FATAL CRASH TRENDS AND ANALYSIS IN SOUTHEASTERN STATES

A Dissertation
Presented to
The Academic Faculty

by

Chunyan Wang

In Partial Fulfillment
of the Requirements for the Degree
Ph.D. in the
School of Civil and Environmental Engineering

Georgia Institute of Technology
May 2006

FATAL CRASH TRENDS AND ANALYSIS IN SOUTHEASTERN STATES

Approved by:

Dr. Karen D. Dixon, Advisor
School of Civil and Environmental Engineering
Oregon State University

Dr. William Bachman
Vice President
GeoStats

Dr. Patrick McCarthy
School of Economics
Georgia Institute of Technology

Dr. Michael Meyer
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Peter Parsonson
School of Civil and Environmental Engineering
Georgia Institute of Technology

Date Approved: April 10, 2006

To my parents and sisters

ACKNOWLEDGEMENTS

I would like to acknowledge the Federal Highway Administration, Georgia Department of Transportation, and supporting agencies and researchers from the states of Alabama, Mississippi, South Carolina, and Kentucky for their contributions to the work effort outlined in this dissertation.

I would like to especially thank my Ph.D. committee chair, Karen K. Dixon, members Patrick S. McCarthy, Peter Parsonson, William Bachman, and Michael Meyer, and communication specialist Lisa Rosenstein. I would not have been able to finish my Ph.D. without their guidance and support.

I would also like to thank my parents and sisters for encouraging me to study abroad and pursue the Ph.D. degree, colleagues for being supportive while I was writing the dissertation and friends for all the help during the last six years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADT	Average Daily Traffic
AADT	Average Annual Daily Traffic
CEC	Contributing Environment Circumstances
CRC	Contributing Road Circumstances
FARS	Fatality Analysis Reporting System
FC	Functional Classification
FHWA	Federal Highway Administration
ft	feet
LL	Log likelihood
LTVs	Light Trucks and Vans
obs	observations
RHR	Roadside Hazard Rating
SUVs	Sport Utility Vehicles
SV	Single Vehicle Crash
MLE	Maximum Likelihood Estimation
MV	Multi-vehicle Crash
NHS	National Highway System
VMT	Vehicle Miles Traveled

SUMMARY

Southeastern states have about 26 percent of the nation's total fatalities, and are about 24 percent above the national mean over recent years. Descriptive statistics, graphs, and figures are used to illustrate and quantify the crash trends, which depict a comprehensive picture of status and trends of the fatal crashes in southeastern states. The severity of crashes is studied as a function of characteristics of the person involved in the crash, vehicle, traffic condition, physical road geometry, and environmental factors. Detailed geometric feature data were collected for this study, which makes it possible to investigate the relationship between geometric features and crash severity. This study identifies causal factors contributing to the high fatality rate in southeastern states, and sheds light on the differences and similarities among these states for reducing the severity of fatal crashes, by developing multinomial logit models to explain the severity and type of fatal crashes.

CHAPTER 1: INTRODUCTION

For decades, the highway networks have provided the convenience of mobility at the expense of traffic crashes. The crashes are associated with economic losses and human suffering. In the US, "in 2003, there were an estimated 6,328,000 police reported traffic crashes, in which 42,643 people were killed, 2,889,000 people were injured, and 4,365,000 crashes involved property damage only." (NHTSA, 2003) These numbers depict a snapshot of the long existing highway safety problems in the US. For every year during the period from 1975 to 2003 that records for traffic crashes exist, traffic crashes have taken over 40,000 lives, caused injury for another 3 million people, and caused 4 million property-damage-only crashes in the States. Of even greater concern is the fact that road traffic injuries are the leading cause of death for people between the age of 2 and 34, and the third leading cause of the death for people between the age of 35 and 44 in the US. (NHTSA, 2003)

1.1. Background

Given these numbers as a backdrop, numerous studies have been carried out to improve the safety of the highways from different perspectives. Each study makes its own contribution to the highway literature depending on the subject they studied. Different from the previous studies, this dissertation focuses on fatal crashes on rural two lane highways in the individual southeastern state as well as in the southeast region.

1.1.1. High Fatality Rate in Southeast Region

Although the total number of fatalities has oscillated between 41,817 and 44,599 over the years, traffic volumes have increased and the fatality rate per 100 million vehicle miles traveled have decreased steadily from 3.35 in 1973 to 1.48 in 2003. These numbers show that much progress has been made in reducing the number of fatalities and other serious injuries on United States (U.S.) highways. However, the reduction of the number and severity of motor vehicle crashes differ widely among the 50 states and the District of Columbia. In the U.S., the eight states in the southeastern region (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee) experienced a significantly higher fatality rate when compared with the national average for the same time period and thus a slower reduction in fatalities.

The numbers in Table 1.1 and 1.2 are based on the data from the U.S. Department of Transportation's Fatality Analysis Reporting System and Federal Highway Administration (NHTSA, 2003.) Table 1.1 includes number of fatalities in the southeast region by state from the years 1975 to 2003. While the overall total number of fatalities slightly decreased over the years in the US, all eight southeast states experienced a constant increase in the number of fatalities. Southeastern states represented about 8 percent of the nation's total fatalities in year 1975 and the percentage has steadily increased. In 2003, the southeastern region accounted for about 14 percent of the nation's total fatalities.

Table 1.1 Numbers of Vehicle Crashes Fatalities in the Southeast Region by State (1975 to 2003)

State	1975	1985	1990	1995	2003	Difference 1975-2003 (%)
AL	902	882	1,121	1,114	1,001	+11
FL	1,998	2,832	2,891	2,805	3,169	+59
GA	1,360	1,361	1,562	1,488	1,603	+18
KY	863	712	849	849	928	+8
MS	546	662	750	868	871	+60
NC	1,506	1,482	1,385	1,448	1,531	+2
SC	820	951	979	881	968	+18
TN	1,126	1,101	1,177	1,259	1,193	+6
USA	44,525	43,825	44,599	41,817	42,643	-4

Table 1.2 includes the vehicle crashes fatality rate per 100 million vehicle miles traveled in the southeast region by state from 1975 to 2003. If the increasing vehicle mileage traveled is taken into account, the southeast states have still experienced fewer safety improvements than the national average. Other than Georgia, the fatality rate in all the seven remaining southeastern states have ranged from 6 to 70 percent above the national mean since 1990. The wide range of the difference in fatality rates between different states and the national mean indicates that these states may have unique characteristics contributing to their various fatal crashes.

Table 1.2 Vehicle Crashes Fatality Rates in the Southeast Region by State, 1975-2003

State	1975	1985	1990	1995	2003	Difference 1975-2003 (%)
AL	3.63	2.51	2.65	2.2	1.71	-53
FL	3.24	3.22	2.63	2.19	1.71	-47
GA	3.46	2.53	2.22	1.74	1.47	-58
KY	3.5	2.5	2.52	2.07	1.99	-43
MS	3.8	3.45	3.07	2.94	2.32	-39
NC	4.14	2.97	2.21	1.9	1.63	-61
SC	3.98	3.56	2.85	2.28	2.01	-49
TN	3.42	3.03	2.52	2.24	1.73	-49
USA	3.35	2.47	2.08	1.73	1.48	-56

The numbers in Table 1.1 and Table 1.2 suggest that approximately one-fourth of the nation's fatalities occur in the eight southeastern states, where the fatality rate is about 20 percent above the national average. This dissertation was conducted to determine why fatal crash rates were higher in the southeast region (1.71 to 2.32 per 100 million vehicle miles) than in the rest of the nation (1.48), why the fatal crash rate is different from one state to the other, and what could be done to reduce fatal crashes in the region.

1.1.2. High Fatality Rate on Rural Two-lane Highways

Rural two lane highways account for 40 percent of the vehicle miles traveled, but they account for 60 percent of all fatal crashes (NTHSA, 1996). Two-lane rural highways include many different types of road conditions, carry different traffic volume, and therefore serve different functions. Although they are generally undivided, they can be winding roads with sharp curves and super-elevated cross sections, or roads with gentle curves and typical rooftop cross sections. They have considerable differences in site characteristics including lanes, shoulders, and roadside features. For instance, the widths of traffic lanes and shoulders vary drastically from site to site. At some sites, lane width was as narrow as 8 feet while some sites had wide paved shoulders or wide lanes up to 17 feet.

Furthermore, although the risk of a personal-injury-crash per miles traveled is higher on access controlled freeways, the risk of a fatal crash per vehicle miles traveled is higher on rural two lane roads. Differences between injury and fatal crashes indicate the need to focus on the rural two lane highways.

A better understanding of fatal crash contributing factors of rural two lane highways in the southeastern states may help to reduce both the frequency and severity of crashes in the southeastern region.

1.2. Previous Southeast Region Crash Studies

The southeastern crash statistics have raised interest in inter-regional and intra-regional comparisons of the effect of possible contributing factors on the fatal crash occurrence. Washington et al. (1999) conducted an inter-regional comparison of fatal crashes in the southeastern and non-southeastern United States. Their study identified differences in fatal crashes between the southeastern region and the rest of the U.S. The results suggested that regional differences in fatal crashes may indeed exist. Their study also provides insights on some inter-regional factors that play a role in the occurrence of fatal crashes. Some examples of the factors are seat-belt usage, vehicle miles traveled by functional classification, and speed limit differences are a few examples of the factors. However, their study did not include an intra-region comparison. This goal of this dissertation, therefore, is to fill the knowledge gap about the comparison of the relative safety performance records among the southeastern U.S. states.

In response to these higher fatality crash rates, the southeastern states initiated a pooled fund study in 2001 in an attempt to isolate contributing factors and identify potential solutions. Researchers from six participating states, Alabama, Georgia, Mississippi, North Carolinas, South Carolinas, and Kentucky, collected extensive information on 150 (100 in Mississippi) randomly selected fatal crashes in their own state. Data for four of these states is included in the analysis summarized in this dissertation. The data set includes information on drivers, passengers, vehicles, traffic, physical road geometric features of crash sites, and environmental factors. This unique data set, including site-specific field observations, provides the opportunity to explore the effects of specific geometric features on the fatal crashes in a level of detail that is not possible with crash reports as the sole data source.

No detailed evaluations have been conducted to quantify the effect of these factors. An advanced study was needed in order to gain greater insight about the differences across southeastern states and determine why these differences may be occurring. Moreover, the continuation of the pooled fund study would capitalize on significant efforts already undertaken by many researchers. Researchers in each participating state have collected detailed site geometric data for every crash selected. This rich data source offers the opportunity to explore the effects of geometric features on fatal crashes and identify the source of crash variations among the Southeastern states. The dissertation is a continuation of the pooled-fund study to determine why fatal crash rates were higher in southeastern United States and what could be done to reduce fatal crashes in the region.

1.3. This Dissertation

This dissertation identifies causal factors contributing to the high fatality rate on two lane rural highways in southeastern states, and sheds light on the differences and similarities among these states and the rest of the nation for reducing the severity and frequency of fatal crashes. This dissertation reviews the development of appropriate statistical models to explain the severity and type of fatal crashes.

This dissertation has three major objectives, and each objective is explored in detail in Chapters 4, 5, and 6, respectively.

- Chapter 4: Perform a detailed analyses of the fatal crash statistics and trends,
- Chapter 5: Develop multinomial logit models for explaining and predicting variations in fatal crash severity, and
- Chapter 6: Develop multinomial logit models for explaining and predicting variations in fatal crash type.

To accomplish these objectives, three major steps are taken to analyze the fatal crash data. The first step is using descriptive statistics, graphs, and figures to illustrate the crash trends, quantify the relationship between contributing factors and crash severity and type, and depict a comprehensive picture of status and trends of the fatal crashes in all southeastern states. The second step is estimating logit regression models of crash severity, including fatality, incapacitating nonfatal injury, non-incapacitating nonfatal injury, possible injury, and no injury. The third step is developing multinomial logit models of crash type including running off the road, rollover, head on, rear-end, sideswipe, etc. These models associate probabilities of crash severity and type with numerous roadway, traffic, and environmental factors, and establish a relationship between recommended countermeasures and the crash type and severity.

