				
Yes	2.12 (0.75-5.99)	0.157	3.76 (1.57-9.00)	0.003
No	1 (Ref.)		1 (Ref.)	

Table 5.4 Continued

Independent Variable	Large logging truck crashes (multiple vehicles) (n=636) No injury or property damage only (O) (Base outcome)			
	Higher severity (KAB) Crash n (Col%) (n=118)		Minor Severity (C) Crash n (Col%) (n=177)	
	Adjusted OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Crash Characteristics				
Daylight				
Yes	1 (Ref.)		1 (Ref.)	
No	2.58 (1.44-4.61)	0.001	1.10 (0.63-1.92)	0.749
Manner Of Collision				
Same direction	1 (Ref.)		1 (Ref.)	
Head-on or opposite direction	2.93 (1.25-6.90)	0.014	1.34 (0.68-2.64)	0.394
Angle	4.94 (2.21-11.06)	0.000	2.12 (1.16-3.87)	0.014
Rear-end	3.65 (1.66-8.01)	0.001	2.40 (1.38-4.17)	0.002
Other or Unknown	0.97 (0.32-2.98)	0.959	0.86 (0.41-1.80)	0.689

Notes: (1) Abbreviation: Higher severity (KAB) crash includes crash severities classified fatal (K), Severe (A), or Moderate (B) severity; Minor severity (C) crash includes crash severities classified as complaints or possible injury (C) and O injury includes no injury or property damage only (O). Odds Ratio (OR) and Confidence interval (CI).

CHAPTER VI

SUMMARY

Introduction

This dissertation examined associations between driver, vehicle, and crash factors and crash severity, stratified by vehicle type and crash type, using data from the Louisiana Department of Transportation and Development from 2010-2018. The two specific aims of this dissertation were

1. Determine whether driver, vehicle, and crash factors are associated with crash severity (higher severity versus lower severity) in large logging and non-logging truck crashes, stratified by crash type (single versus multiple vehicles), using data from the Louisiana Department of Transportation and Development from 2010-2018; and
2. Estimate the associations between driver characteristics and behaviors and higher crash severity, stratified by crash type (single and multi-vehicle crashes) in large logging truck crashes while adjusting for vehicle and crash variables, using data from the Louisiana Department of Transportation and Development from 2010-2018.

Addressing Specific aims

This subsection will discuss how the two specific aims were addressed in this dissertation.

Aim 1

For specific aim 1A and 1B, the null hypothesis was that there are no statistically significant associations between driver, vehicle, and crash variables and crash severity (higher severity versus lower severity) in large logging and non-logging truck crashes for single-vehicle crashes or multi-vehicle crashes, in Louisiana from 2010-2018.

For specific aim 1A and aim 1B, the dependent variable was binary and classified as higher crash severity (KAB) crashes and lower severity crashes (CO).

A false discovery rate post hoc analysis was conducted to examine the issue of multiple comparisons between crash characteristics and crash severity (KAB versus CO crash severity) by crash type (single versus multiple vehicle crashes) in large logging trucks and non-logging truck crashes. The Pearson chi-square test was used to determine whether there is a statistically significant relationship between crash characteristics (all variables are either binary or categorical) and crash severity (KAB versus CO crash severity) by crash type (single versus multiple vehicle crashes) in large logging (Aim 1A) and non-logging truck crashes (Aim 1B). After analyzing chi-square or Fisher's exact test results, the false discovery rate was computed and interpreted.

Aim 2

Aim 2 estimated the associations between driver characteristics and behaviors and higher crash severity, stratified by crash type (single and multi-vehicle crashes) in large logging truck crashes while adjusting for vehicle and crash variables, using data from the Louisiana Department of Transportation and Development from 2010-2018.

For specific aim 2A, the dependent variable was binary and classified as higher severity crashes (KAB) and lower severity crashes (CO). A binary logistic regression model was constructed to identify the associated driver, and behavioral crash characteristics in higher severity crashes involving only the large logging truck after adjusting the model for vehicle and environmental factors. The final results were interpreted using adjusted odds ratios and 95% confidence intervals.

For specific aim 2B, the dependent variable was categorical and classified as higher severity crashes (KAB), minor severity crashes (C), and no injury or property damage crashes (O). Multinomial logistic regression was utilized to identify the associations between driver and behavioral factors and higher crash severity in multi-vehicle crashes involving large logging trucks while adjusting the model for vehicle and crash factors. The Hausman test and suest-based Hausman test were conducted to determine if the MNL specification is appropriate for the use of the model. The final results were interpreted using adjusted odds ratios and 95% confidence intervals.

Summary of Findings

Characterize crash factors in large logging-related crashes

Limited literature is available that compares crash characteristics by crash severity for large logging and non-logging truck crashes. The present study provides new information indicating that crash characteristics differ significantly by crash severity and crash type in large logging and non-logging truck crashes in Louisiana from 2010 to 2018.

This study identified and compared the crash factors in SV and MV crashes by type of crash severity. Overall, there is a difference in crash factors associated with higher severity crashes for SV and MV crashes taken separately. Distracted driving, lack of seatbelt use, careless driving, and a truck that ran off the road to the left side were more prevalent in higher severity SV crashes than lower severity SV crashes. Truck drivers involved in higher severity MV crashes were associated with truck rollover, truck ROR to the right side, and truck ROR to the left side. Other vehicle drivers involved in higher severity MV crashes were more often coded with distracted driving, no seatbelt use, citation for driving left of center, and a citation for careless driving. However, the current study only examined bivariate associations. Consequently, future research should focus on identifying the factors most strongly associated with higher severity crashes after statistical adjustment using multiple logistic regression.

Characterize crash factors in large non-logging related crashes

SV large non-logging truck crashes have different crash characteristics associated with higher severity crashes than MV crashes. Factors include a higher proportion of impaired driving, driving while fatigued, no seatbelt use, careless driving, and speeding in higher severity SV crashes. These behavioral factors are associated with higher severity SV crashes. Other crash factors which had a higher proportion of higher severity SV crashes were truck rollover, cargo shift, ROR to the right or left, hitting a stationary tree, crossing median or centerline, and hitting pedestrians. A greater proportion of higher severity SV crashes happened in clear weather, on dry road surfaces, on blacktop roads, and Interstate and U.S. highways compared to lower severity crashes.

Driver fatigue and not wearing a seatbelt at the time of the crash led to a greater proportion of higher severity MV crashes than lower severity crashes. A higher proportion of older large non-logging trucks were involved in higher severity MV crashes than lower severity MV crashes. MV crashes that experienced rollover, ROR to the right or left, hitting a stationary tree, crossing median or centerline, and hitting pedestrians could be associated with higher severity crashes. MV crashes on weekends, curve roads, blacktop roads, and Interstate and U.S. highways could be related to higher severity crashes. A smaller proportion of impaired drivers were involved in MV crashes, but most sustained higher severity injuries. Rear-end, head-on, opposite direction, and angle collisions could be associated with higher severity MV crashes. This study provides baseline information for future in-depth research to compare the crash characteristics in higher severity crashes in large logging and non-logging truck crashes.

Association between behavioral factors in single large logging truck crashes

More than 40% of the large logging truck crashes in Louisiana from 2010 to 2018 were SV. The no seatbelt use, careless driving, and harmful event running off the road to the left side were associated with higher severity SV crashes.

Association between behavioral factors in multiple-vehicle crashes involving a large logging truck

Almost 50.0% of the large logging truck crashes involved two vehicles and at least one of the vehicles was large logging truck in Louisiana from 2010 to 2018. About 18.6% of MV crashes resulted in higher severity injuries, 27.8% minor injuries, and

53.6% no injuries. The no seatbelt use, harmful event ROR to the right side of the road, and harmful event crossed median/centerline were associated with higher severity MV crashes compared to no injury crashes. Harmful event crossed median/centerline was associated with minor severity MV crashes compared to no injury crashes. In comparison to same direction collision, this study found that head-on or opposite direction, angle, and rear-ended collisions were significantly associated with higher severity crashes than no injury crashes. Compared to same direction collisions, this study found that angle and rear-ended collisions were significantly associated with minor severity crashes compared to no injury crashes. Careless driving assigned to large logging truck drivers was significantly associated with minor severity crashes compared to no injury crashes.

Limitations

This section discusses the potential limitations which are associated with crash database analysis. The collection of data on roadway crashes presents several challenges. For example, not all police officers receive the same training. This lack of uniformity could result in variations in how they report roadway crashes, with the same crash factors and conditions being recorded differently by different police officers. Time on-scene may be limited for two reasons: fatal or severe injuries will require an officer’s immediate attention and coordination with other first responders, and the crash may cause traffic congestion that needs to be cleared (Farmers, 2003). As a result, the officer or officers on the scene may not have the time to collect all the information about the crash to complete the crash report fully and correctly. Conversely, fatal and more severe crashes often receive more scrutiny and investigation, which can improve the correct recording of data fields on the crash report.

Previous literature on crash data analysis suggests the potential underreporting of non-fatal and less severe crashes. No injury or minor injury crashes are less likely to be reported to police to avoid the involvement of insurance companies and the possibility of getting traffic citations (Farmer, 2003; Savolainen, Mannering, Lord, & Quddus, 2011). The underreporting of no injury and less severe injuries could lead to overestimating the odds of factors associated with higher injury severity crashes and underestimating frequency of lower severity crashes (Ye & Lord, 2011).

Misclassification of injury severity can be an issue, as law enforcement officers are not clinicians. The police officers identify fatal injury and no injury reasonably accurately, but they can misclassify various types of non-fatal injury (Farmers, 2003). Fatal crashes get updated within 30 days of the incident with detailed information about the death (LaDOTD, 2005). Except in the case of fatal crashes, the police reports may not classify the injuries as accurately as medical providers. The accuracy of the reporting rate for fatalities ranged from 85 to100% (Aptel et al., 1999; Blincoe et al., 2002). The accuracy of police reports improves as injury severity increases compared to hospital records (Agran, Castillo, & Winn, 1990; Aptel et al., 1999; Cercarelli, Rosman, & Ryan, 1996; Harris, 1990; Rosman & Knuiman, 1994).

Historically, misclassification of severe injuries was more common when the victims were males and elderly drivers rather than female and younger drivers (Farmer, 2003), but this may not be true for current trends with advances in reporting technologies. The misclassification between possible and no injury levels could affect the parameter estimates (Winston et al., 2006). Hausman, Abrevaya, & Scott-Morton (1998) developed correction procedures to analyze misclassification in discrete data. This procedure was applied by Winston et al. (2006), and the authors found that misclassification was not a significant factor in their study. The grouping of injury severity levels into two broad categories as injury (fatal, severe, and moderate injury) and no injury (possible or no injury) can reduce the misclassification bias (Winston et al., 2006).

For various reasons, the use of seat belts has been misreported in the crash data. Seatbelt use in non-fatal crashes could be overestimated, as police collect this information often from vehicle occupants (Farmers, 2003; Yamamoto, Hashiji, & Shankar, 2008), who may not be telling the truth to avoid penalties.

The information about driver distraction is complicated to collect, and the data often are unknown or missing. In general, driver distraction and inattention are likely to be underreported (Stutts & Hunter, 2003), as these factors are difficult to verify and measure (National Highway Traffic Safety Administration, 2010). In addition, police officers have to choose from the list of different types of distractions (e.g., cell phone, other distractions inside or outside the vehicle) and may be mistaken in their choice. To partially address this issue, the different types of distraction often are grouped into a single distraction variable.

Misclassification of fatigue is common due to the difficulty of observing and identifying this behavior (Filtness, Armstrong, Watson, & Smith, 2017; Radun, Radun, Ohisalo, Wahde, & Kecklund, 2013). The impairment from alcohol and drugs often is misclassified as alcohol-only impairment. Drug-only impairment often is mistaken for driving without attention (Mercer & Jeffery, 1995). Kim (1999) compared police crash reports and hospital records and found that police crash records underreported the alcohol involvement rate.

The posted speed limit provides no information about the vehicle's actual speed at the time of the crash unless a police officer report speeding as a contributing factor. The posted speed limit variable was not used as a proxy for speeding as a contributing factor.

Police also may not be aware that the collected data are used for research. Another complication is that the crash report form is not designed with research as the primary objective, so the research is limited to the data collected on the crash report.

Misclassification of crash data is a concern because the overall prevalence of behaviors and characteristics can be underestimated. In addition, misclassification can bias point estimates for the association between exposure variables and higher crash severity, the outcome variable. If misclassification is differential, then the odds ratio would be biased toward the null. However, if the misclassification is differed by the categories of the outcome variable, then the odds ratio would be biased away from the null.

The findings of this dissertation need to be carefully interpreted since data are limited to only one state, and the analysis plan was designed specifically for this study. In summary, this dissertation examines the most recent crash data (2010-2018) for Louisiana only, and findings from this study may not be generalizable to other locations and times.

Public Health Significance

The number of logging-related crashes on public roadways is a significant public health issue, especially from an occupational health perspective. Few studies have investigated such collisions at the state and national levels, and no rigorous analysis of logging truck crashes has been conducted for Louisiana, a major lumber-producing state. This dissertation utilizes statewide crash data from 2010 to 2018 to perform an in-depth analysis of large logging truck crashes in Louisiana, intending to gain insights on the driver, environmental, vehicle, and crash characteristics associated with the severity of large logging truck crashes in Louisiana.

Overall, logging truck crashes on public roadways have risen since 2012 (Cole, 2018; Conrad, 2018). The crashes impact not only the logging truck drivers but also other roadway users. This lack of knowledge is a concern, given that the forestry industry is the second largest manufacturing industry and a significant contributor to Louisiana (Louisiana Forestry Association, 2018). To address the problem, there is a need to identify the risk factors associated with occupationally-related crashes on public roadways (Farmers, 2003).

The findings of this study provide insights on potential recommendations for future research. Modifications to the crash data collection form and definitions could be suggested to improve the classification of cargo body type and avoid misclassification of logging truck crashes. The information and lessons learned from crash data analysis add to epidemiologic research. Most significantly, the findings on the associated behavioral factors can be used to develop targeted educational measures focusing on the promotion of roadway safety and reduction in the number of crashes.

The logging industry is directly affected by the national truck driver shortage, aging driver workforce, lack of qualified and experienced truck drivers, and higher insurance premiums for a truck drivers (Costello Bob, 2017). The American trucking industry is facing difficulty replacing aging and experienced truck driver. It is crucial to ensure the health and safety of truck drivers. The traffic crash could add to truck drivers' mental and physical health and financial issues. Significantly, higher severity crashes cause a burden on traffic safety and as well as an economic burden on society. In 2018, overall traffic crash fatalities resulted in $55 billion in medical and work loss costs, and $1.3 billion of it was contributed by Louisiana (CDC, 2020). The average cost of fatal crashes involving medium/heavy trucks was $3,604,518 per crash (FMCSA, 2007). The financial burden is greater for truck drivers, and acquiring insurance coverage is very difficult for logging trucks which adds more financial burden on the trucking industry. For insurance companies, providing coverage for logging trucks is riskier than providing other commercial auto insurance because logging trucks tend to be more expensive than other heavy vehicles (Conrad, 2018). Targeted training and enhanced safety measures for logging truck drivers could help to reduce the severity of crashes and financial burden on truck drivers.

The large logging trucks are often combined with other commercial trucks while evaluating the associated crash factors. This dissertation focuses on large logging truck crashes and compares large logging and non-logging truck crashes. This study improves the understanding of the differences in crash factors associated with large logging and non-logging truck crashes. The study findings add information to literature that SV large logging truck crashes have distracted driving, no use of a seatbelt, careless driving, and a truck that ran off the road to the left side is more prevalent in higher severity crashes than lower severity crashes. This study also adds that large logging truck crashes had more prevalence of truck rollover, truck ROR to the right side, and truck ROR to the left side in higher severity crashes than lower severity crashes.

This dissertation also studied the association between behavioral factors and crash severity in SV and MV large logging truck crashes. The analysis of single large logging truck crashes found that not wearing a seatbelt, careless driving, and a harmful event running off the road to the left side were associated with higher severity crashes. The analysis of multiple vehicle crashes involving a large logging truck identified the association between higher severity and crash factors not wearing a seatbelt, a harmful event ROR to the right side of the road, and a harmful event the crossed median/centerline. This study identifies behavioral factors associated with higher severity crashes in Louisiana that could help to mitigate the frequency and severity by designing targeted safety training programs for large logging truck drivers.

This study adds information to occupational-related crashes and improves the understanding of driver characteristics and behaviors associated with the higher severity of large logging truck crashes. The study findings will help direct future research and design a more targeted safety program for large logging truck drivers. The ultimate goal would be to promote evidence-based training programs and cost-effective strategies to design the preventive tactics to improve the logging truck driver's health and safety.

Future Directions

Additional research needs to focus on drivers' behavioral factors by interviewing the logging truck drivers involved in crashes to understand the risk factors in depth. Future studies could focus on understanding injury severity classification using hospital data, comparing the finding with other states to understand the generalization of this study's findings, and exploring other databases to tackle the underreporting of crashes.

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APPENDIX

Table A.1: Literature review for contributing factors associated large logging truck-related crashes on public roadways

No.	Article	Data source	Population	Objective	Conclusion/Results
1	Alexander, B. H., Franklin, G. M., & Fulton-Kehoe, D. (1999). Comparison of fatal and severe non-fatal traumatic work-related injuries in Washington state. American Journal of Industrial Medicine, 36(2), 317-325.	Workers' compensation claims data from the Washington State Department of Labor and Industries (WSDLI)	335 fatal injuries and 4,405 hospitalized non-fatal injuries, of which 1,105 were classified as severe	This article compared fatal and hospitalized non-fatal work-related traumatic injuries by occupation and cause.	The analysis of fatal and hospitalized non-fatal work-related traumatic injuries claim from log-hauling occupation from 1991-1995 estimated 7 fatalities with the rate of 11.2 per 10,000 FTE; 10 more-severe non-fatal injuries with the rate of 16 per 10,000 FTE; and 19 less-severe non-fatal injuries with the rate of 30.4 per 10,000 FTE. In those log-hauling occupation-related fatalities, 6 were from motor vehicle crashes, and one was from the electricidal current. More severe non-fatal injuries in a log-hauling occupation included 5 of these injuries from being struck by an object, and three were from motor vehicle crashes. The claims from logging occupation included two more-severe non-fatal injuries from motor vehicle crashes. **Conclusion**: Logging and log-hauling occupations have high rates of work-related fatalities. These occupations are among the top risk classes for fatal and more severe non-fatal injuries. Fatal injuries in log-hauler were primarily from motor vehicle crashes.
2	Baker, S., & Tyson, J. The Winding Roads of Log Truck Insurance.	Federal Motor Carrier Safety Administration (FMCSA) 2010-2015	N/A	This study examines the reason for higher premiums for a logging truck.	Logging truck crashes doubled in the United States from 2010 to 2015. Logging truck crashes were more severe than other types of crashes. In 2015, 79% of logging truck crashes resulted in injuries, and 56% of all heavy truck crashes resulted in injuries. Fatal logging truck crashes were declined since 2010 but were still highest compared to any