This dissertation documents the research approach and results of an investigation to identify problem areas related to highway safety in which southeast region is over-represented relative to other states and the nation as a whole. It also documents a multiple-step process used to identify highway safety problem areas unique to this region, as well as lessons learned, and recommendations for future research.

The dissertation provides a strategy for directing future research to explore why and how problem areas are over-represented in one state compared to other states. The research results provide policy makers and highway safety advocates with a better understanding of factors that may contribute to higher fatality rates in the states in the southeastern region. The highway engineering practices and legislative policies in these states can benefit from the results and information provided in this dissertation to improve the safety in their states.

This dissertation has seven chapters. Chapter 1 introduces the overall scope and the background of this dissertation. Chapter 2 includes the review of the safety study literature and comments on the difference between this dissertation and the literature. Chapter 3 defines the analytical framework for this study. It covers the data reduction method and various logit regression models that are applied in this dissertation. Chapter 4 describes the database that is used in this study, provides detailed information about the five data elements, and identifies the fatal crash trends in the southeastern states. It also discusses the data reduction and selects most influential factors to develop crash model. Chapter 5 summarizes the crash-severity model for all states studied in this dissertation as well as the model for each individual state. It also reviews the selection and interpretation of the influential factors critical to crash severity. Chapter 6 summarizes the crash-type model for all participating states as well as for each individual state and discusses the influential factors important to crash type. Chapter 7 presents the key findings and significant contributions of this dissertation. Possible future researches are also discussed in this chapter.

CHAPTER 2: LITERATURE REVIEW

As stated in the previous chapter, the objective of this dissertation is to identify a comprehensive list of candidate safety factors that are likely to be effective for reducing the severity of traffic crashes in each participating state of the pooled fund study. Highway safety researchers have examined and analyzed the effects of various factors in different states in the past. The objective of the chapter is to comprehensively review the safety literature of different kinds of factors in various conditions on rural two lane highways.

The extensively studied factors include but are not limited to gender, age, driver alcohol usage, roadside features, vehicle type, personal and behavioral characteristics, traffic volume, highway design, and seat belt usage. However, of the available literature on this topic, most studies concentrated on the personal factors and vehicle characteristics. Only a few studies evaluated highway geometric features and their influence on safety. Although there are many similarities in the studies concerning the safety effects of causal factors, conflicting results can also be found.

This chapter consists of a comprehensive literature study and a compilation of existing results of safety studies. Each subsequent section of this chapter covers the findings and discussions of a specific factor or a subgroup of the factors and their resulting effects on severity or type of traffic crashes. The literature review of the methodology used in existing safety study on crash severity and crash type are included in Chapter 3: Methodology.

2.1. Gender and Age

Several studies have investigated the differences of crash severities between males and females (Evans, 1986; Abdel-Aty and Abdelwahab, 2001; Ulfarsson and Mannering, 2004). Evans (1986) determined that females have a higher probability of fatal injury than males in similarly severe crashes in the same type of vehicle. Also, Abdel-Aty and Abdelwahab (2001) found that female drivers were more likely to suffer severe injury than males. Ulfarsson and Mannering (2004) explored differences in injury severity between male and female drivers by estimating separate multinomial logit models for injury severity of male and female drivers. They found that the differences in injury severity between male and female drivers exist in single and two-vehicle crashes involving different types of vehicles, including passenger cars, pickups, sport-utility vehicles (SUVs), and minivans. They also found out that some variables, such as striking a barrier or a guardrail, increase the probability of lesser severity for male drivers while increase the probability of greater severity for female drivers.

While most researchers conclude that gender and age are important factors for crash severity, Kim et al. (1995) determined personal characteristics of age and sex are generally insignificant. All research suggests that there are significant differences between male and female severity in significance level, different degrees of impacts. Most important is some factors have opposite effects.

O'Donnell and Connor (1996) predicted the severity of motor vehicle crash injuries using models of ordered multiple choice. This paper presented how variations in the attributes of vehicle occupants can lead to variations in the probabilities of sustaining different levels of injury in traffic crashes. The benchmark they used for comparison is a

33-year-old male involved in a head-on collision while traveling at 26 miles per hour in a 10-year-old vehicle. Their results showed that the probability the victim will remain uninjured or be killed is almost zero, that he will require treatment from a medical officer is approximately 0.7, and that he will be admitted to hospital is approximately 0.3. Increases in the age of the victim and vehicle speed slightly increase the probabilities of serious injury and death. They also found some factors, including seating position, blood alcohol level, vehicle type, vehicle make and type of collision, which have a similar or greater effect on the probabilities of different types of injury.

2.2. Person Type

In most of the severity studies, the studied objects are always vehicle drivers and the observations can only be applied to the drivers unless otherwise specified. The lack of relevant studies about the severity of the passengers makes it difficult or inaccurate to estimate the effectiveness of the safety improvements on the passengers.

McCarthy P. and Talley W. K. (2001) studied the effects of recreational boating safety investments and the influence of current on boating injury severity for both the boat operator and passengers. Their study on 1989-2003 boating crashes indicated that the some safety factors have different effects on the boat operator and the passengers. For example, higher levels of operator (passenger) alcohol consumption increase operator (passenger) injury severity, but have no impact on passenger injury severity. They also found that some variables, such as the human capital investments in safety, have the same effects on both boat operators and the passengers. Although this cited study focused on boating safety, it enhanced our understanding of the different effects of the same factor on the severity of boat operator (drivers) and passengers.

Based on results in McCarthy and Talley's study, it is worth the effort to explore the effects of the factors on the drivers and the passengers separately in this dissertation. The severity models developed in this dissertation are estimated on the information including both the drivers and the passengers.

2.3. Driver Alcohol Use

Driver alcohol use is an important factor in causing severe traffic crashes. If the driver had been drinking, the crash is more likely to result in a severe injury or death than are crashes caused by sober drivers. Many researchers have studied the impact of driver alcohol use on traffic crash severity. Traynor (2005) estimated the impact of driver alcohol use on average crash severity using a crash dataset that was supplemented with location based socioeconomic information. The logit model estimates indicate that at-fault driver alcohol use increases both the expected highest degree of injury resulting from a crash and the number of injuries or deaths per crash. These results indicate that at-fault drinking drivers are more likely to be involved in violent crashes and cause more serious injuries during the crash than those caused by at-fault sober drivers can do.

2.4. Roadside Features

Roadside features have been extensively studied because of their significant effects on the severity of people involved in the run-off-the-road vehicle crashes.
Some researchers studied it at an aggregated level. Al-Ghamdi (2002) studied the effect of the crash location along with crash type, crash time, crash cause, vehicle type, and licensing status. Al-Ghamdi determined that location is one of the two significant factors associated with the severity of the crashes. The crash locations are classified as intersection, median opening, circle, exit, and road section. The results indicate that the

probabilities of being involved in a fatal crash at a non-intersection location are 2.64 times higher than those at an intersection.

Other researchers estimated the impact of some specific roadside features on the frequency and severity of run-off-roadway crashes. The specific roadside features include roadway guardrail systems (Lee and Mannering, 2002), utility poles (Dixon et al., 2002; Lee and Mannering, 2002), bridges (Zegger and Council, 1995), sign supports (Lee and Mannering, 2002), side slopes (Zegger and Council, 1995), and ditches and fences (Eugene et al, 2000).

These studies provide some initial insight into this important problem by analyzing the effects of the roadside features on single vehicle crashes. The run-off-the-roadway crash severity is an interaction between the vehicles and the roadside features including the guardrail, utility poles, trees, side slope, etc. While some of these features contribute to fatal crashes as the run-off-the-roadway vehicles may hit the fixed objects, some features help mitigate the crash severity by changing the driver behavior or vehicle path.

Some researchers (Kloeden et al., 1999) have focused on countermeasures for roadside hazards to make the roadsides safer for all crashes. Key findings indicated that roadside hazards were the immediate cause of at least one death in 40 percent of all crashes in which a vehicle occupant was fatally injured. Changes to the roadside slopes or the provision of guardrails could have prevented many of the rollover fatal crashes. Countermeasures aimed at reducing traveling speed, drunk driving, and driver fatigue not only decrease the frequency of roadside hazard crashes but also reduce other types of crashes. However, dangers caused by roadside hazards cannot rely on changes to driver behavior alone.

2.5. Cause of Crashes

Al-Ghamdi (2002) applied logit regression to crash-related data collected from police crash reports in order to determine the contribution of several variables to crash severity. The tested sample included a total of 560 serious crashes. Each crash in the database was classified as being involved in either a fatal or non-fatal crash. Therefore, severity in this study was defined as a binary variable with two categories, fatal and non-fatal. Because of the binary nature of this dependent variable, Al-Ghamdi (2002) used logit regression approach to develop the models. Other than speeding, running red light, wrong way, and failure to yield, the location and cause of crash were two other significant factors obtained from police crash reports.

2.6. Vehicle Type

Kockelman and Kweon (2002) used ordered probit models to examine the risk of different injury levels sustained under all crash types including both multi-vehicle crashes and single vehicle crashes. In single vehicle crashes, pickups and sport utility vehicles are less safe than passenger cars. In multi-vehicle crashes, however, pickups and sport utility vehicles are associated with less severe injuries for their drivers and more severe injuries for vehicle occupants of other vehicle involved in the crash. Many other studies such as Ulfarsson and Mannering (2004) have made similar observations.

2.7. Behavioral Characteristics

Researches on drivers and driving behavioral characteristics cover a wide range of topics and approaches (Kim et al., 1995; Groeger and Rothengatter, 1998; Parker et al., 1995). They developed statistical models explaining the relationships between certain driver characteristics and driving behaviors, and injury severity in their studies. These studies have shown that the risk of involved in traffic crashes is associated with the tendency to commit driving violations, speeding, and a lack of thoroughness in decision making.

Kim et al. (1995) applied techniques of categorical data analysis to comprehensive crash data in Hawaii during 1990. The discrete model related driver characteristics and behaviors to type of crash and injury severity. Kim et al. found that driver behaviors of alcohol or drug use and lack of seat belt use greatly increase the chances of more severe crashes and injuries. Driver errors were found to have a small impact on injury severity in their study.

The key to the development of crash countermeasures is the understanding of how drivers perceive the road environment and how they process the information obtained from the environment. Groeger and Rothengatter (1998) reviewed the traffic psychology and behavior related literature, including driver perception and cognition and the social psychology of driving. The countermeasures proposed in their study not only include traditional approaches such as road user education and training, but also include the application of psychological knowledge about driver perception and cognition. These new countermeasures can contribute to optimal road and vehicle design.

Parker et al. (1995) studied the behavioral characteristics in different types of traffic crashes. The studied crash types were rear end collisions, right-of-way violations, and loss-of-control crashes. Together these three crash types accounted for more than 70 percent of the crashes. Based on the position of the vehicle, the role of the reporting driver is defined as active (striking) or passive (struck). Parker et al. (1995) examined the driver behavior measured by tendency to commit violations, driving style measured by frequency of fast driving, and decision making measured by thoroughness in decision making. The results showed that a high tendency of violation activities was associated with crashes in general, both active and passive. It was specifically associated with active loss-of-control crashes and passive right-of-way crashes. High driving speed and low attention were associated with active crashes only. High speed was associated with active right-of-way violations. Low attention was specifically associated with active rear-end collisions and active right-of-way violations.

2.8. Traffic Volume

Golob and Recker (2003) developed a model for relating type of crash to traffic flow characteristics on urban freeways. Crashes were classified in terms of the following criteria, including the type and location of the collision, the number of vehicles involved, movements of these vehicles prior to collision, and severity. Traffic flow characteristics were measured by the mean and variations of traffic volume and speed for three different lanes at the time and place of the crash occurrence. The results indicated that the associations between freeway crash characteristics and prevailing traffic flow conditions were well-defined. The descriptive characteristics of crashes had distinctive tendencies and temporal variations under different traffic flow conditions if the light condition and road surface condition are controlled. Each type of crashes that is most likely to occur had a matching traffic flows pattern. The matching between distinctive traffic flow parameters and crash types reveals how congestion affects highway safety.

2.9. Highway Design, Crash Type, Driver Characteristics, Vehicle, and Environment

Shankar et al. (1996) estimated a nested logit model of crash severity with five-year crash data from a 38 mile section of rural interstate highway in Washington State. Four levels of severity were considered in their study: (1) property damage only; (2) possible injury; (3) evident injury; and (4) disabling injury or fatality. The estimated results provided valuable insights on the effect that environmental conditions, highway design, crash type, driver characteristics, and vehicle attributes contributes to different levels of crash severity.

2.10. Seat Belt Usage

Washington et al. (1999) studied the phenomenon of high traffic fatality rates compared with the national average that had existed several decades in the southeast region. Their objective was to identify the causal factors and possible effective countermeasures. They determined that a primary factor contributing to the high fatality rate was that drivers were not wearing, or not properly wearing, their seat belts in this region. They also found out that the usage of seat belts appear to vary significantly across regions and even across states in the same region. Based on their results, about 1400 fatal more crashes in the southeastern region occurred in 1995 due to the fact that the drivers were not wearing safety restraints, assuming that the region and restraint use are independent and crashes are proportional to Vehicle Miles Traveled (VMT).

In the aforementioned study conducted by Kim et al. (1995) on crashes in Hawaii during 1990, the authors of the study also found that lack of seat belt use increases the chances of more severe crashes and injuries to a greater extent.

2.11. Crash Type

Several researches mentioned in the earlier sections, such as Kockelman and Kweon (2002), Parker et al. (1995), and Golob and Recker (2003), studied the relationship of crash type with various factors. Kockelman and Kweon (2002) determined that people driving different types of vehicles have different chances of sustaining injury for these crashes. Parker et al. (1995) studied the effects of behavioral characteristics on different types of traffic crashes. They found that different driving characteristics are associated specifically with involvement in each one of the crash types. Golob and Recker (2003) developed a model for relating crash types to traffic flow characteristics on urban freeways. The results indicated that different types of crashes were related to some traffic flow characteristics including central tendency and variation of traffic flow volume.

2.12. Discussion

Much of the existing literature focus on the human factors and vehicle related factors. Only a limited number of studies have been conducted to examine the impacts of the limited geometric features of the sites. The common studied geometric feature is roadside hazards. Except for roadside features, very little is known about the influence of geometric features on the actual crash condition. This study focuses on the effects of selected geometric features in the southeastern states.

Another important characteristic about previous studies is that most of the data used are from one state or even one segment of roadway, and so the variation in the geometric features of the crash sites is limited. This dissertation also examines the crash trends or the differences in the effects of factors across several different states.

CHAPTER 3: METHODOLOGY

This chapter discusses the two major methodologies that are employed in this dissertation. Section 3.1 discusses the theory of cluster analysis used to identify the homogeneous group among the eight southeastern states with similar crash characteristics. For various reasons, not all southeastern states have data available, as discussed in Chapter 4. The result of the cluster analysis can help us extend the findings within the states with data to the states without data available. Section 3.2 discuss as different types of logit regression models used to investigate the impacts of personal factors, geometric features, vehicle characteristics, and ambient environment on the type and severity of the crashes described in Chapter 5 and Chapter 6. Details of why a particular type of the model is selected or where it is applied in this dissertation are discussed in this section.

3.1 Cluster Analysis

Cluster analysis detects the relationships among a set of observations, and classifies them into two or more mutually exclusive groups or clusters based on the distances among the observations. The observations in a given cluster tend to be similar to each other since they share characteristics. The observations in different clusters are less similar to each other. Based on this feature of the clusters, the results of crash severity and type study in one state can offer valuable information to those states that are in the same group but have no data available. The eight southeastern states are classified in several homogeneous groups and the results are discussed in section 4.2.

This section briefly reviews how cluster analysis works and presents the methodology of cluster analysis. The general approach is to start with the creation of a proximities matrix, which includes relative similarities or differences between all observations. The information in the proximities matrix is then used to combine the observations into multiple clusters. The method of combining observations into clusters is called a clustering algorithm. The idea is to combine similar observations into one cluster. The results of the cluster analysis are usually presented as a tree structure (Stockburger D. W., 1998). These major components of cluster analysis are presented in section 3.1.1 to 3.1.3.

3.1.1. The Proximities Matrix

For this dissertation, cluster analysis starts with a table, where the observations -- the eight different states in the southeast region -- are rows, and the measures -- the fatal traffic crash rate in year 1975 to 2003 in all eight states -- are columns, as in Table 1.2. Starting with this information, another table, which is also called the proximities matrix, is constructed where element (i, j; i, j = AL, FL, GA, KY, MS, NC, SC, NY) measures the similarity or difference between observations i and j. Table 3.1 is an example proximities matrix for the year 1975. The numbers in the matrix are the differences of fatal crash rates between each pair of states in 1975.

Table 3.1 The Proximities Matrix for the Year 1975

	AL	FL	GA	KY	MS	NC	SC	TN
AL	0	0.39	0.17	0.13	-0.17	-0.51	-0.35	0.21
FL	-0.39	0	-0.22	-0.26	-0.56	-0.9	-0.74	-0.18
GA	-0.17	0.22	0	-0.04	-0.34	-0.68	-0.52	0.04
KY	-0.13	0.26	0.04	0	-0.3	-0.64	-0.48	0.08
MS	0.17	0.56	0.34	0.3	0	-0.34	-0.18	0.38
NC	0.51	0.9	0.68	0.64	0.34	0	0.16	0.72
SC	0.35	0.74	0.52	0.48	0.18	-0.16	0	0.56
TN	-0.21	0.18	-0.04	-0.08	-0.38	-0.72	-0.56	0

Proximities matrices are generated for every year from 1975 to 2003. Then the value in each corresponding cell is added into a combined proximities matrix.

3.1.2. Clustering Algorithm

After the distances between objects are found, the next step of the cluster analysis procedure is to divide the objects into groups based on the distances in the proximities matrix. Two general methods of clustering algorithm are available: the “flat” method and the hierarchical clustering method.

A "flat" method might be preferable if the number of groups is already known. Using this method, the first step assigns the observations to a given group based on some initial criterion. The means for each group are calculated after the assignment. Then the algorithm reassigns the observations to groups based on the object's similarity to the current mean of that group. The means of the groups are recalculated. The process is repeated until no observations change groups.

Hierarchical clustering method is preferred if there is no prior knowledge of the number of groups. Two hierarchical clustering methods -- the divisive technique and the agglomerative technique -- classify the clusters in different ways. The divisive technique starts with all observations in one single group, separates the group into several subgroups, and keeps separating these subgroups further into smaller subgroups until each observation forms its own subgroup. The agglomerative technique starts with each observation in its own group, and then combines similar subgroups into more inclusive subgroups until there is only one single group.

3.1.3. Tree Structure

The results of the application of the clustering technique are best described using a tree structure. The interpretation of a tree structure is straightforward. Nodes represent the observations. Branches illustrate which subgroups contain the observations that are similar to each other. The lengths of the branch indicate the similarity between the subgroups. The longer the branch is, the less similar the subgroups are. Figure 4.2 illustrates this graphically.

3.2. Logit Regression Models

As stated in Chapter 1, the objective of this dissertation is to identify the causal factors of the high fatal crash rate in southeastern United States and discover the differences of the factors among the studied states. The crash severity and crash type, by definition, are multi-category variables. Due to the discrete nature of these variables, logit regression was used to investigate the relationship between the crash severity or type and the various causal factors.

In the literature, researchers have employed various limited dependent variable methodologies to analyze crash severity. Some researchers employed ordinal regression models (e.g. ordered logit analysis, ordered probit analysis) while other researchers have used the multinomial logit model. Kockelman and Kweon (2002) used ordered probit models to examine the risk of different injury levels sustained under all crash types, two-vehicle crashes, and single vehicle crashes. O'Donnell and Connor (1996) predicted the severity of motor vehicle crash injuries using an ordered logit model and found that increases in the age of the vehicle's occupants and vehicle speed lead to increases in the probability of severe injury. Carson and Mannering (2001) studied the effectiveness of ice warning signs and other spatial, temporal, traffic, and roadway characteristics in Washington State using multinomial logit model. Ulfarsson and Mannering (2004) explored the differences in male and female injury severities in different vehicle configurations with a multinomial logit model.

A clear understanding of different types of logit models is critical in selecting the right model for exploring the effects of factors on crash severity and type. Section 3.2.1 discusses why logit models are chosen over ordinal linear regression models for studying discrete dependent variables. Sections 3.2.2, 3.2.3, and 3.2.4 review the assumptions and estimation of logit based regression models, specifically multinomial logit model, the ordinal logit model, and the multinomial logit model with cluster effects. Section 3.2.5 discusses the applications of logit models in this dissertation.

3.2.1. Why Logit Model?

Ordinary linear regression analysis is not appropriate for estimating models with discrete dependent variables such as crash severity and crash type. The discrete nature of the dependent variable precludes using linear regression models for the following reasons. First, linear regression models implicitly assume that the error terms have constant variance. However, in a linear regression framework with discrete data, the errors are heteroskedastic since they depend on the probability of the individual. Second, the errors in the linear regression models are assumed to be normally distributed. This is violated and the error terms are not normally distributed when the dependent variable only takes a set of discrete values. Third, although the linear regression model can be interpreted as a probability model, the predicted value of the dependent variable from a linear regression model can take a value outside of the [0, 1] range which contradicts the model's interpretation as a probability model.

The probability models, such as logit type models, do not suffer from the problems that ordinary linear regression models have. The discrete nature of the dependent variable requires alternative estimation models and logit models offer the ability to associate the discrete dependent variable with the values of certain determining and explanatory variables. Two logit regression models are considered in this thesis: the multinomial logit model and the ordered logit model.

3.2.2. Multinomial Logit Model

Multinomial logit analysis is employed in this dissertation to explore the relationship between both the crash severity and crash type and the various factors. This section introduces the underlying rationale of the multinomial logit model. It also discusses the model assumption, the maximum likelihood estimation, and the elasticity of the multinomial logit model.

3.2.2.1. Model Introduction

Suppose the drivers traveling on the road are indexed with numbers $i = 1, \ldots, I$. Let P_{im} denote the probability of driver i being injured with crash type or severity level m, where $m = 1, 2, \ldots, M$. Suppose that the severity of a person who is involved in an crash is determined by a linear function of contributing factors, $\beta_{mr} x_{ir}$, where β_{mr} is an array of coefficients associated with the rth character of the ith person for the mth severity level, and x_{ir} is an array of r contributing factors for person i representing the characteristics of the person and vehicle who is involved in the crash, crash site, and the prevailing environment condition. The probability that person *i* experiences severity level or crash type *m* is (Long, 1997),

$$\begin{aligned} &P(y_i = m) \\ &= P(\sum_{r=1}^{R} \beta_{mr} x_{ir} + \varepsilon_{im} > \sum_{r=1}^{R} \beta_{jr} x_{ir} + \varepsilon_{ij}) \\ &= P(\varepsilon_{ij} - \varepsilon_{im} < \sum_{r=1}^{R} \beta_{mr} x_{ir} - \sum_{r=1}^{R} \beta_{jr} x_{ir}) \end{aligned}$$

for all $j=1, \ldots, M, j \neq m$.

If the error terms ε_{im} $(i = 1, \ldots, I; m=1, \ldots, M)$ are independently and identically distributed with Weibull distribution $F(\varepsilon_{im}) = e^{e^{-\varepsilon_{im}}}$, then the probability that alternative m is chosen is (McFadden, 1973)

$$P_{im} = P(y_i = m | x_i) = \frac{\exp(\sum_{r=1}^{R} \beta_{mr} x_{ir})}{\sum_{j=1}^{M} \exp(\sum_{r=1}^{R} \beta_{jr} x_{ir})}$$

In order to identify the model, it is necessary to set one of the coefficient vectors equal to 0. Assuming that alternative 1 is the normalizing alternative then $\beta_{1r} = 0$ is and the model estimates *(M-1)* vectors of coefficients, β_{jr} $(j=2, \ldots, M)$. In this dissertation, fatal injury of severity level in Chapter 5 and single vehicle crash of crash type are used as the normalizing alternatives.

3.2.2.2. Independent of Irrelevant Alternatives (IIA) Assumption

The multinomial logit model is the most frequently used model for nominal discrete levels. The effects of the independent variables are allowed to differ for each level. That is, the coefficient β is different for each category.