No.	Article	Data source	Population	Objective	Conclusion/Results
					truck-type crashes tracked by FMCSA. **Conclusion**: Baker and Tyson concluded that logging-related crashes were rising from 2010 to 2015 and expressed concern over the increasing cost of logging truck insurance in the past few years.
3	Baker, S.A., J. Cutshall, and D. Greene. 2012. Logging vehicle accident rates decline in Georgia. Forest Resources Association Technical Release 12-R-7. Rockville, MD. 2 pp.	Georgia Department of Motor Vehicle Safety Database (DPS-523 form) 2004-2008	N/A	This study identified trends in accident factors and compared factors associated with accidents before regulation (1988-1991) to those seen in subsequent years.	This technical report used the Georgia Department of Transportation highway accidents record data from 1988-2008 and compared the numbers and causes of accidents involving logging vehicles (logging tractor-trailers and logging trucks combined) with other heavy trucks. The reduction in mechanical failure related logging vehicle accidents has been stable since the mid-1990s. The increase in the rate of logging vehicle accidents per million tons hauled through 2003 was reported, but since 2003, these rates have been declining. **Conclusion:** This article concluded that the reduction in the logging-related crashes from a mechanical failure in Georgia since 1991 was an impact of random roadside inspection regulation.
4	Carnahan, B. J. (2004). Identifying training needs of logging truck drivers using a skill inventory. Journal of agricultural safety and health, 10(4), 221.	Surveyed logging truck drivers from the states of Alabama, Georgia, and Mississippi	1039 logging truck drivers	This study aimed to determine if the Driver Skill Inventory (DSI) could be used to identify the self-assessed driving performance of commercial logging truck drivers.	The analysis of survey data found that 1) Seatbelt use while driving is a legal requirement, but only 55.5% of logging truck drivers responded that they always wore the safety belt. 2) Violations: About 14% of logging truck drivers responded that they received two or more moving violations, and 24% of logging truck drivers responded that they received one moving violation. 3) Involved in crashes: Logging truck drivers responded that they were involved in at least one roadway crash (13.8%) and two or more road

No.	Article	Data source	Population	Objective	Conclusion/Results
					crashes (2.8%). 4) Hours of driving: Driving of logging truck after business hours and at night is prohibited. Among surveyed logging truck drivers, 1.5%' of them reported that they always drove after business hours (6:00 PM-12: 00 AM) and 24.7% sometimes. Logging truck drivers who always drove at night (12:00 AM-6: 00 AM) were 2.5%, and 22.8% sometimes drove at night. 5) Driver's age and experience: The mean age for logging truck drivers was 41.4 years, and the mean years of experience was 16 years (0.04-50 years). 6) Driver's Ethnicities: Among participants, 65% were Caucasian, 20% were African American, and 15% were Hispanic. **Conclusion**: The safety and perceptual-motor subscale scores were statistically significant. The driver's age, years of driving experience, and estimated kilometers drove per year were weakly correlated. The regression analysis found that a decrease in respondent age (and years of experience) with an increase in driving exposure increases the likelihood of getting moving violations and being involved in roadways crashes.
5	Cole, N. B. (2018). Regional Analysis of Log Truck Crashes in the United States between 2011 and 2015 (Doctoral dissertation, Virginia Tech).	Fatality Analysis Reporting System (FARS) and Motor Carrier Management Information System (MCMIS) (2011-2015)	383 logging truck crashes	This dissertation identified national and regional log truck crashes and examined the differences between log truck crashes and other trucks.	The average age of log trucks involved in fatal crashes was 13 years, significantly older (p=.0109) than the overall average age for other large trucks (7.6 years). The Southeast region had the highest crash rate for log trucks, with 0.9 fatal crashes per 100 million ft3 of wood harvested. The fatal log truck crashes increased by 41% from 2011 to 2015. The involvement of log tractor-trailers in fatal

No.	Article	Data source	Population	Objective	Conclusion/Results
					crashes increased by 33%, higher than all tractor-trailer crashes by 16%. **Conclusion**: Fatal crashes involving log tractor-trailers were on the rise in the United States from 2011 to 2015 compared to all types of tractor-trailer crashes.
6	Cole, N., S. Barrett, C. Bolding, and M. Aust. 2017. Log truck accidents in the United States. Presentation at the 40th annual meeting of the Council on Forest Engineering, July 30-August 2, 2017, Bangor, ME.	Fatality Analysis Reporting System (FARS) (2007-2015) and Motor Carrier Management Information System (MCMIS) (2007-2016)	576 fatal logging truck crashes and 11,014 Injury causing or property damage crashes (in total 11590)	This presentation identified log truck crashes and examined the differences between log truck crashes and other trucks in the United States	Logging truck crashes accounted for 576 fatalities during 2007-2015 and 11,014 injuries or property damage during 2007-2016. Logging truck crashes (25.3%) had higher rollover events than other truck crashes (12.8%). Logging trucks involved in crashes had a higher average vehicle age (13.2 years) than the average vehicle age of all trucks (9.4 years). **Conclusion**: Logging trucks involved in fatal crashes were older than all other trucks involved. Rollover was the most reported event in fatal crashes involving logging trucks than other trucks.
7	Conrad IV, J. L. (2018). Log truck liability insurance in Georgia: Costs, trends, and solutions. Project report prepared for the Georgia Forestry Association Center for Forest Policy Studies.	Georgia logger survey in 2017; Insurance Services Office (ISO) for log trucks and other heavy vehicles for 2007-2016; Georgia Uniform Motor Vehicle Accident Reports 2006-2016.	N/A	The author has identified the reason behind increasing liability insurance premiums for logging trucks in Georgia between 2006 and 2016.	The total logging truck crashes declined by 69% from 2006 to 2012 but increased by 24% since 2012. The logging truck crash rate dropped from 16.1 accidents per million tons hauled in 2006 to 5.1 crashes per million tons hauled in 2012 and increased to 6.3 accidents per million tons hauled in 2016. Consequently, while crash rates declined substantially from 2006 to 2012, there has been an increasing trend to the present since 2012. **Conclusion**: This report updated the analysis from Greene et al. (2007) and Baker et al. (2012) studies and reported an increase in logging truck crashes since 2012. These increasing crash rates can have a direct effect on the rising logging truck insurance

No.	Article	Data source	Population	Objective	Conclusion/Results
					costs.
8	Conway, S. H., Pompeii, L. A., Casanova, V., & Douphrate, D. I. (2017). A qualitative assessment of safe work practices in logging in the southern United States. American Journal of Industrial Medicine, 60(2), 58-68.	Six focus group sessions among logging supervisors (n=17) and crew members (n=10) in Arkansas, Louisiana, and Texas	27 (crew member (n=17) and supervisor (n=10))	The focus group discussions were mainly to understand the perception of logging risk and its association with safe work practices in logging supervisors and crew members in the southern U.S.	Conway et al. 2017 did a qualitative assessment of logging safety practices in the Southern region. Logging-related crashes were identified as the primary source of injuries and deaths at work sites. In an interview, supervisors and logging company owners expressed that logging truck drivers are at a higher risk of injury and death, but they found that on-site crashes were a bigger issue than road crashes. The participants also mentioned that experienced loggers are safer logging truck drivers than contract logging truck drivers. **Conclusion**: Logging is considered a dangerous profession, and logging truck crashes were identified as the primary source of risk for injury and death on work sites.
9	Crowe, M. P. (1986). Hardwood logging accidents and counter-measures for their reduction. Australian Forestry, 49(1), 44-55.	This article collected data from five large pulp or woodchip companies and the Inspectorate of the Timber Industry Regulations Act in Western Australia (New South Wales, Victoria, Tasmania, and Western Australia) during	452 injuries in hardwood logging	This study identified the accident types, nature, location of injuries, high-risk groups, and their association with accidents and management and production systems.	The fallers and dumpmen (61%) were five times more likely to be involved in logging-related injuries than log truck drivers (11%). **Conclusion**: This article is old and no longer relevant to current statistics.

No.	Article	Data source	Population	Objective	Conclusion/Results
		1979-83.			
10	Driscoll, T., Marsh, S., McNoe, B., Langley, J., Stout, N., Feyer, A. M., & Williamson, A. (2005). Comparison of fatalities from work-related motor vehicle traffic incidents in Australia, New Zealand, and the United States. Injury Prevention, 11(5), 294-299.	1. Coroners' data: Australia (1989–92), 2. Coroners' data: NZ (1985–98), 3. National Traumatic Occupational Fatalities surveillance system (NTOF): US (1989–92)	521 work-related motor vehicle traffic deaths in Australia, 210 traffic deaths in NZ, and 4322 traffic deaths in the US	This study compared the extent and characteristics of fatal occupational injuries in motor vehicle crashes on public roads in Australia, NZ, and the United States (US).	This article compared the magnitude and characteristics of fatal occupational injuries in motor vehicle traffic crashes on public roads in Australia (1989–92), New Zealand (NZ) (1985–98), and the United States (US) (1989–92). Agriculture, forestry (including logging), and fishing (AFF) industry reported fatal injury rate 1.84 (95% CI 1.25–2.61) in Australia; 0.91 (95% CI 0.54–1.42) in NZ and 2.69 (95% CI 2.42–2.96) in the US. Australia reported higher occupational fatal motor vehicle traffic crashes than NZ and the US. This study did not focus only on the logging industry, but the logging industry was part of the AgFF industry. **Conclusion**: Australia reported higher occupational fatal motor vehicle traffic crashes than NZ and US, but the US has higher crude and standardized rate for Agriculture, forestry (including logging), and fishing industry compared to other countries.
11	Enez, K., Topbas, M., & Acar, H. H. (2014). An evaluation of the occupational accidents among logging workers within the boundaries of Trabzon Forestry Directorate, Turkey. International Journal of Industrial Ergonomics, 44(5), 621-628.	The data source is face-to-face questionnaires performed and anthropometric measurements in logging workers in the boundaries of the Trabzon Regional Forestry Directorate, comprising the	378 logging workers belonging to 24 cooperatives in the three provinces in the region	This study aimed to estimate the frequency of occupational injuries among logging workers and possible risk factors.	Enez et al. 2014 found that 7% of logging workers' injuries were from transport or loading motor vehicle. **Conclusion**: This article provides limited information on logging-related roadway crashes.

No.	Article	Data source	Population	Objective	Conclusion/Results
		provinces of Trabzon Gumushane and Rize. During April and September of 2007.			
12	Gejdoš, M., & Vlčková, M. (2017). Analysis of Work Accidents in Timber Transport in Slovakia. In MATEC Web of Conferences (Vol. 134, p. 00014). EDP Sciences.	Timber transport crash record from National Labor Inspectorate, from the General Directorate of Lesy SR, state enterprise in Banská Bystrica.	105 registered work injuries in timber transport were reported between 1996 and 2014	This article analyzed the risk of work injuries in the timber transport phase of State forestry entities and self-employed persons.	Gejdoš and Vlčková (2017) reported that 7% of registered work injuries were from timber transport. The trends of timber transport-related crashes did not change between 1996 and 2014. Timber transportation crashes contributed 2.85 per transported timber in a million m3 (in 2000) and 0.8 per transported timber in a million m3 (in 2012). **Conclusion**: This study only focused on timber transportation in the forestry industry. It is an international article conducted in Slovakia which probably not relevant to logging-related roadway crashes in the United States.
13	Green, C. A. (2005). Log Truck Study II– Final Report. Michigan Tech Transportation Institute, Michigan Tech University.	Log truck crashes from Michigan Crash Database in the U.P. during 2001-2003.	96 logging truck crashes	Updated the Literature Review from the 2003 report. Described characteristics/configu rations of Log Trucks and log loads. Analyzed logging truck crashes and spills and recommended practices and	In total, 96 log truck crashes happened in the Upper Peninsula of Michigan between 2001 and 2003. About 25% of logging truck crashes were single motor vehicle crashes (logging truck only), 64.6% were multiple vehicle crashes, and 10.4% involved logging trucks and animals. The trend was similar between the logging truck and overall heavy truck and bus crashes in the Upper Peninsula. Most logging truck crashes (56%) happened within 150 feet of an intersection, and 69%’ of logging crashes occurred on a state highway. The survey data from logging truck drivers indicated that they perceived

No.	Article	Data source	Population	Objective	Conclusion/Results
				innovations for existing documented hazards.	traffic conditions (69%) were the most dangerous part of their job. **Conclusion**: The distribution and patterns of logging truck crashes were similar to all traffic and truck or bus traffic in Michigan's Upper Peninsula. The solutions are needed for the prevention of log spills.
14	Greene, D. (2010). Accident causes with Georgia logging tractor-trailers. Logging Safety; Timber Harvesting and Transportation Safety 06-R-03. Available at: https://loggingsafety.com/publications/accident-causes-with-Georgia-logging-tractor-trailers/	Logging truck crash data from Georgia Department of Motor Vehicle Safety (forms DPS-523) between 1988 and 2004.	All heavy trucks crashes, including logging vehicles in Georgia between 1988 and 2004.	This report identified the trends in crash factors and compared the factors associated with crashes before and after changes in random inspection regulation.	The mechanical failure rates dropped from 10.9% in 1988-1991 to 4.8% in 2001-2004 for logging tractor crashes, and also these rates dropped from 12.9% in 1988-1991 to 4.2% in 2001-2004 for logging truck crashes. Brake failure has declined by 69% (from 6.51% to 1.60%) of crashes from 1991. Slick tire-related crashes reduced from 3.46% in 1988-1991 to 1.29% in 2001-2004. Improper lighting citations were declined by 80%. Improper lighting citations in logging truck crashes dropped from 2.05% (1988-1991) to 0.42% (2001-2004) of crashes. The top three contributing factors in 2001-2004 leading to logging tractor-trailer and other heavy truck crashes were following too close, misjudged clearance, and failed to yield. **Conclusion**: This article concluded that the reduction in the logging-related crashes from a mechanical failure in Georgia since 1991 was an impact of random roadside inspection regulation.
15	Greene, D. Log Hauling Vehicle Accidents in the State of Georgia, 1988-2008.	Logging truck crash data from Georgia Department of Motor Vehicle Safety (1988–	N/A	This study evaluated the reduction in mechanical failures associated with log truck accidents after the enforcement of the	University research paper analyzed the conclusion from Greene et al. 2007 with additional data from 2005 to 2008. The reduction in logging truck crashes from mechanical failure remained the same as an effect of the changes in inspection legislation. The proportion of logging tractor-trailer crashes

No.	Article	Data source	Population	Objective	Conclusion/Results
		2008)		new legislature in 1991 and if the effect of the legislature remained the same from 2001-2004 through 2005-2008.	(2.9%) and logging truck crashes (0.9%) remained low for 2005-2008 data compared to 1988-1991 (3.7% & 3.1% respectively) and 2001-2004 data (1.8% & 1.0% respectively). The frequency of truck crashes where mechanical failure was contributing factor remained low for logging trucks in 200-2008 (3.2%) compared to 1988-1991 (12.9%) and 2001-2004 (4.2%). But for logging tractor-trailers, mechanical failure contributing factor reported a slight increase in 2005-2008 (5.5%) from 2001-2004 (4.8%). Following too closely, loss of control of the vehicle and misjudged clearance were the top 3 contributing factors cited the most in 2001-2004 and 2005-2008 data. Mechanical failure misjudged clearance, and too fast for conditions were the top three contributing factors cited most in 1988-1991. **Conclusion**: This article concluded that the reduction in the logging-related crashes from a mechanical failure in Georgia since 1991 was an impact of random roadside inspection regulation.
16	Greene, W. D., Baker, S. A., & Lowrimore, T. (2007). Analysis of Log Hauling Vehicle Accidents in the State of Georgia, USA, 1988–2004. International Journal of Forest Engineering, 18(2), 52-57.	Logging truck crash data from Georgia Department of Motor Vehicle Safety (1988–2004)	N/A	This study evaluates the association between mechanical failures and log truck accidents and how the Georgia Forest Products Trucking Act (1991) affected this association.	This study found that logging trucks and all types of truck crashes had similar contributing factors. After Georgia Forest Products Trucking Act (1991) took effect, the mechanical failure rates dropped from 10.9% in 1988-1991 to 4.8% in 2001-2004 for logging tractor crashes, and also these rates dropped from 12.9% in 1988-1991 to 4.2% in 2001-2004 for logging trucks crashes. **Conclusion**: This article concluded that the reduction in the logging-related crashes from a mechanical failure in Georgia since 1991 was an

No.	Article	Data source	Population	Objective	Conclusion/Results
					impact of random roadside inspection regulation.
17	Greene, W. D., Jackson, B. D., Shackleford, L., Izlar, R. L., & Dover, W. (1996). Safety of log transportation after regulation and training in the state of Georgia, USA. Journal of Forest Engineering, 7(3), 25-31.	Logging truck crash data from the Georgia Department of Motor Vehicle Safety Database (1988-1994)	68,229 heavy truck crashes	This study determined the factors associated with highway crashes involving logging vehicles. It provided the database for analysis of the impact of the government regulations and training efforts on contributing factors associated with logging vehicle crashes. They also developed training material to educate logging truck drivers about the contributing factors in the logging vehicle crashes.	This study compared the various mechanical failures associated with logging vehicle crashes before (January 1, 1988-June 30, 1991) and after (July 1, 1991-December 31, 1994) the regulation of Georgia Forest Products Trucking Rules (July 1, 1991). Logging tractor-trailers highway crashes from mechanical failures declined (from 10.9% to 6.4%) in Georgia State. A significant decline was observed in brake failure related to logging tractor-trailers and other heavy trucks accidents. A significant reduction in improper lights was reported for logging tractor-trailers accidents. **Conclusion**: This article concluded that the reduction in the logging-related crashes from a mechanical failure in Georgia since 1991 was an impact of random roadside inspection regulation.
18	Holizki, T., McDonald, R., & Gagnon, F. (2015). Patterns of underlying causes of work-related traumatic fatalities–Comparison between small and larger companies in British Columbia. Safety Science, 71, 197-204.	Workers' Compensation Board of British Columbia for data on all traumatic fatalities for the period 2003–2007	422 traumatic fatalities (243 in small businesses and 179 in larger businesses)	This study identified the patterns of safety behavior and described the differences in injury and fatality rates between small and larger businesses.	This study identified the patterns of traumatic occupational injuries in small and larger companies from the Workers' Compensation Board of British Columbia database for data on all traumatic fatalities from 2003 to 2007. The most traumatic fatalities were from vehicular crashes, contributing 36% fatalities (87 of 243) among small businesses and 25% fatalities (44 of 179) among larger businesses. Thirteen cases were related to logging hauling vehicular crashes, of which all were from small businesses. In these logging hauling

No.	Article	Data source	Population	Objective	Conclusion/Results
					vehicular crashes, 23% (3/13) were reported positive for cannabis, and 61.54% (8/13) did not use seatbelts among log-hauling drivers. **Conclusion**: This study did not primarily focus on the logging-related roadway crashes but provided important information on the existence of driving under the influence and lack of seatbelt use in log-hauling drivers. This is an international article probably not relevant to the logging-related roadway crashes in the United States.
19	Kossoris, M. D., & McElroy, F. S. (1941). Causes and Prevention of Accidents in Logging and Lumber Mills, 1940.	Survey data by the Bureau of Labor Statistics in logging sawmill and planing-mill industries.	This study included 4,332 disabling injuries, 166 permanent injuries, and 56 fatal from the logging industry; 4,814 disabling injuries, 210 permanent injuries, 30 fatalities from the sawmill industry; and 3,742 disabling injuries, 237 permanent injuries, and 9 fatalities from the planing mill	This study analyzed the national and regional causes of fatal and non-fatal injuries in logging mills, sawmills, and planing mills.	The logging industry had 5.4% of fatal and permanent total disability, 8.4% of permanent partial disability, and 3.1% of temporary total disability from struck by striking against a vehicle. The injury rate was 3.36, and the injury rate (severity) was 1.31 for logging workers from struck by striking against a vehicle. Sawmills industry had 10.0% of fatal and permanent total disability, 2.4% of permanent partial disability, and 2.4% of temporary total disability from struck by striking against a vehicle. The injury rate was 2.5, and the injury rate (severity) was 0.24 for sawmills workers from struck by striking against a vehicle. The planing mills industry had 11.1% of fatalities and permanent total disability, 2.3% of permanent partial disability, and 2.4% of temporary total disability from vehicle and machinery in motion. The injury rate was 0.83 and the injury rate (severity) 0.16 for planing mills workers from vehicle and machinery in motion. **Conclusion**: This article is old and no longer relevant to current statistics.