The ratio of the probability that one level *m* is chosen over the other level *j* in the multinomial logit model is

$$\frac{P_m}{P_j} = e^{\sum_{i=1}^{R}(\beta_{mr}-\beta_{jr})x_r}$$

This formula indicates that the ratio is independent of the rest of the options. This is the property of the multinomial logit model called independent of irrelevant alternatives (IIA). IIA can be stated as "Where any two alternatives have a non-zero probability of being chosen, the ratio of one probability over the other is unaffected by the presence or absence of any additional alternative in the choice set" (Ben-Akiva and Lerman, 1985).

The IIA property of multinomial logit model leads to a closed form specification of the probability, which is easy to estimate. However, the estimates will be biased if the IIA property is violated.

3.2.2.3. Maximum Log Likelihood Estimation

Let $P(y_j = m \mid x_i, \beta_2, ..., \beta_M)$ be the probability of $y_j = m$, given x_i and parameters β_2 through β_M. If P_{im} *is* the probability of alternative m or the i^{th} observation and assuming that the observations are independent, then the likelihood function is

$$L(\beta_2, ..., \beta_M \mid y, X) = \prod_{i=1}^{I} P_{im} = \prod_{m=1}^{M} \prod_{y_i=m} \frac{e^{x_i\beta_m}}{\sum_{j=1}^{M} e^{x_i\beta_j}}$$

where $\prod_{y_i=m}$ is the product over all cases for which y_i is equal to m.

3.2.2.4. Marginal Effects and Elasticity

The relative influence of each attribute is given by its coefficient in the model. The interpretation of the coefficients is relative to that of the normalizing alternative. Therefore, the interpretation of the coefficient is not straightforward due to the nonlinear nature of the multinomial logit models. Calculating the marginal effects and elasticities identify the various impacts of changes in the causal factors.

The marginal effect is the change in the probability of alternative *m* due to a one unit change in the level of contributing factor x_r, that is

$$\frac{\partial P_m}{\partial x_r} = \frac{\partial \dfrac{\exp(x_r \beta_m)}{\sum_{m=1}^{M} \exp(x_r \beta_j)}}{\partial x_r}$$

For non-normalized alternative, the marginal effect is

$$\frac{\partial P_m}{\partial x_r} = (\beta_{rm} - \sum_{j=1}^{M} \beta_{rj} P_j) P_m$$

For normalized alternative, the marginal effect is

$$\frac{\partial P_m}{\partial x_r} = (-\sum_{j=1}^{M} \beta_{rj} P_j) P_m$$

An elasticity represents the responsiveness of a one percent change in individual's choice probability to a one percent change in the value of some attribute. For the multinomial logit model, elasticity provides the extent to which crash type probabilities are sensitive to changes in an explanatory variable. All elasticities reported in this dissertation are calculated at the mean of the variables. By definition, for non-normalized group, elasticity is

$$E = \frac{\partial P_m}{\partial x_r}\frac{x_r}{P_m} = (\beta_{rm} - \sum_{j=1}^{M}\beta_{rj}P_j)x_r$$

For normalized group, the elasticity is

$$E = \frac{\partial P_m}{\partial x_r}\frac{x_r}{P_m} = (-\sum_{j=1}^{J}\beta_{rj}P_j)x_r$$

3.2.3. Ordered Logit Models

An alternative methodology to multinomial logit analysis is ordered logit. After the model is introduced, the parallel slope assumption of the ordered logit model is discussed along with Maximum Likelihood Estimation (MLE) of the parameters and the elasticity of the variables.

3.2.3.1. Model Introduction

Some discrete data encountered in transportation applications are ordered. In contrast to data that are not ordered, ordinal discrete data possess additional information on the ordering of responses that can be used to improve the efficiency of the model's parameter estimates. If a relation with an ordinal dependent variable is estimated by the methods of multinomial logit model, the information conveyed by the ordered nature of the data is ignored, which entails a loss of efficiency.

Let the cumulative logit distribution function for random variable X be

$$P(X \le x) = \Lambda(x) = \frac{e^x}{1+e^x} = \frac{1}{1+e^{-x}}$$

Assuming that the error term follows a logit distribution, then the probabilities for the j categories are:

$$P(Y_i = 1) = \Lambda(\delta_1 - Z_i) = \frac{1}{1 + e^{Z_i - \delta_1}}$$

……

$$P(Y_i = m) = \Lambda(\delta_m - Z_i) - \Lambda(\delta_{m-1} - Z_i) = \frac{1}{1 + e^{Z_i - \delta_m}} - \frac{1}{1 + e^{Z_i - \delta_{m-1}}}$$

……

$$P(Y_i = M) = 1 - \Lambda(\delta_{M-1} - Z_i) = 1 - \frac{1}{1 + e^{z_i - \delta_{M-1}}}$$

For the ordered logit model, ε has a logit distribution with a mean of 0 and a variance of $\pi^2 / 3$. The probability density function of the error term is

$$f(\varepsilon) = \frac{e^{\varepsilon}}{(1 + e^{\varepsilon})^2}$$

and the cumulative density function of the error term is

$$F(\varepsilon) = \frac{e^{\varepsilon}}{1 + e^{\varepsilon}}.$$

3.2.3.2. The Parallel Slopes Assumption

A critical assumption of the ordered logit model is that of parallel slopes, i.e., the slope coefficients β_r will be the same for all categories. That is to say, the ordered logit model fits the following form:

$$\log \frac{p_1}{1 - p_1} = \alpha_1 + \sum_{r=1}^{R} \beta_r X_{ir}$$

$$\log \frac{p_1 + p_2}{1 - p_1 - p_2} = \alpha_2 + \sum_{r=1}^{R} \beta_r X_{ir}$$

……

$$\log \frac{p_1 + p_2 + \ldots + p_{M-1}}{1 - p_1 - p_2 - \ldots - p_{M-1}} = \alpha_M + \sum_{r=1}^{R} \beta_r X_{ir}$$

$$p_1 + p_2 + \ldots + p_M = 1$$

To explore the validity of the parallel slope assumption, a multinomial logit model with the same set of independent variable is estimated. The multinomial logit model allows the slope coefficients β_r to differ between the levels $m=1,\ldots, M$, while the ordered logit model restricts slope coefficients β_r to be equal for the different levels $m=1,\ldots, M$. While the ordered logit model estimates R coefficients, the multinomial logit model estimates $R(M-1)$ parameters. If L_1 is the likelihood value from the ordered logit model and L_2 is the likelihood value from the multinomial logit model, then one can compute $2(L_2-L_1)$ and compare with χ^2 (R(M-2)). It is important to note that this is not strictly a likelihood ratio test because the ordered logit model is not nested within the multinomial logit model. Consequently, the test is only suggestive: a very large χ^2 value would provide grounds for concern and lead one to use multinomial logit analysis despite the fact that dependent variable is clearly ordinal.

3.2.3.3. Maximum Likelihood Estimation

The estimates of the β_r, δ_1, and δ_2 are obtained by maximizing the likelihood function. Let β be the vector with parameters from the multinomial logit model, with the intercept β_0 in the first row, and let τ be the vector containing the threshold parameters. Only the difference in coefficients is identifiable and the coefficients are therefore identifiable only up to an additive constant. Either β_0 or τ_1 is constrained to 0 to identify the model.

$$P(y_i = m \mid x_i, \beta, \tau) = F(\tau_m - x_i\beta) - F(\tau_{m-1} - x_i\beta)$$

If the observations are independent, the likelihood equation is

$$L(\beta,\tau \mid y,X)=\prod_{i=1}^{I}P_{im}=\prod_{m=1}^{M}\prod_{y_i=m}P(y_i=m \mid x_i,\beta,\tau)=\prod_{m=1}^{M}\prod_{y_i=m}[F(\tau_m-x_i\beta)-F(\tau_{m-1}-x_i\beta))$$

$\prod_{y_i=m}$ indicates multiplying over all cases where y is observed to equal m.

The log likelihood equation is obtained by taking logs of the likelihood equation.

$$\ln L(\beta,\tau \mid y,X)=\sum_{m=1}^{M}\sum_{y_i=m}[F(\tau_m-x_i\beta)-F(\tau_{m-1}-x_i\beta)]$$

This equation can be maximized with numerical methods to estimate that τ's and the β's. Newton-Raphson method has been demonstrated to converge to a global maximum and the resulting estimates are consistent, asymptotically normal, and asymptotically efficient.

3.2.3.4. Marginal Effects and Elasticity

For continuous variables, the marginal effect on the various levels of a small change in the variables influencing the level changes, under a logit distribution, is

$$\frac{\partial P(Y_i=1)}{\partial X_{ir}}=\frac{d}{dZ_i}\Lambda(\delta_1-Z_i)\frac{\partial Z_i}{\partial X_{ir}}=-\Lambda'(\delta_1-Z_i)\beta_r$$

$$\frac{\partial P(Y_i=2)}{\partial X_{ir}}=\frac{d}{dZ_i}[\Lambda(\delta_2-Z_i)-\Lambda(\delta_1-Z_i)]\frac{\partial Z_i}{\partial X_{ir}}=[\Lambda'(\delta_2-Z_i)-\Lambda'(\delta_1-Z_i)]\beta_r$$

…

$$\frac{\partial P(Y_i=M)}{\partial X_{ir}}=\frac{d}{dZ_i}[1-\Lambda(\delta_{M-1}-Z_i)]\frac{\partial Z_i}{\partial X_{ir}}=\Lambda'(\delta_{M-1}-Z_i)\beta_r$$

The effects of a category variable should be analyzed by comparing the probabilities that result when the category variable takes one value with the probabilities that result that are the consequence of it taking the other value, the values of the other variables remaining unchanged between the two comparisons.

3.2.4. Multinomial Logit Models with Cluster Effects

Logit models implicitly assume that the observations in the dataset are independent. However, this assumption does not hold for the dataset used in this dissertation to estimate the crash severity models for two reasons. First, for people who are occupants in the same vehicle, the vehicle information is the same. Second, for everybody involved in the same crash, the crash, site, and environmental information are the same. These causes the observations on some factors are repeated. Repeated measurements are obtained for these factors for every unit of analysis. Multinomial logit model with cluster effect describes whether there are significant differences in the trend across groups of subjects defined by characteristics such as crashes.

Logit models with cluster effects enable us to not only describe the trend of crashes but also take account of the correlation that exists within each crash. These models in which the regression coefficients are allowed to vary across the clusters and errors are correlated within a cluster. These models have two components: 1) Within-crash component: the severity of people involved in the same crash is described by a regression model with a population-level intercept and slope; 2) Between-crash component: variation in severity of people involved in different crashes is captured by crash-level intercepts and slopes.

Results presented in this dissertation are based on the grouping by crashes. There are generally 1 to 5 observations in each cluster and over 500 clusters in the dataset.

3.2.5. Application of Logit Models in this Dissertation

In this dissertation, logit regression models postulate that the probability of individuals experiencing any of the injury levels or crash type as a function of vehicle characteristics, geometric features, personal characteristics, and ambient environments. Multinomial logit regression models with clustered effects have been estimated for crash injury in Chapter 5. Multinomial logit regression models have been exploited for crash type.

There are five major crash types for crashes studied in this dissertation: run off the road, rear end, head-on, same direction angle, and opposition direction angle collisions. These types of crashes are mutually exclusive and collectively exhaustive, which are indexed *1, …, 5*. Let variable Y represent the type of crash that driver i experienced so that $Y_i=1$ if the first type of crash, run-off the road, occurs for this driver; $Y_i=2$ if the second level, read-end, occurs and so on. In this case, the value taken by the discrete dependent variable Y_i is irrelevant for any one of these types of crashes. For different crash types, there is no order between anyone of these types versus the other. When there is no inherit order between the categories of a variable, the variable is nominal and a multinomial logit model is used.

The severity status of a crash is defined as the most severe injury to the person involved in a crash. In this dissertation, the severity status is classified into seven categories: fatal injury (K), nonfatal injury incapacitating nonfatal injury (A), nonincapacitating nonfatal injury (B), possible nonfatal injury (C), no injury (O), not reported and unknown. The categories are ordered from the most severe to moderate then to mild injuries. Even though there is a clear ordering of the different categories of the variables, as the parallel slope assumption for ordinal logit models is violated on the dataset, multinomial logit models are employed instead of the ordinal logit model. The rationale of why the multinomial logit models are adopted is discussed in the following subsections.