No.	Article	Data source	Population	Objective	Conclusion/Results
			industry.		
20	Kuhn, G. C., Kolodziej, S. F., & Cruz, E. R. (2015). Evaluation of risks in the forest terrestrial transportation. Procedia Manufacturing, 3, 4808-4815.	Injuries related to forest transportation data obtained from the newspapers between 2012 and 2014	N/A	This study analyzed different activities involving forest transportation to identify hazards, evaluate risks, and introduce control measures for the correlated risk activities in forest terrestrial transportation at Misiones province.	The analysis of different activities involved in forestry transportation found that driving forest transport unit (trucks) activity has significant risk with extreme severity factor and a significant magnitude of risk. **Conclusion:** This is an international article probably not relevant to the logging-related roadway crashes in the United States.
21	Lagerstrom, E., Magzamen, S., & Rosecrance, J. (2017). A mixed-methods analysis of logging injuries in Montana and Idaho. American Journal of Industrial Medicine, 60(12), 1077-1087.	Workers' compensation claims data (Idaho and Montana State) and focus groups (professional loggers)	801 Workers' compensation claims (July 2010 to June 2015) and focus group included 63 professional loggers	This study identified the risk factors associated with injuries and fatalities in the logging industry.	In total, 143 (17.9%) claims were from truck drivers and 4.2% of truck drivers involved in a vehicle collision. Focus group participants included 12 (19%) truck drivers. Logging truck drivers reported that the high risk of road crashes was due to poor drivers on the highways and fatigue (from driving long distances to sawmills). Lower back pain is common in truck drivers from long hours of sitting. Focus groups reported following job tasks contributed to risks and injuries for truck drivers: Manually placing stake extensions (poor positions, slippery work area, heavy and awkward lift, and falls), driving distance and time to mills, vehicle collisions (with other vehicles, single-vehicle slide off the road due to weather conditions). The focus group identified that the highest-risk job task involves felling trees, skidding, and truck driving. **Conclusion:** Logging-related job tasks are

No.	Article	Data source	Population	Objective	Conclusion/Results
					significantly different in the type of incidents ($p<0.0001$) and in the nature of injuries depending on the job task ($p<0.0001$). One-third of fatality claims were recorded in truck drivers.
22	Lefort, Jr., A., de Hoop, C., Pine, J., & Marx, B. (2003). Characteristics of Injuries in the Logging Industry of Louisiana, USA: 1986 to 1998. International Journal of Forest Engineering, 14(2).	Claims reported to the Louisiana Department of Labor, Office of Workers' Compensation Administration	4348 injury claims from the logging industry	This study characterized crashes and injuries in the logging sector based on the nature, type, source, and frequency of the injuries and demographics of the workers in Louisiana from 1986 to 1998.	Lefort et al. 2003 reported that 8% of logging-related crashes were related to transportation in Louisiana between 1986 and 1998. **Conclusion:** This study provides limited information on the logging-related crashes on public roadways.
23	Mason, C. L., Casavant, K. L., Lippke, B. R., Nguyen, D. K., & Jessup, E. (2008). The Washington log trucking industry: Costs and safety analysis. University of Washington and Washington State University. Available online at http://www.ruraltech.org/pubs/reports/2008/log_trucks/index.asp [Last accessed March 30, 2019]	Crash data from Washington State Patrol and the Washington Department of Transportation from 2002 to 2007; statewide survey of the log truck industry 2006	772 logging truck drivers, 129 companies operating 336 trucks	This report investigates the Washington logging truck industry's role in understanding the costs of providing logging truck services.	Logging truck crashes declined by 11% from 2004 to 2006 in Washington. In total, 772 logging truck crashes were reported in Washington from 2002 to 2007 and with an average of 129 crashes per year. Logging truck traffic proportion (0.4%) of total vehicle miles traveled (VMT) in Washington in 2006. A statewide survey of the logging truck industry included 129 companies operating 336 trucks. Driver's age correlated with collision rates. NHTSA (1993) indicated that the risk of collision decreases with age until 60, and after 60, this risk increases. Based on survey data, the average age of logging truck drivers was 55 years (range from 32 to 82 years). The average experience in trucking operations was 27 years (range from 0 to 54 years). But there is no information available on the driving experience and its association with logging truck crashes. Most logging truck drivers (86%)

No.	Article	Data source	Population	Objective	Conclusion/Results
					recognized that traffic and roads were the most hazardous. Logging truck drivers responded that they traveled commonly on paved roadways (83%) and only 17% on gravel roads. The majority of respondents (87%) found it challenging to find and retain qualified truck drivers. This report also analyzed the WA Department of Licensing data and determined that the number of registered logging trucks declined by 36% in Washington. **Conclusion:** This article analyzed crash records and qualitative data on logging-related roadway crashes in Washington. The crash analysis of logging-related crashes indicated no evidence of increased crashes, injuries, or fatalities from 2002 to 2007. The 2006 log truck industry survey analysis provided general demographic, job details, and perceived challenges.
24	Milham, S. (1983). Occupational mortality in Washington state. NIOSH Pub. no. 83, 116.	The data source is death certificate information in Washington State (male deaths for 1950-1989 and female deaths for 1974-1989)	588,090 male deaths for 1950-1989 and 88,071 female deaths for 1974-1989	This report analyzed the detailed causes of deaths (161 causes) for 219 occupational categories for males and 68 occupational categories for females.	The fatalities in logging truck drivers were 1246 from asthma, motor vehicle accidents, and blows from falling objects (logs) show excess deaths. **Conclusion**: This article is old and no longer relevant to current statistics.
25	Myers, J. R., & Fosbroke, D. E. (1994). Logging fatalities in the United States by region, cause of death, and other factors—	National data from the National Traumatic Occupational Fatality surveillance	1,278 logging industry deaths	This study defined the differences between logging fatalities due to cause of death, forest region, race, and other demographic	This article defined differences between logging fatalities due to cause of death, forest region, and demographic characteristics using the National Traumatic Occupational Fatality surveillance system data between 1980 and 1988. Truck drivers reported 11% of deaths from logging-related

No.	Article	Data source	Population	Objective	Conclusion/Results
	1980 through 1988. Journal of Safety Research, 25(2), 97-105.	system from 1980 to 1988		characteristics in the United States from 1980 to 1988.	crashes. Most logging trucks were involved in motor vehicle crashes (65.6%), leading to 84 deaths of logging truck drivers. The South region (143.2) reported a larger average annual fatality rate per 100,000 than the Lake States (98.6) and Northeast regions (87.0). **Conclusion**: This study is more than 25 years old, and we need to review current data for the Southern region to improve the safety measures for logging truck drivers on public roads.
26	United States Department of Labor, Occupational Safety, and Health Administration. Logging Review Report: A Review of Logging Fatalities Investigated by the Occupational Safety and Health Administration in FY 1996 and FY 1997. October 2000. Available online at https://www.osha.gov/dea/reports/logging/logging_report_all-in-one.pdf	OSHA's Integrated Management Information System (IMIS)	1996 (126 fatalities) to 1997 (129 fatalities);107 OSHA-investigated logging fatalities	This report aims to update the information on the nature and extent of fatal occupational logging injuries at facilities classified as Standard Industrial Classification (SIC) 2411 in FY 1996 and FY 1997.	**Part 1:** National Logging and Wood Fiber Transportation-related fatalities increased from 1996 (126 fatalities) to 1997 (129 fatalities). Five states with the highest fatalities were Alabama (29), North Carolina (20), Virginia (20), Kentucky (17), and Mississippi (17). Louisiana reported 7 logging and Wood Fiber Transportation-related fatalities, of which four from 1996 and three from 1997. **Part 2:** Logging fatalities investigated by OSHA in FY 1996 and FY 1997 report. Total 25 fatalities were from operating machines or equipment (logging trucks included) in OSHA-investigated logging fatalities by employee activity. In these 25 were in 1996 and 10 in 1997. Three or 3% died in a logging truck crash. Logging fatalities included 22% (8) of 36 machine/equipment operators, which were the operator of logging trucks. The OSHA investigated logging-related fatalities from operating machines/equipment, including 5

No.	Article	Data source	Population	Objective	Conclusion/Results
					(in 1994) and 3 (in 1997) logging truck drivers. Region X (AR, WA, OR, and ID) had 63% of the eight (8) logging truck drivers' fatalities. 63% of the log truck drivers' fatalities were in Oregon and Washington. The total of four deaths was from a run/rollover of moving or tumbling machines (trucks, tractors, skidders, etc.), and of those four deaths, three were in 1996, and one was in 1997. But these frequencies do not give a clear picture of logging truck drivers' injuries or fatalities. **Conclusion:** This report provided information on the frequency of logging-related injuries and little information on logging-related truck crashes.
27	Patterson, P. B. (2007). Attributions of danger and responses to risk among logging contractors in British Columbia's Southern interior: implications for accident prevention in the forest industry. In The economics of health and wellness: Anthropological perspectives (pp. 103-125). Emerald Group Publishing Limited.	Interviews (Narrative data) were conducted within the forest harvesting industry of the North Okanagan/Shuswap region during seven months of fieldwork, from October 2001 to March 2002	forest industry contractors (N=4), retired loggers (N=2), government and industry association personnel (N=4), and the spouses of several participants (N=3)	This study investigated the attitude of logging contractors toward risk at the workplace and added information on the likelihood of success of the recommended policy changes.	This study investigated the logging contractor's attitude toward danger at the workplace and added information on the odds of success of the proposed policy changes in British Columbia. A participant identified that log trucks are at high risk of fatal accidents based on survey data narratives. Snow could be a hazardous factor for logging truck drivers. **Conclusion:** Survey participants perceived logging trucks as being at high risk of fatal crashes.
28	Pine, J. C., Marx, B. D., & de Hoop, C. F. (1994). Characteristics	Workers' compensation injuries in	N/A	This article evaluated occupation-related injuries in the logging	The article also indicated that workers' compensation injuries claims and costs are still the primary concern. About 20% of worker