Statistical models are developed to estimate the probability of different levels of driver-injury severity and crash types based on the condition that a fatal crash has occurred. A fatal crash is defined as a crash where at least one vehicle occupant of the involved vehicles(s) or, if applicable, involved pedestrian died within a 30 day period as a result of injuries obtained in the crash. Other than fatal injury, there are four other injury severity levels: incapacitating nonfatal injury, non-incapacitating nonfatal injury, possible nonfatal injury, and no injury. These five levels are inherently ordered; this means that the level associated with a larger value of the variable Y_i is ranked higher than the level associated with a smaller value of the variable Y_i. In other words, the discrete variable, Y_i, associated with the levels is ordinal: "severer" levels are associated with larger values of the variable. Note that this ordinal nature of this classification has no implication for differences in the severity of the levels; the level associated with $Y_i=2$ is not twice as severe as that associated with $Y_i=1$. Therefore, $Y_i=3$ is defined if the fatal injury occurred, $Y_i=7$ if the capacitating injury occurred, and so on, so long as larger values correspond to severer levels.

For crash severity models, the severity of a traffic crash is an ordinal response variable. Ordered logit models are preferred to quantify the effects of the contributing factors on the ordinal response variable. Otherwise, the information about the ordering is lost. The critical assumption of ordered logit models is the parallel slope assumption. The multinomial logit model allows the slope coefficients β_m to be different between the outcomes. On the contrary, ordered logit model does not allow the slope coefficients β_m

to vary according to the different levels of outcome being considered. This means that if there is a change in a variable, the likelihood of a person being in the one level of severity is assumed to be the same across all other severity levels.

In the literature, most studies used ordered logit models to estimate the crash severity models. This model approach has the restriction that the effect of the variables across outcomes is identical. That is, the changes in independent variables increase or decrease the outcome probabilities with the same amount across the range of severity categories. There is no option for a variable to only increase the probabilities of the some levels severity categories while decrease the probabilities of the others. This assumption restricts ordered logit regression model application in highway safety research. Much evidence indicates that some factors such as age and airbag usage do not have the same effect across all levels of crash severity. They may increase the probability of mid-level severities and reduce the probability of fatal/disabling injury. Take age for an example: older people and toddlers have less chance to survive in crashes compared to young adults in the same crashes. Ordinal analysis cannot account for such effects. The chi-square of the differences of the maximum likelihood of the ordinal model and the multinomial model indicates that the parallel assumption of the ordered logit model does not hold on the highway safety data and thus proves our suspicion that ordinal model is not appropriate for this analysis.

The multinomial logit analysis rather than ordinal analysis is used in this analysis because of the parallel slope assumption of the ordered models is violated on the dataset used in this dissertation. Table 3.1 summarizes the chi-square test results of parallel slope assumption for crash severity models developed in Chapter 5. The chi-square critical values in the last column are for significance level of 0.10. The testing results on our dataset indicate that the difference between L_1 and L_2 is significant for majority of the model except for single vehicle crash severity model in Mississippi, which means that the parallel slope assumption is invalid on our dataset. The slope coefficients associated with a particular variable are different across the different severity levels. The ordered logit are no longer appropriate for estimating crash severity and a multinomial logit model has to be used in this study.

Table 3.2 Results of an Approximate Chi-square Test for Parallel Slope Assumption

		Multinomial Logit	Order Logit	2(L2-L1)	k	m	k(m-2)	chi(k(m-2))
SV	All	-387.11	-462.14	150.06	21	5	63	77.74
	AL	-79.15	-90.42	22.54	6	5	18	25.99
	GA	-79.72	-96.95	34.46	8	5	24	33.20
	MS	-40.23	-51.81	23.16	11	5	33	43.72
	SC	-122.38	-167.26	89.76	10	5	30	40.26
MV	All	-1066.09	-1173.80	215.42	22	5	66	81.08
	AL	-178.18	-226.23	96.10	12	5	36	47.19
	GA	-256.31	-301.00	89.38	15	5	45	57.49
	MS	-179.38	-241.23	123.70	17	5	51	64.15
	SC	-212.85	-258.57	91.44	15	5	45	57.49

Our statistical testing proves the empirical observations/suspicion about the applicability of ordinal logit regression model on highway safety dataset and partly explained the low fit of the ordinal logit models in the literature. This study points out the restriction of ordered logit regression model application in highway safety research.

3.2.6. Stepwise Model Development

The small number of the records causes potential problems in model estimation. Due to the nature of multinomial logit model, the number of records should be at least 6 to 10 times the degree of freedom to obtain valid model estimates. As there are limited numbers of observations in the subset used for model estimation, the stepwise variable selection method is used to see which one is the most predictive variable in the model development in Chapters 5 and 6.

A significance level of 0.1 is required to allow a variable into the model in this dissertation. , The choice of the significance level represents the following two concerns: 1) a larger entry significance level allows too many variables into the model; and 2) a smaller entry significance level results in few or no predictor variables at the expense of increasing the risk of type II error.

A significance level of 0.15 is required for a variable to stay in the model. The significance level to remove a variable is higher than the significance level for a variable to enter the model. This difference of significance levels is used to avoid the cycling problem where a variable is continuously entered and removed from the model.

CHAPTER 4: DATA

Traffic crashes are the combined result of interactions among driver, vehicle, road, and ambient environment. The frequency, type, and severity of crashes can be viewed as a function of traffic, physical road geometry, and environmental factors. The descriptive statistics of these factors can depict the trends of the fatal crashes and shed light on the important causal factors of the high fatal crash rate in the southeastern states. With this, this chapter serves the first objective of this dissertation, as stated in Chapter 1.

These broad categories of factors influencing traffic crashes are collected in order to investigate the occurrence of high fatality rate in the southeast region and significant variation among the eight southeast states. What follows are some examples of how some of the factors impact the traffic crashes.

Driver age and experience have a considerable effect on the severity of vehicle crashes that occur each year. As mentioned in the first chapter, the road traffic injuries are the leading cause of death for persons of every age between 2 and 34, the third leading cause of the death for persons of age between 35 and 44, and the eighth leading cause of the death for persons of age between 45 and 64 in 2002 in US.

Vehicle speed is also important factor for causing severe traffic crashes. Higher vehicle speed gives less time for the drivers to respond to the unexpected situation. One second can make the difference for the driver surviving the crash or not. Moreover, with higher speeds, there is no doubt that the person in the vehicle will suffer more severe injury when the vehicle hits a fixed object or a moving vehicle.

Washington et al. (1999) found out that the possible factors for high fatality rate in the southeastern region include functional class, speed, use of safety constraints, driver age, VMT by functional classification, and speed limit differences. Other possible reasons for state variations include differing degrees of urbanization, amounts of travel, types of travel, types of vehicles, state laws, emergency care capabilities, weather, topography, and a variety of other factors.

The type and severity of crashes also depends on some ambient factors such as weather and light condition that cannot be controlled or altered by human beings. Vehicle configuration and vehicle age shall be added to the list as well.

Most important of all, as mentioned in the Washington et al. (1999) study, the southeast states have higher proportion of travel on rural two lane highways than do non-southeast states. Recent economic development in this area exacerbates the situation as the vehicle of miles traveled increased out of proportion of the infrastructure development. The current system was not designed to handle the traffic volume and speed that it currently serves. This might be the major reason that this region has a higher fatal traffic crash rate than other regions. What are the specific geometric factors that need to be improved? How could they be improved? Answers to questions like these are the focus of this dissertation.

The major tasks of this dissertation are developing multinomial logit models or nested logit models that shed some lights on the high fatality rate of crashes in southeast region and the differences between the states. An extensive geometric feature database for participating states was collected. Combined with vehicle, crash, people, environmental data, the database provides an extensive coverage of the factors that affect the severity of traffic crashes.

4.1. Data Collection

Every participating state was individually responsible for collecting the data in its own state. In Georgia, for example, highway safety engineers and researchers reviewed the state-maintained roads using the GDOT video library and personally visited the roads that are not state maintained to collect the geometric features of every crash site. A field data checklist was developed for this purpose and it was shared with the other states. The participants in the other states either visited the sites or combined theirs as was done in Georgia (video plus site visits).

All factors of interest were included in the database that includes 150 random sample crashes from each of the four states (100 samples from Mississippi). Note that all crashes occurred on rural two lane highways, as this type was disproportionately represented by fatal crashes for each state. All study crashes involved at least one fatally injured person (fatality.) The crash, persons involved in the crashes, environmental data, and vehicle information were acquired from the police reports. Highway engineers and researchers from each state visited the sites (or viewed the sites via video libraries) and used this information to develop site data elements.

4.2. Data Transferability

For this dissertation, data were obtained from the previously discussed pooled fund study for the Federal Highway Administration for the state of Alabama, Georgia, Mississippi, and South Carolina. Each participating southeastern state collected detailed information on 150 fatal crashes, which were randomly selected from all fatal crashes, occurred around year 1997 and 1998.

Kentucky did participate, but they did not provide a copy of the database (even after repeated requests from FHWA). It appears that they could not locate the database once their part of the work was complete.

Florida also participated, but decided to focus on a different condition since their primary problem did not appear to be the 2-lane rural road. (This may be due to the state of Florida's definition of rural vs. urban.) Since they did not focus on the 2-lane rural road, their information was not included in the follow-up study.

Tennessee was really the only state that did not participate at all. They assigned someone to be in charge of the project, initiated contracts, and then for some reason just never did the project.

North Carolina only has environmental data elements information available; thus, it is excluded from the analysis.

For these various reasons, only data from four out of these eight states are available to us and thus makes the database down to 550 (100 crashes in MS) cases with information for fatal crashes in the state of Alabama, Georgia, Mississippi, and South Carolina. This raises the question of whether or not if this dataset is a good representation of the states in the southeastern region.

To answer this question, the difference of the fatality rate of each eight states with the fatality rate of the nation's average from year 1975 to year 2003 is examined. The differences of eight individual states are plotted against time in Figure 4.1.

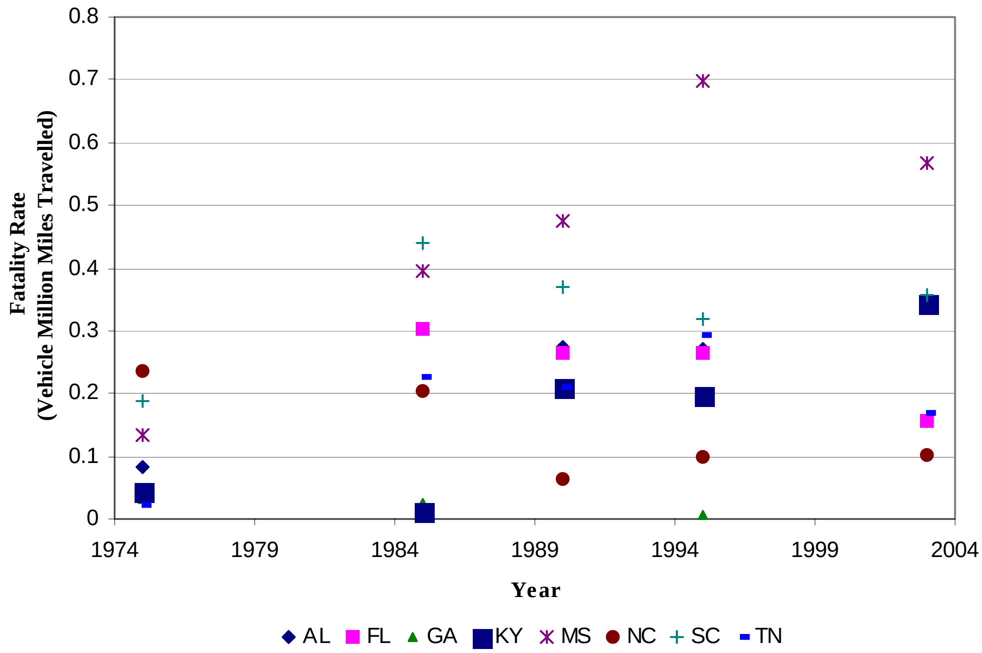


Figure 4.1 History of Difference of Fatality Rate between Eight States and National Average

In year 1975, the differences of the fatality rates of each eight states with the fatality rate of the nation's average are between 3 percent and 23 percent and the eight states have a small variance of difference between its fatality rate from the nation's average fatality rate. From 1985 to 2003, the difference of the fatality rate between the eight states and the nation's average increases in terms of both mean and variance among the states. In year 1995, the closest year to out study year 1997, the differences varied from 1 percent to 70 percent. This indicates the differences between the eight states as well as the region versus the nation.

Based on the cluster analysis of the differences from year 1985 to 2003, the eight states are grouped as in the Figure 4.2. The similarities of the differences between fatal crash rate and national average in eight southeastern states are illustrated as a tree structure and are classified into three groups labeled by group A, B, and C, respectively. Group A has the state of Mississippi only. Group B includes South Carolina, Florida, and Tennessee. Group C includes Alabama, Kentucky, Georgia, and North Carolina. The states in the same group have similar levels of fatality rate. Note that inside the group B and C, there are subgroups connected by the lines. For example, Alabama and Kentucky in group B are connected because that their fatality rate level are more similar to each other than to the fatality rate of Georgia and North Carolina.

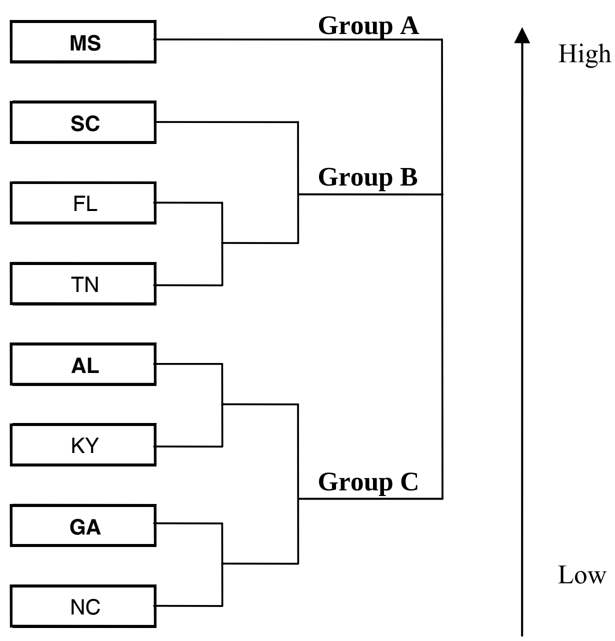


Figure 4.2 Group of Eight Southeastern Sates by Cluster Analysis

The axis in the left of the figure indicates the difference between the fatality rate in each state and the national average increases from the states at the bottom of the figure to the top of the figure. That is, the state of Mississippi consistently has the largest fatal crash rate differences. Mississippi is called an "outlier" because it does not enter any group until near the end of the procedure.

The state names in bold are the ones whose data are available to us. Although data is only available only for four out of eight states, it represents the region fairly well since data is available in virtually every group other than the subgroup of Florida and Tennessee.   Furthermore, data is available for the worst two states, Mississippi and South Carolina.

4.3. Five Data Elements

The database depicts fatal crashes with five different data elements types:

- *Crash data* elements describe the overall crash conditions with information such as time and location of the crash, number of vehicles and people involved, source of information, whether the crash is work zone related, number of fatal and non-fatal injuries, and drug use;
- *Person data* includes driver's year of birth, sex, city of residence, safety protection system usage including seatbelt and air bag, violation code, alcohol test and drug test results (if available), non-motorist information, and injury description;
- *Vehicle data* include vehicle make, model, year, state of registration, hazardous materials involvement for cargo, vehicle maneuver, point of impact, crash avoidance maneuver, sequence of events, driver violations, most harmful event of the vehicle, most damaged area, extent of the damage, travel speed, fire occurrence, and carrier information;

- *Site data* include direction, horizontal curvature (sharp versus mild), vertical curve, cross slope, vertical grade, turning/passing/emergency lanes, average daily traffic (ADT) or average annual daily traffic (AADT), traffic count, shoulder, adjacent influences, bridge/railroad involvement, pavement marking, delineator presence and type, signal and signs, speed limit, roadside parking, surface type, guardrail/bridge railing, and intersections; and
- *Environmental data* include relation to roadway, manner of impact, weather condition, ambient light, and contributing circumstances.

The five data elements are discussed in detail in the remaining of this chapter. The discussion includes a list of variables for each data element, quality of the data collected, and the availability for the variables.

4.3.1. Crash Data Elements

The crash data elements contain the general information about crash state, crash case number, crash date and time, crash county, crash city/place, number of vehicle involved in the crash, number of driver/occupants, number of non-motorists, crash roadway location, source of information, data and time crash reported to police agency, school bus related, work zone related, total fatal injuries, total non-fatal injuries, alcohol/drug involvement, hit and run, day of the week, date incident reported, time incident reported, time dispatch reported, time dispatch notified, data unit notified, time unit notified, time unit responding, time arrival at scene, time of arrival at patient, time unit left scene, time arrival at destination, incident number, and agency/unit number.

The total number of vehicles involved in the crash does not include non-motorized vehicles such as bicycles. Table 4.1 summarizes the percentage of number of vehicles in the fatal crashes for each state. Approximately 50 percent to 60 percent of the study crashes involve single vehicles; 34 percent to 48 percent of the crashes involve only two vehicles; and the remaining crashes involve three or four vehicles.

Table 4.1 Percentage of Vehicle involved in Fatal Crashes

State / Number of vehicles	AL (%)	GA (%)	MS (%)	SC (%)	All (%)
One Vehicle	61	53	50	59	56
Two Vehicles	34	40	48	38	39
Three Vehicles	3	7	2	3	4
Four Vehicles	2	1	0	1	1

4.3.2. Person Data Elements

The person data elements have one record for every person, i.e., drivers, passengers, and non-motorists, involved in the crash. The elements include the following information: general info, all vehicle occupants, drivers only, and non-motorist only.

General information includes the crash state, crash case number, date of birth, gender, person type, and injury status. For all vehicle occupants, the occupant's vehicle unit vehicle, seating position, occupant protection system use, air bag deployed, ejection, trapped only are recorded. Drivers only data include driver license state/province, driver license number, driver name, contributing circumstances (Driver), driver condition, cited, violation codes, driver license class, driver license status, driver license restrictions, license endorsements, license compliance, driver presence, previous recorded crashes, previous recorded suspensions, previous DUI convictions, previous speeding convictions, previous other motor vehicle convictions, month/year of last crash, month/year of first crash, driver's address. Not all of this information was available for each crash. The drivers and non-motorists only data include alcohol/drug suspected, type of alcohol and drug test, test status, and test result. The non-motorist only data include non-motorist number, type, action, condition, location prior to impact, and safety equipment. For detailed description about these variables, please refer Appendix A.

4.3.2.1. Age

In the database, people involved in the fatal crashes include drivers, passengers and non-motorists 0 to 92 years old. In the traffic safety facts (NTHSA, 2003), the traffic crashes are among the top 10 lists of leading causes for the death of people across all age groups in year 2002. The traffic crashes are the leading cause for the death in age groups 4 to 34, whereas it is the eighth cause for toddlers and the elderly. To explore the differences in different age groups, the variable age is classified into 10 categories, as shown in Table 4.2.

Table 4.2 Classification of Age

Group	Name	Age Range
1	Infants	<1
2	Toddlers	1~3
3	Children	4~7
4	Young Children	8~15
5	Youth	16~20
6	Young Adults	21~24
7	Other Adults (1)	25~34
8	Other Adults (2)	35~44
9	Other Adults (3)	45~64
10	Elderly	>65

4.3.2.2. Gender

Table 4.3 illustrates the distribution of number of male and female by state and person type. There are more male drivers than female drivers in these randomly selected fatal vehicle crashes. The ratio of male and female drivers is 5:2 for all four states. There are about same number of male and female passengers.

Table 4.3 Gender of the People Involved in the Crash

Gender	AL			GA			MS			SC		
	D	P	NM	D	P	NM	D	P	NM	D	P	NM
Male	155	62	1	167	67	6	105	70	0	169	70	3
Female	60	70	1	67	56	5	47	55	0	55	57	0

* D=Driver
* P=Passenger
* NM=Non-motorists

4.3.2.2. Person Type (Passengers and Drivers)

Most of the safety severity literature is limited to only driver related information and severity of the passengers are usually ignored largely due to the different roles that the drivers and passengers play in the traffic crash. Compared to the drivers, the passengers are the passive party involved in the crashes. For the drivers who are involved in the crashes, the drivers' maneuver influences whether the crash happens and how severe it is to a large extent. However, in the case that a crash occurred, no one has comprehensively studied if there are any significant differences in the injury levels that they sustain. In this dissertation, both driver and passenger data are included in the crash severity analysis and separate crash severity models for drivers and passengers are estimated. If the estimation results are different, then the drivers and passengers have different sustainability in terms of crash severity.

4.3.2.3. Safety Restraint Usage and Seating Position

Table 4.4 tabulates the number of persons in the database across the seating positions and the seat belt usage.

Table 4.4 Cross Table for Safety Restraint Usage and Seating Position

		None	Shoulder Belt Only	Lap Belt Only	Shoulder and Lap Belt	Child Safety	Helmet
Front Seat	left side	351	6	16	242	1	8
	middle	14	0	2	0	0	0
	right side	124	3	2	83	3	0
Second Seat	left side	34	1	4	9	6	0
	middle	15	0	2	0	5	0
	right side	32	0	1	7	7	0
Third Row	left side	1	0	0	1	0	0
	middle	1	0	1	0	0	0
	right side	1	0	0	1	0	0
Passenger in enclosed area		6	0	0	0	0	0
Passenger in unenclosed area		3	0	0	0	0	0

Safety restraint usage is highly correlated with the seating position. Slightly more than half of the vehicle occupants positioned in the front seats did not wear a shoulder or lap belt when the vehicle was involved in the crash. Occupants who sat in the second row or third row had an even lower seat belt usage rate. There were not many people who sat in the middle of the front row; however, they were most likely not wearing a seatbelt, given a no use rate of 87.5 percent.

The seat belt usage information is not available for crashes in Mississippi. The variable is included in the models specific to other three states, but not the general model for all states.

4.3.2.4. Ejection

The ejection variable indicates the location of each occupant's body as being completely or partially thrown from the vehicle as a result of a crash. In Alabama, Georgia, Mississippi, and South Carolina, about 20 percent of the people involve in the fatal crashes were totally ejected or partially ejected from the vehicle. For single vehicle crashes, 30 percent of people involved in fatal crash in Georgia and South Carolina were totally ejected or partially ejected from the vehicle, whereas the percentage for multi-vehicle crashes was 10 to12 percent in Alabama, Georgia and Mississippi, and 20 percent in South Carolina.

4.3.3. Vehicle Data Elements

Vehicle data elements include crash state, crash case number, vehicle unit number, vehicle registration state and year, vehicle license plate number, vehicle make, trailer registration state and year, trailer license plate number, vehicle configuration, cargo body type, weight rating of power unit, vehicle adaptive equipment or modifications, hazardous materials involvements, vehicle authorized speed limit, vehicle maneuver, point of impact, sequence of events, most harmful event for this vehicle, underride/override, most damaged area, extent of damage, vehicle model year, vehicle model, vehicle body type, vehicle identification number, registered vehicle owner type, travel speed, vehicle towed, fire occurrence, crash avoidance maneuver, and number of deaths.

There are no meta data for the following variables: point of impact, sequence of events, most harmful events, and the most damaged area of the vehicle. No descriptive statistics are provided for them.