No.	Article	Data source	Population	Objective	Conclusion/Results
	of Workers' Compensation Injuries for Logging Operations in Louisiana: 1985-1990. Southern Journal of Applied Forestry, 18(3), 110-115.	logging operations in Louisiana		industry in Louisiana during 1985-1990.	compensation claims included truck drivers. The logging-related injuries declined in Louisiana from 1985 to 1990. **Conclusion**: This article is old and no longer relevant to current statistics.
29	Roberts, T., Shaffer, R. M., & Bush, R. J. (2005). Injuries on mechanized logging operations in the southeastern United States in 2001. Forest Products Journal, 55(3), 86.	This study used a random sample of injuries from the 2001 claim records of four workers' compensation insurance providers in the southeastern United States.	315 sample injuries selected from 3,000 worker s compensation insurance (WCI) claims	Compared this study with 1996 study to determine if the characteristics of injuries on mechanized logging operations in the United States South had measurably changed; 2) Also conducted the additional analyses which were not possible in 1996 study since 2001 database broader than 1996 study, and 3) provided updated injury statistics for the continued development of targeted safety training programs and materials.	Robert et al. 2005 studied the sample of injuries from the year 2001's injury claims records. They analyzed data from four Workers' compensation insurance providers from the Southeastern United States. This study compared the 1996 and 2001 characteristics of injuries on mechanized logging operations in the United States South and performed an additional analysis with the 2001 database. About 20% of the logging injuries occurred on roads or highways. Log truck drivers (22%) received injuries most frequently, and in those, 48% sustained injuries while driving. Log truck drivers are most often injured while driving a loaded truck (79%) than injured while driving empty trucks (21%). The logging truck drivers were involved in more motor vehicle crashes in the 2001 study (41%) compared to the 1996 study (35%). More log truck drivers were injured while driving their trucks in 2001 than in 1996 (48% vs. 35%). **Conclusion**: This article indicated that logging truck crashes increased from 2001 to 1996 in the Southeastern United States.
30	Rodriguez-Acosta, R.	The data source	125	This study identified	The distribution of logging-related fatalities was

No.	Article	Data source	Population	Objective	Conclusion/Results
	L., & Loomis, D. P. (1997). Fatal occupational injuries in the forestry and logging industry in North Carolina, 1977–1991. International Journal of Occupational and Environmental Health, 3(4), 259-265.	is the NC Office of the Chief Medical Examiner which collects information on occupational injury fatalities in the logging industry in NC from 01/01/1977 to 12/31/1991.	occupational injury fatalities in the logging industry	the patterns and trends of occupational fatal injuries in the forestry and logging sectors in North Carolina between 1977 and 1991.	Piedmont region (31.2%), Southern Coast Region (28.8%), Mountains (25.6%), and the Northern Region (14.4%). In total, 6 (4.8%) of logging-related injuries were caused by motor vehicle or traffic crashes in NC. In those logging-related motor vehicle or traffic crashes, 1 (2.6%) in Piedmont, 1 (5.6%) in the Northern region, and 4 (11.1%) in the Southern region. Motor vehicle crashes were the second leading cause of logging-related injuries in Piedmont and Southern Coastal regions. The third leading logging-related cause of death in NC was traffic crashes in logging workers (4.8%). **Conclusion:** This study focused on logging-related injuries in general and provided limited information on the logging-related crashes on public roadways.
31	Rosecrance, J., Lagerstrom, E., & Murgia, L. (2017). Job Factors Associated with Occupational Injuries and Deaths in the United States Forestry Industry. Chemical Engineering Transactions, 58, 115-120.	Worker compensation claims data and survey in professional loggers through logging companies and professional logging associations in the states of Idaho and Montana	Eight hundred worker compensation claims and Interviewed truck drivers (n=4) (16 professional loggers). MT and ID. 2010 to 2015	This study identified the perception of professional loggers towards the association between job tasks and occupation-related injuries or fatalities in the intermountain region of MT and ID.	Injury risks in truck drivers are associated with the following job tasks: awkward postures while securing logs on the truck, slippery conditions due to snow and ice, prolonged sitting, and at times heavy lifting. Professional loggers perceived work conditions (extremely cold weather and steep incline of mountain slope) and job factors (felling trees, skyline skidding, and driving logging trucks) as contributing factors in increased risk for logging-related injuries. **Conclusion:** This study found the association between fatigue from driving logging trucks for many hours in the day and at night and elevated risk of crashes. Driving a truck is one of the high-risk contributing factors in logging-related injuries.

No.	Article	Data source	Population	Objective	Conclusion/Results
32	Shaffer, R. M., & Milburn, J. S. (1999). Injuries on feller-buncher/grapple skidder logging operations in the Southeastern United States. Forest Products Journal, 49(7/8), 24.	This study used a random sample selected from 1997 injury claims from mechanized logger operators from three cooperating workers' compensation insurance providers in Piedmont and Coastal Plain regions of the South.	303 sample injuries selected from 2000 claims from mechanized logger operators	This study determined the accident and injury characteristics for "mechanized" feller-buncher/grapple skidder logging operations in Piedmont and the coastal plain region of the South.	This study analyzed the logging injury claim data (1997) from three Workers' compensations insurance providers. Logging truck drivers more often sustained injuries (24%), and they were primarily injured while driving (35%), performing maintenance (14%), trimming the load (10%), and getting into or out of the truck (8%). **Conclusion:** This study focused on logging-related injuries in general and provided limited information on the logging-related crashes on public roadways.
33	Smith, S., De Hoop, C., Marx, B., & Pine, J. (1999). Logging injuries in Louisiana: nature, trends, and rehabilitation considerations. Work, 12(3), 261-273.	Reportable claims (fatality, a permanent disability, a disability resulting in eight or more lost workdays) were reported to the Office of Workers' Compensation between 1985 and 1992 in Louisiana	3366 logging-related injuries in Louisiana during 1985-1992	This article analyzed occupational injuries in the logging industry in Louisiana from 1985 through 1992.	The highway and non-highway vehicle collisions were the second most common cause of fatalities (20% of the claims). Causative factor 'injuries from a vehicle' contributed higher logging-related injuries in 1992 (10.6%) than in 1985 (4.2%) in Louisiana. **Conclusion:** This study focused on logging-related injuries in general and provided limited information on the logging-related crashes on public roadways. This article is old and no longer relevant to current statistics.

No.	Article	Data source	Population	Objective	Conclusion/Results
34	Sullman, M. J., Meadows, M. L., & Pajo, K. B. (2002). Aberrant driving behaviors amongst New Zealand truck drivers. Transportation Research Part F: Traffic Psychology and Behavior, 5(3), 217-232.	The data source is a part of a more extensive survey of New Zealand truck drivers. The information was collected through the mail-in questionnaires.	378 truck drivers	This study is testing the generalizability of DBQ to a sample of New Zealand truck drivers. They have investigated the level of self-reported aberrant driving behavior, the factor structure of the DBQ, the correlations between the DBQ factor scores and crash involvement, and the prediction of crash involvement for New Zealand truck drivers.	Sullman et al. 2002 utilized the driver behavior questionnaire (DBQ) to investigate the level of self-reported aberrant driving behaviors amongst a sample of truck drivers in New Zealand and included 47.9% of log-hauling truck drivers. This study found that only the violations factor was significantly predictive of a driver being involved in a crash in the past three years. They also found that younger drivers with less experience were involved in more accidents than older experienced drivers. This study found the association between high annual mileage and accident risk. Speeding was the most common reported aberrant driving behavior. **Conclusion:** This is an international article probably not relevant to the logging-related roadway crashes in the United States.
35	Wang, J., Bell, J. L., & Grushecky, S. T. (2003). Logging injuries for a 10-year period in Jilin Province of the People's Republic of China. Journal of safety research, 34(3), 273-279.	National Forestry Bureau of China collects work-related fatality and injury data. This study isolated fatality and injury data for Jilin workers who performed logging operations from 1981 to 1990.	4,499 non-fatal injuries (65.5% of total injuries) and 105 fatalities (43.4% of total fatalities)	This article analyzed logging-related injuries in the Jilin Province of the People's Republic of China (1981-1990).	Wang et al. (2003) found that 3%' (4/119) of fatal injuries in the logging industry was from motor vehicles and a rate of 0.08 per million cubic meters of timber produced. The non-fatal injuries in the logging industry were 8.7% (18/206) from the motor vehicle and rate 0.36 per million cubic meters of timber produced. **Conclusion:** This is an international article probably not relevant to the logging-related roadway crashes in the United States.
36	Wolf, C. H., &	"Employer's First	1,172 logging	This study analyzed	This study analyzed the descriptive statistics of

No.	Article	Data source	Population	Objective	Conclusion/Results
	Dempsey, G. P. (1978). Logging work injuries in Appalachia.	Report of Injury" submitted to state workmen's compensation agencies. Loggers' reports of injuries in Appalachia from 1971 to 1974 were analyzed in this report.	injuries (18 fatalities, 713 disabling or time-lost injuries, 212 non-disabling injuries, and 229 cases where the severity of the injury was not reported)	statistics on the logging injuries in Appalachian (West Virginia, Kentucky, Tennessee, and Virginia) from 1971 to 1974.	logging work-related injuries in Appalachia from 1971 to 1974. This study reported 41 motor vehicle crashes, and of those, 31 were truck drivers, and the remaining 10 were operators of skidders, dozers, or other vehicles. Three percent of the site of the accident was roadways, and 13.9% were truck drivers. This paper does not explicitly focus on motor vehicle crashes in the logging industry. **Conclusion:** This study focused on logging-related injuries in general and provided limited information on the logging-related crashes on public roadways. This article is old and no longer relevant to current statistics.
37	Wrona, R. M. (2006). The use of state workers' compensation administrative data to identify injury scenarios and quantify costs of work-related traumatic brain injuries. Journal of safety research, 37(1), 75-81.	Washington State from Workers' Compensation (WC) claims data and hospital billing data	928 traumatic brain injuries (TBI) cases	This article identified the TBI cases in the working population and their economic burden based on profession.	Wrona (2006) reported that the logging industry was the first among the risk classes with the highest relative risk of 34.2 in insurances classes and second among North American Industrial Classification System (NAICS) with the relative risk of 18.1. But this study did not focus on motor vehicle crashes in the logging industry. Log-hauling has relative risks greater than 10. There were no significant changes in the relative risk of TBI for log-hauling. **Conclusion:** This study focused on logging-related injuries in general and provided limited information on the logging-related crashes on public roadways.