4.3.3.1. Vehicle Configuration

Vehicle configuration indicates the configuration of the vehicle. Sixty-six percent of the vehicles in the database were passenger cars; twenty three percent of them were light trucks with only four tires, which include vans, minivans, pickups, and sport utility vehicles. Over the last 10 years, consumers have increasingly purchased light trucks and vans. Light trucks and vans (LTVs) account for slightly more than 50 percent of new vehicle sales. Nineteen percent of new LTV sales are SUVs (NTHSA, 2003). A disproportionately high level of rollover related fatalities characterizes SUV crashes. The SUV is the only vehicle type in which the number of occupant deaths in rollovers exceeds the number of occupant deaths in non-rollover crashes. In 2002, almost two-thirds of occupant fatalities in SUV crashes occurred in rollovers (NHTSA, 2003).

As 89 percent of the vehicles involved in the fatal crashes were passenger cars and light truck, the cargo body type, weight-rating unit of power unit, and vehicle adaptive equipment or modifications did not have a lot variation in the dataset. The cargo body type is not applicable for 91 percent of the vehicles in the database; majority of the weight rating of power unit information is missing and unknown; 29 percent of the vehicles have no observed adaptive equipment or modifications and this information was not reported or unknown for the rest of vehicles.

4.3.3.2. Total Occupants in the vehicle

Sixty-four percent of the vehicles were driven alone when the crashes occur, 22 percent of them had one passenger, 7 percent of them had two passengers, 4 percent had three passengers, and the rest 3 percent had four or more passengers. For single vehicle crash and multi-vehicle crashes, about the same percentage of vehicles had passengers in the vehicle.

4.3.3.3. Vehicle Role

In terms of the role that the vehicle plays in the crashes, the vehicles were classified as noncontact, noncollision, striking, struck, both striking and struck. For single vehicle crashes, no collision happened at about half of the crashes and half of the vehicles hit some objects, either a tree or roadside obstacle. For multi-vehicle crashes, about half of the vehicles played a striking role in the crashes, 35 percent played a struck role in the crashes, and 15 percent played both striking and struck roles. However, the striking or struck role that the vehicles played in the crashes does not imply if the vehicle was at-fault.

4.3.3.4. Vehicle Authorized Speed Limit and Travel Speed

Authorized speed limits of the crash sites are indicated by the posted speed limit, blinking signs at construction zone, etc. The posted speed limit at the crash site was 35 mph for 7 percent of the vehicles, 40 mph for 4 percent of the vehicles, 45 mph for 20 percent of the vehicles, 50 mph for 1 percent of the vehicles, and 55 mph for 67 percent of the vehicles. In other words, at most of the crash sites, the posted speed limit was 45 mph or 55mph.

Travel speed is an estimate of the travel speed, most likely a judgment rather than a measurement. As opposed to the authorized speed limit, 32 percent of the vehicles were traveling at a speed above 55 mph or more. The following graph is the cumulative distribution function of the probabilities of the authorized speed limit versus the perceived travel speed.

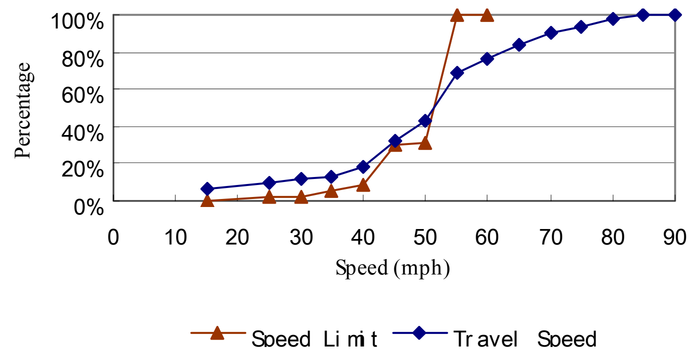


Figure 4.3 Comparison of Vehicle Authorized Speed Limit and Travel Speed

The maximum difference between the travel speed and the authorized speed limit was 55 mph. The speed variable is further classified as a three category variables, 1 if the difference was less than –10mph, 2 if it was between –10 and 10 mph, and 3 if it was greater than 10mph. Travel speed data was not available for the crashes occur in the state of Georgia and Mississippi, therefore, this variable is not included in the model for all states but it is included in the specific model for the other two individual states.

4.3.3.5. Traffic Control Device Type

The type of traffic control at a crash site includes traffic control signal, flashing traffic control signal, stops signs, warning signs, and railway crossing device. No school zone signs and yield signs were present at the crash sites in the database. This information was not available for crashes in South Carolina. For the other states, 73 percent sites did not have a traffic control device, 18 percent sites had warning signs, and 9 percent had a stop sign. Only a tiny fraction, less than 1 percent of the sites, had other types of traffic control. This variable is not included in the model simply because it is the result of the geometric design features.

4.3.3.6. Vehicle Maneuver

When the crashes occurred, 82 percent of vehicles were moving straight, 4 percent were overtaking or passing, 4 percent were entering and leaving the traffic lane, 4 percent were turning left, 1 percent was slowing or stopped in traffic, less than 1 percent was changing lanes, turning right, or making u-turn, and the others were not specified.

4.3.3.7. Underride/Override

An underride refers to a vehicle sliding under another vehicle during a crash. An override refers to a vehicle riding up over another vehicle. There were only 4 underride and 2 override vehicles in the database. The rare cases have limited variation in the factor, thus their low explaining power.

4.3.3.8. Extent of Damage and Vehicle Towed

For the vehicles involved in the fatal crashes, 53 percent of the vehicles were totaled or severely damaged, 43 percent of the vehicles were disabling damaged, and only 3 percent were functionally damaged. These numbers conveys the same message as the vehicle towed does since 96 percent of the vehicle were towed away after the crashes.

4.3.3.9. Vehicle Model Year and Model

Vehicle model year is the year that the vehicle was manufactured. One-third of the vehicles involved in the crashes were less than 5 years old, another one-third were between 6 and 10 years, about twenty percent were between 11 and 15 years. The older the vehicle age, the fewer safety features the vehicle is likely to be equipped with.

Vehicle model denotes a family of vehicles within a make with a similarity in construction. In the database for this dissertation, there were more than 100 different models. The sheer size of this variable makes it of little use in predicting the causation of crashes.

<u>4.3.3.10. Fire Occurrence</u>

Fire only happened to 15 out of more than 800 vehicles during crashes. Fire occurrence is generally a consequence of the crash, rather than a causation factor.

<u>4.3.3.11. Crash Avoidance Maneuver</u>

In addition to the vehicle maneuver prior to the crash, there is a variable that describes the type of the maneuver the driver executes to attempt to avoid the crash. Although there are a large number of cases where no crash avoidance maneuver occurred, for those crashes that avoidance maneuver did occur, the principal crash avoidance maneuvers included braking and steering. About 5 percent of the drivers tapped their breaks, 9 percent of the drivers used steering, and 2.5 percent of the drivers used both maneuvers (steering and braking) to avoid the crash. The rest of the drivers did not appear to use any avoidance maneuver.

4.3.4. Site Data Elements

Site data elements reflect characteristics of crash site proximity where vehicle(s) collide or leave the roadway. They include site reviewer, data of site review, time of site review, crash state, crash case number, sequential case number, horizontal alignment, grade, cross section, national highway system, functional classification of rural roadway, guardrail/bridge railing, lanes, average daily traffic, lane width, shoulder type/width, nature of adjacent influences, driveways, bridge or railroad involvement, bridge / structure identification, railroad crossing ID, roadside illumination, pavement markings, longitudinal, bikeway, delineator presence, traffic control device, speed limit, roadside parking, roadside hazard rating, roadside barrier, roadside pavement reflectors, and terrain. The same data elements were collected for the crossing road if the crashes happened at an intersection.

The lack of detailed roadside data, due primarily to the cost of collecting and maintaining such data, has been an obstacle to the development of detailed statistical models of the relationship between geometric features and crash severity. Some researchers studied the impact of roadside features on the frequency and severity of run-off-roadway crashes (Lee and Mannering, 2002).

Site data elements were examined at the state level in order to identify possible different trends in different states. The factors that were not well populated or did not have variation in the data are not discussed. The examples are bikeway, roadside barrier, bridge or railroad involvement, and traffic control device.

4.3.4.1. Horizontal Alignment

Horizontal alignment specifies the geometry in general horizontal alignment of a roadway. It indicates whether it is a straight segment or a curved segment. If it is a curved segment, the direction of the curve and the radius of the curves are two important features of the curve.

Table 4.5 summarizes the horizontal alignment of the four states. In the database, 52 percent of the crashes occurred on the straight segment, and 48 percent happened on the curved segments. About one-third of the curved segments required the driver speed adjustment and about two thirds of the curved segments were mild or gentle curve. About half of the roads curved to the right and half of the roads curved to the left.

If a crash occurred on a curved segment, about half of the crashes occurred on the inside of the curve, the other half occurred on the outside of the curve.

Table 4.5 Horizontal Alignment Characteristics by State

Horizontal Characteristics \ State		AL (%)	GA (%)	MS (%)	SC (%)
General Alignment	Straight	59	50	51	48
	Curved	41	50	49	52
Direction of Curve	Right	13	27	26	25
	Left	27	23	23	25
	NA	59	50	51	50
Estimated Curve Radius	Sharp Curve	13	27	24	4
	Mild Curve	29	23	25	46
	NA	59	50	51	49
Crash Curve Location	Inside of Curve	16	18	17	34
	Outside of Curve	17	30	29	17
	NA	67	52	54	49

4.3.4.2. Vertical Alignment

Vertical alignment is the inclination of a roadway, expressed as a percent of grade. For all states, 23 percent of the segments had positive grades, 34 percent had negative grades, and 43 percent were flat. Twenty-six percent of the segments were level with a vertical slope less than 1 percent, 36 percent of the segments had a mild vertical slope between 2 percent and 6 percent, and 2 percent of the segments had a steep slope greater than 6 percent. Of all the segments, 12 percent had a crest vertical curve and 5 percent had a sag vertical curve.

Table 4.6 presents details of direction of slope, percent of the slope, crest vertical curve, and sag vertical curve in each state. No obvious differences exist between states in terms of vertical alignment of the roadways.

Table 4.6 Vertical Alignment Characteristics by States

Vertical Alignment \ State		AL (%)	GA (%)	MS (%)	SC (%)
Direction of slope	Up	13	32	21	26
	Down	44	39	29	23
	Flat	43	29	50	51
Percentage of the slope	Level	25	25	36	24
	Mild Slope	37	43	40	26
	Steep Slope	1	3	2	2
	NA	37	30	22	48
Crest vertical curve, and sag vertical curve	Crest	11	14	17	8
	Sag	4	3	4	8

4.3.4.3. Cross Section

For all states, about 40 percent of the cross sections of the segments were super-elevated, and the rest of them had a typical rooftop cross-section.

Table 4.7 Cross Section Characteristics by State

Cross Section \ State	AL (%)	GA (%)	MS (%)	SC (%)
Typical Rooftop	63	54	61	58
Super-elevated	37	46	39	42

4.3.4.4. National Highway System and Functional Classification (FC)

The site data includes if the road where the crashes happened are designated as part of the national highway system. Only 13 percent of the roadway segments are part of the national highway system. Mississippi had the lowest percentage of involved roadways that belonged to national highway system.

Table 4.8 National Highway System (NHS) and Functional Classification by State

NHS \ State	AL (%)	GA (%)	MS (%)	SC (%)
Yes	11	22	3	11
No	89	78	97	89

Functional classification of rural roadway includes character of service or function of streets or highways. About 11 percent of the segments were principal arterial, 19 percent were minor arterial, 33 percent were major collectors, 20 percent were minor collectors, and 14 percent were local roads. Most Mississippi crashes happened on minor collector and local roads.

Table 4.9 Functional Classification by State

FC \ State	AL (%)	GA (%)	MS (%)	SC (%)
Principal Arterial	15	13	0	14
Minor Arterial	19	23	0	30
Major Collector	42	36	1	48
Minor Collector	12	11	68	6
Local	13	16	31	1

4.3.4.5. Guardrail/Bridge Railing

Guardrail/Bridge railing information is available for crashes in Alabama, Georgia, and Mississippi. In Alabama, 91 percent of the crash location had no guardrail or bridge rail is involved in the crashes, 3.3 percent had steel breakway guardrail involved, 1.3 percent had concrete barriers involved and 1.3 percent were concrete bridge rail. In Georgia, 98 percent had no guardrail/bridge railing involved, 1.3 percent had steel breakway guardrail, and 0.6 percent had concrete bridge rail. In Mississippi, 96 percent had no guardrail involved, 3 percent had steel breakway guardrail, and 1 percent had concrete bridge rail.