Table A.2: List of dependent and independent variables for the analysis of crashes involving large logging trucks in Louisiana (2010-2018)

VARIABLE NAME	VARIABLE CATEGORIES	SPECIFIC AIM
Dependent Variables		
Crash Severity Definition I	• Injury crash: fatal (K), serious (A), or non-incapacitating injury (B) crash • Possible or no injury crash: possible injury (C) or property damage only (O) crash	Specific Aim 1A&B Specific Aim 2A
Crash Severity Definition II	• Injury crash: fatal (K), serious (A), or non-incapacitating injury (B) crash • Possible injury crash: (C) • No injury: Property damage only (O) crash	Specific Aim 2B
Independent Variables-Driver Demographics and Behaviors		
Driver's Age (years) I	• 25 and younger • 26-35 • 36-45 • 46-55 • 56-65 • 66 & older	Specific Aim 1A&B Specific Aim 2A
Driver's Age (years) II	• 35 & younger • 36-45 • 45-55 • 56 & older	Specific Aim 2B
Driver's Gender	• Female • Male • Other • Unknown	Specific Aim 1A&B Specific Aim 2A&B
Impairment Flag (Alcohol or any illegal or prescription drug use)	• Any driver impaired • No driver impaired • Unknown	Specific Aim 1A&B Specific Aim 2 A&B

VARIABLE NAME	VARIABLE CATEGORIES	SPECIFIC AIM
Distraction Flag (Distraction Flag is defined as distracted if driver condition is inattentive or distracted; the driver was distracted due to cell phone or other electronic device [pager, palm pilot, navigation device, etc.] or other inside the vehicle or other outside the vehicle)	• Driver distracted • No driver distracted • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Fatigue Flag (If driver condition variable is fatigued)	• Driver fatigued • No driver fatigued • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Seatbelt Use	• All occupants wore a seat belt • Any occupants who did not wear seat belt or belt used improperly • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Violations - Failure to Yield	• Driver failed to yield • No driver failed to yield • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Violations - Following Too Closely	• Driver followed too closely • No driver followed too closely • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Violations - Driving Left of Center	• Driver left of center • No driving left of center • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Violations - Cutting In, Improper Passing	• Driver cutting in/improper passing • No cutting in/improper passing • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Violations - Careless Operation	• Driver careless operation • No careless operation • Unknown	Specific Aim 1A&B Specific Aim 2 A&B

VARIABLE NAME	VARIABLE CATEGORIES	SPECIFIC AIM
At-fault Status	• Logging truck driver • Other driver • Unclear	Specific Aim 1A&B Specific Aim 2 B
Independent Variables-Vehicle		
Vehicle Type I*	• Large logging truck • Large non-logging truck	Specific Aim 1A&B Specific Aim 2A (only logging truck)
Vehicle Type II*	• Passenger car, light truck, van, or SUV with Trailer • Motorcycle • Emergency vehicle in use • School bus • Other large trucks • Farm equipment • Other	Specific Aim 2B
Vehicle Condition*	• Defects observed • No defects observed • Unknown • Other	Specific Aim 1A&B Specific Aim 2 A&B
Vehicle Lighting Condition *	• Headlights on • Headlights off • Other • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Harmful Event – Vehicle Overturn/Rollover*	• Vehicle overturn/rollover • No vehicle overturn/rollover • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Harmful Event - Vehicle Cargo/Equipment Loss or Shift*	• Vehicle with cargo/equipment loss or shift • No vehicle with cargo/equipment loss or shift • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Harmful Event - Vehicle Ran Off Road Right*	• Vehicle ran off road right • No vehicle ran off road right	Specific Aim 1A&B Specific Aim 2 A&B

VARIABLE NAME	VARIABLE CATEGORIES	SPECIFIC AIM
	• Unknown	
Harmful Event - Vehicle Ran Off Road Left*	• Vehicle ran off road left • No vehicle ran off road left • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Harmful Event - Vehicle Crossed Median/Centerline*	• Vehicle crossed the median/centerline • No vehicle crossed the median/centerline • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Harmful Event – Vehicle Hit Tree (Standing)*	• Vehicle hit a tree • No vehicle hit a tree • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Harmful Event – Vehicle Hit Other Fixed Objects*	• Vehicle hit other fixed objects • No vehicle hit other fixed objects • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Prior Movement-Vehicle Ran Off Road*	• Vehicle ran off road • No vehicle ran off road • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Prior Movement-Making Left Turn*	• Vehicle making left turn • No vehicle making left turn • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Prior Movement-Crossed Median or Center Line into Opposite Lane*	• Vehicle crossed the median or center line into the opposite lane • No vehicle crossed the median or center line into the opposite lane • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Reason For Movement- To Avoid Other Vehicle*	• Vehicle was trying to avoid hitting other vehicle • No vehicle was trying to avoid hitting other vehicle • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Reason For Movement- Vehicle Out of Control, Not Passing*	• Vehicle out of control, not passing • No vehicle out of control, not passing • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Reason For Movement- Due to Driver Traffic Violation*	• Due to driver traffic violation • Not due to driver traffic violation	Specific Aim 1A&B Specific Aim 2 A&B

VARIABLE NAME	VARIABLE CATEGORIES	SPECIFIC AIM
	• Unknown	
Independent Variables-Crash		
Crash Year*	• 2010 • 2011 • 2012 • 2013 • 2014 • 2015 • 2016 • 2017 • 2018	Specific Aim 1A&B Specific Aim 2 A&B
Crash Type*	• Logging truck only • 2 vehicles (logging truck plus other vehicle)	Specific Aim 1A&B
Crash Time (HH:MM) *	• Morning (06:00 AM to 11:59 AM) • Afternoon (12:00 PM to 05:59 PM) • Evening/Night (06:00 PM to 05:59 AM) • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Day of the Week*	• Weekday • Weekend	Specific Aim 1A&B Specific Aim 2 A&B
Weather Conditions*	• Clear • Other (Cloudy, Rain, Fog/Smoke, Sleet/Hail, Snow, Severe Crosswind, Blowing Sand, Soil, Dirt, Snow, Other) • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Daylight*	Yes No (includes dark with no street lights or continuous street light or street light at an intersection only, dusk, dawn, and other)	Specific Aim 1A&B Specific Aim 2 A&B
Manner Of Collision I*	• Non-Collision with Motor Vehicle • Other or Unknown	Specific Aim 1A Specific Aim 2A
Manner Of Collision II*	• Non-Collision with Motor Vehicle	Specific Aim 1A

VARIABLE NAME	VARIABLE CATEGORIES	SPECIFIC AIM
	• Rear End • Head-On • Angle • Opposite Direction • Same Direction • Other	Specific Aim 2B
Traffic Control - Stop Sign*	Yes No	Specific Aim 1A&B Specific Aim 2 A&B
Traffic Control - Yellow No Passing Line*	Yes No	Specific Aim 1A&B Specific Aim 2 A&B
Traffic Control - White Dashed Line*	Yes No	Specific Aim 1A&B Specific Aim 2 A&B
Traffic Control - Yellow Dashed Line*	Yes No	Specific Aim 1A&B Specific Aim 2 A&B
Traffic Control - No Control*	Yes No	Specific Aim 1A&B Specific Aim 2 A&B
Traffic Control Conditions*	• Controls Functioning • Controls Not Functioning • Controls Obscured • Lane Marking Unclear or Defective • No Controls • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Road Alignment*	• Straight-Level • Curve-Level	Specific Aim 1A&B Specific Aim 2 A&B
Road Surface Type*	• Black Top • Other (Concrete, Brick, Gravel, Dirt, Other) • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Road Surface Condition*	• Dry • Other (Wet, Snow/Slush, Ice, Contaminant includes Sand, Mud, Dirt, Oil, Etc.)	Specific Aim 1A&B Specific Aim 2 A&B

VARIABLE NAME	VARIABLE CATEGORIES	SPECIFIC AIM
	• Unknown	
Roadway Relation*	• On Roadway • Other (Shoulder, Median, Beyond Shoulder – Left, Beyond Shoulder-Right, Beyond Right of Way, Gore, Other) • Unknown	Specific Aim 1A&B Specific Aim 2 A&B
Road Type*	• One-Way Road • Two-Way Road with No Physical Separation • Two-Way Road with A Physical Separation • Two-Way Road with A Physical Barrier • Unknown • Other	Specific Aim 1A&B Specific Aim 2 A&B
Kind of Location*	• Manufacturing • Industrial or business area • Residential related area • Open country	Specific Aim 1A&B Specific Aim 2 A&B
Intersection*	• Yes • No	Specific Aim 1A&B Specific Aim 2 A&B
Highway Type*	• Interstate and US highway • State highway • Parish Road	Specific Aim 1A&B Specific Aim 2 A&B

Note: * Specific aim 2A & 2B models are adjusted for independent variables-vehicle and crash characteristics.

Table A.3: Detailed variable list from Louisiana crash database (2010-2018)

DPSSP Forms	Type of Information	Information Collected
DPSSP 3105: Crash Report	**Crash Specific Data**	Total number of vehicles involved in the crash, date of the crash, time of the crash, district or zone, troop, parish, parish code, city or town, city code, latitude or longitude, quadrant, service road, the crash occurred on (type of roadway), highway number, milepost, roadway name, intersecting roads (intersection or not at an intersection), distance, miles/feet indicating the direction from the nearest intersection, the direction of the highway, street or highway, work zone, hit and run, public property damage, photos made, railroad (RR) train involved (yes/no), fatality (yes/no), pedestrian (yes/no), and injury (yes/no)
	Contributing Factors and Conditions	Road surface, roadway conditions, type of roadway, alignment, primary or secondary factors, weather, type of location, access control, natural lighting condition, vehicle configuration, and cargo body type
	Emergency Services Ambulance	Called time, arrived scene, departed scene, arrival hospital, rescue unit, rescue or fire (time called, arrival scene), ambulance service (name), fire department (name)
	Investigating Agency	Investigating agency, time of notification, time of arrival, time all lanes opened, investigation complete, investigating police agency, date report completed)
	Narratives & Diagram	Officer's narratives, manner of the collision, direction of north, and diagram
DPSSP 3106: Vehicle/Pedestrian Information	**Vehicle Number/s or Pedestrian, Vehicle Information**	Vehicle Configuration (CONF), cargo body type, vehicle year, make (manufacturer), model, number of doors, number of axles, number of tires, vehicle identification number (VIN), vehicle towed, vehicle removed by (driver, owner, or a wrecker service), license plate year, license plate state, license plate type, Gross Vehicle Weight Rating (GVWR) or Gross Combination Weight Rating (GCWR), reason vehicle towed, trailer description (year, make, and type), trailer license plate (year, sate, and number), vehicle classification, truck or bus crash data, carrier information (name and address, interstate carrier, transporting hazardous material (class, identification number, placards displayed, HazMat released)

DPSSP Forms	Type of Information	Information Collected
	Driver Information	Identifier information, seating position in the vehicle, ejected from the vehicle, trapped or extricated), airbag, occupant protection system, demographic information of driver (sex, race, and age), injury code, driver license information (state, class, and endorsements), instructed to exchange information, transported to a medical facility (yes/no), transported to a medical facility (name), pedestrian only (yes/no), pedestrian (clothing information, sex, race, age, injury code), vehicle owner information (same as the driver, contact information, and insurance information), occupant information (contact information, transported to a medical facility (yes/no), transported to a medical facility (name), additional occupant information, Codes (seating position, ejection, trapped or extricated, airbag, occupant protection system used, and injury)
	Contributing Factors and Conditions- Vehicle Specific Data	Vision obscurement, condition of driver or pedestrian, sequence of event or harmful even, violation, driver distraction, movement prior to crash, reason for movement, traffic control, pedestrian actions, vehicle condition, vehicle lighting, traffic control conditions, alcohol or drug involvement, affix blood alcohol kit label, direction before crash, name of street, final location of vehicles, distance traveled after impact, speed (estimated and posted), skid mark data, damage to vehicle (area damaged, extent of deformity), citation number, notice of violation issued
DPSSP 3108: Additional Occupant Supplement	**Occupant Information**	Identifier information, seating position in the vehicle, ejected from the vehicle, trapped or extricated, airbag, occupant protection system, demographic information of driver (sex, race, and age), and injury code.
DPSSP 3110: Narrative Supplement & Alternative Grid	**Narrative text and diagram**	Additional space for narratives of traffic crash and space to draw the diagram
DPSSP 3111: Driver/Witness Voluntary Statement-	**Written statements from drivers and/or witnesses involved in a traffic crash.**	Narrative text

DPSSP Forms	Type of Information	Information Collected
DPSSP 3112: Railroad Grade Crossing Crash Supplement	**Describe additional data for crashes involving a vehicle and a railroad train, at a public crossing.**	This information includes train code (yes/no), streetcar code (yes/no), DOT crossing number, Train ID number or consist number, set of tracks, track speed limit, train in motion, crossing type, roadway surface, estimated speed of train before braking, company operating RR train or streetcar, company owning tracks, Engineer's information (identifiers, and personal and injury information, certification number), Conductor's information (identifiers, and personal and injury information), warning devices, Advance Warning Devices and Active Warning Devices Functional, highway user, train information, distance traveled after impact (train), Headlight Functional (yes/no), Ditch Lights Functional (yes/no), Horn Functional (yes/no), Bell Functional (yes/no), Event Data Recorder Equipped (yes/no), Data Recorder Speed, side impact, impact information, and hazardous materials.

Figure A.1: Flow Chart 1: Large Logging Truck Crashes in Louisiana (2010-2018)

*A logging truck is coded as a cargo body type of logging truck (H).

**A large truck is coded as a truck with a vehicle configuration type of single-unit 2 axle (L), single-unit 3 axle (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), truck double (R).

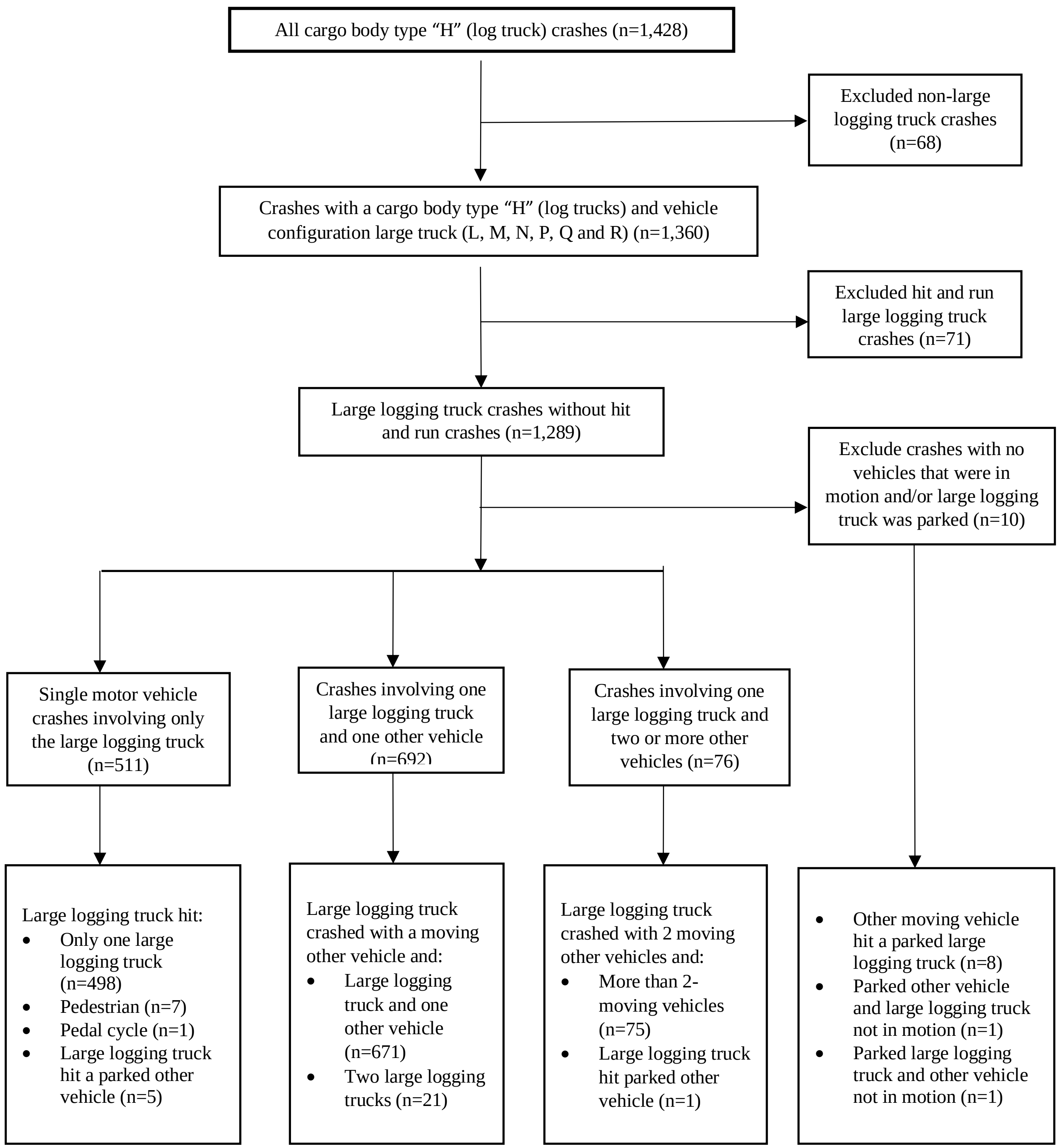

Figure A.2: Flow Chart 2: Large Non-Logging Truck Crashes in Louisiana (2010-2018)

*A non-logging truck is coded based on a cargo body type which is not a logging truck (H) and pole-trailer (K). These include bus (A), Van/Enclosed box (B), Cargo Tank (C), Flatbed (D), Dump Truck/Trailer (E), Concrete Mixer (F), Auto Transporter (G), Garbage/Refuse (I), Hopper (J), and Other (Z).

**A large truck is coded as a vehicle configuration type of single-unit 2 axle (L), single-unit 3 axle (M), truck/trailer (N), truck/tractor (P), tractor semi-trailer (Q), or truck double (R).