4.3.4.6. Lanes

In Alabama and Georgia, 4 to 5 percent of the sites had one turning lane, 95 to 96 percent of the sites did not have any turning lanes. In Mississippi, 3 percent had one turning lanes, 4 percent had two turning lanes, and 93 percent of them did not have any turning lanes. No involved sites in South Carolina had any turning lanes.

In Alabama, 0.7 percent of the crash sites had one passing lane, 2.7 percent had two passing lanes, and 96.7 percent had no passing lanes. In Georgia, 3.8 percent sites had one passing lane, and 96.2 percent had no passing lanes. Study sites in Mississippi and South Carolina had no passing lanes.

Only one site in Alabama had an emergency lane in addition to the two main lanes.

4.3.4.7. Average Daily Traffic (ADT)

Average daily traffic was counted over a week on actual roads where crashes occurred in Alabama and ranged from 80 to 17,960 vehicles per day. ADT ranged from 80 to 16,500 in Georgia. ADT was collected over a 24 hours period in Mississippi. Two thirds of them were collected on actual roadways and one-third from similar roadways. The Mississippi ADT ranged from 200 to 12,000 vehicles per day. ADT is obtained from actual roadway in South Carolina with a range from 2 to 25,700. Overall, as observed from Figure 4.4, half of the sites had an ADT less than 2000, and 90 percent had an ADT less than 7,500.

Average daily traffic (ADT) is an approximate number for many of the low traffic volume roads in the database. Depending on the districts, the approximation varied dramatically from state to state. As in this database, the lowest ADT is 2, 80, 80, and 200 for South Carolina, Alabama, Georgia, and Mississippi, respectively. The ADTs on heavily traveled road are more accurate as they are most likely actually collected onsite.

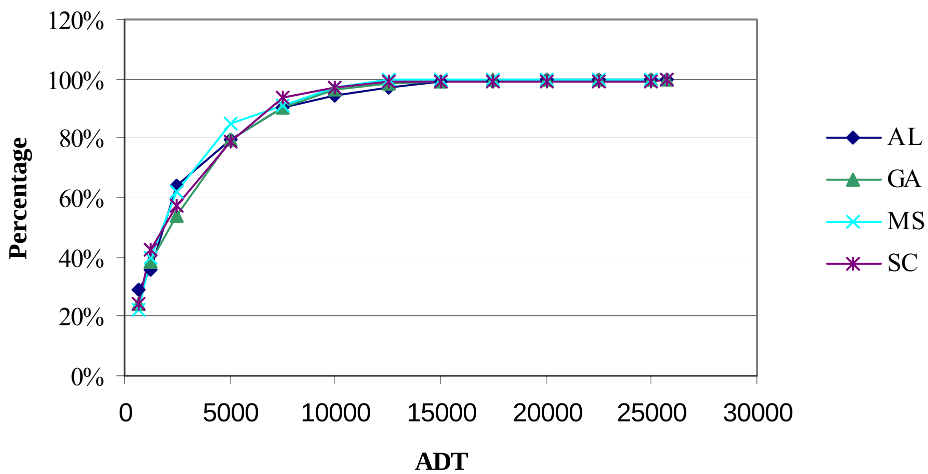


Figure 4.4 Average Daily Traffic by State

ADTs for every state are further classified into 5 categories with about 20 percent of the sites in each category. The cut off points for the five categories are: 500, 1500, 3000, and 6000 vehicles per day.

4.3.4.8. Lane Width

Lane width measures the width of the lane where crashes occur. The percentage of sites with different lane widths in each state is summarized in the Table 4.10. As shown the table, 12 feet was the most frequently used lane width in these states, followed by 11 feet, and then followed by 9 feet lane widths.

Table 4.10 Lane Width by State

Lane Width \ State	AL (%)	GA (%)	MS (%)	SC (%)
2 ft	0	0	0	1
7 ft	0	0	2	0
8 ft	2	2	0	2
8.5 ft	0	2	0	0
9 ft	9	8	6	6
9.5 ft	0	7	0	0
10 ft	30	18	25	32
10.5 ft	0	7	0	0
11 ft	23	22	27	31
11.5 ft	0	3	0	0
12 ft	36	31	39	26
12.5 ft	0	1	0	0
13 ft	0	1	0	1
14 ft	0	0	1	0
17 ft	0	0	0	1

4.3.4.9. Shoulder Type and Width

Table 4.11 presents the type of shoulders of the crash sites in each study state. Most of the shoulders were graded; fewer were paved shoulders, and even fewer still were a combination of paved and graded shoulders. Only a small fraction of shoulders had a raised curb. In Alabama, Georgia, and Mississippi, there were 5 percent to 10 percent of the sites with no shoulder at all.

Table 4.11 Shoulder Type by State

Shoulder Type \ State	AL (%)	GA (%)	MS (%)	SC (%)
Paved	15	3	6	4
Graded	76	68	83	96
Combination of Paved and Graded	11	25	11	4
Raised Curb, Traversable	2	0	1	0
Raised Curb, Barrier	0	1	0	0
No Shoulder	11	6	5	1

The percentages of paved shoulder width are presented in the Table 4.12. Given the small percentage of the paved shoulders, the shoulder widths were mostly between 2 feet and 4 feet.

Table 4.12 Paved Shoulder Widths by State

Paved Shoulder Width \ State	AL (%)	GA (%)	MS (%)	SC (%)
0.5^{ft}	3	0	0	0
1^{ft}	23	23	0	8
2^{ft}	35	48	53	8
3^{ft}	10	14	6	25
4^{ft}	16	11	0	0
5^{ft}	6	2	0	0
6^{ft}	0	2	6	8
7^{ft}	3	0	0	8
8^{ft}	3	0	12	0
9^{ft}	0	0	0	17
10^{ft}	0	0	24	8
11^{ft}	0	0	0	8
12^{ft}	0	0	0	8

Table 4.13 presents the graded shoulder width. In Alabama, the graded shoulder width was between 2 feet and 4 feet. In Georgia and Mississippi, the graded shoulder width was between 4 feet and 8 feet. In South Carolina, most shoulder widths were between 5 feet and 10 feet.

Table 4.13 Graded Shoulder Widths by State

Graded Shoulder Width \ State	AL (%)	GA (%)	MS (%)	SC (%)
1 ft	2	1	0	0
2 ft	45	6	8	1
3 ft	15	10	2	5
4 ft	20	24	60	6
5 ft	6	13	1	11
6 ft	3	15	15	15
7 ft	4	8	0	10
8 ft	1	17	13	11
9 ft	0	1	0	14
10 ft	4	5	1	13
11 ft	1	0	0	6
12 ft	0	0	0	7

4.3.4.10. Nature of Adjacent Influences/Driveways/Intersections

In Alabama, 60 percent of the sites were close to residential driveways. In Georgia, 30 percent of the sites were close to billboards, 54 percent were close to residential driveways, and 5 percent were close to commercial driveways. In Mississippi, 71 percent sites were close to residential driveways. In South Carolina, 63 percent were close to residential driveways, 14 percent were close to commercial driveways, and 4 percent were close to industrial driveways.

The number of driveways within 250 feet upstream and 250 feet downstream of the crash site varied from 1 to 13. Circular drives that have two access points are counted as two. Driveways directly across the street from each other are counted as two driveways. One-third of the sites did not have driveways; about 40 percent of the sites had one or two driveways in the surrounding area.

Table 4.14 Number of Driveways by State

Number of Driveways \ State	AL (%)	GA (%)	MS (%)	SC (%)
0	31	33	33	32
1	21	28	25	27
2	18	16	15	22
3	15	8	15	8
4	9	6	2	8
5+	7	9	10	4

The number of intersections within 250 feet upstream and 250 feet downstream of the crash site varied from 0 to 3. A four-way intersection was counted as two intersections to determine conflict patterns. Fifty-five to sixty-five percent sites did not have any intersections in the surrounding area. Thirty to forty percent sites had one intersection close to them.

4.3.4.11. Roadside Illumination

The majority of the sites did not have spot or continuous illumination within 250 feet of crash site. Only 2.5 percent to 5 percent of the sites had spot illumination. Crash sites in Georgia had 2 percent continuous illumination and sites in Mississippi had 5 percent continuous illumination.

4.3.4.12. Longitudinal Pavement Markings/Delineator Presence/ Roadside Pavement Reflectors

Most sites had a yellow centerline, either in a skip dash form, solid, or solid double form. Most sites also had white edge lines.

Only a small fraction of the sites had reflective delineators installed. In Alabama, 6 sites had delineators on either the right or left side. In the remaining three states, each had only two crash sites with delineators.

Half of the sites in Alabama and Georgia had raised pavement reflectors used to accent or replace painted pavement markings. In Mississippi and South Carolina, the percentages were lower with a percentage of 35 percent and 22 percent, respectively.

4.3.4.13. Roadside Hazard Rating (RHR)

Roadside hazard rating is a subjective measure of the hazard associated with the roadside environment. The rating values indicate the crash damage likely to be sustained by errant vehicles on a scale from one to seven. The ratings are determined from a 7-point rural pictorial scale, as shown in Appendix B (Zegeer et al., 1988). A value of one refers to a low likelihood of an off roadway collision or overturn. A value of seven refers to a high likelihood of a crash resulting in a fatality or severe injury. The data collectors selected the rating value that most closely matched the roadside hazard level for the crash sites. In many cases, the roadside hazard level along a section varied considerably, so the roadside hazard rating represents a middle value. For example, if the ratings generally ranged from 4 to 6 along a section, a rating of 5 was used to best represent the roadside hazard rating of the section. Please refer to Appendix B for detailed information and photos of example sites regarding roadside hazard rating.

Table 4.15 presents the roadside ratings for the crash site. In Alabama, 67 percent of the sites had a roadside hazard rating of 4 or 5. In Mississippi, 67 percent sites had a roadside hazard rating of 5 or 6. In South Carolina, 70 percent sites had a rating of five. In Georgia, 82 percent of the sites had a roadside hazard rating between 3 and 5.

Table 4.15 Road Side Hazard Rating by State

RHR \ State	AL (%)	GA (%)	MS (%)	SC (%)
1	1	1	0	0
2	5	11	3	0
3	15	31	7	1
4	34	30	23	22
5	33	22	35	70
6	11	4	32	6
7	1	1	0	0

4.3.4.14. Surface Type

Most roadway surfaces of the crash sites were made of asphalt in Alabama and Georgia. Two thirds of the surfaces were asphalt in Mississippi and South Carolina. However, one-third of the surfaces were slag, gravel or stone in Mississippi and one-third of the surfaces were concrete in South Carolina.

Table 4.16 Surface Type by State

Surface Type \ State	AL (%)	GA (%)	MS (%)	SC (%)
Concrete	1	2	1	35
Blacktop	96	96	68	65
Slag/Gravel/Stone	2	1	31	0
Dirt	1	1	0	0

4.3.4.15. Terrain

The state of Mississippi had 86 percentage of the crash sites with rolling terrain, higher than the other three states: 38 percent in Alabama, 46 percent in Georgia, and 51 percent in South Carolina.

Table 4.17 Terrain by State

Terrain \ State	AL (%)	GA (%)	MS (%)	SC (%)
Flat	61	51	14	48
Rolling	38	46	86	51
Mountainous	1	3	0	1

4.3.4.16. Cross Road Involved

Most of the crash sites do not have crossroads involved. If a crossroad was involved, then the same site information was collected for the cross road as was collected for the main road.

Table 4.18 Cross Road Involved by State

Cross Road \ State	AL (%)	GA (%)	MS (%)	SC (%)	All (%)
No	89	87	83	92	88
Yes	11	13	17	8	12

4.3.5. Environmental Data Elements

Environmental Data Elements include crash state, crash case number, sequential case number, crash date and time, Crash County, weather condition, ambient light, road surface condition, contributing circumstances environment, contributing circumstances road. These factors are discussed in detail in the following sections.

4.3.5.1. Contributing Environment Circumstances and Weather Condition

Environment condition of the road includes weather condition, physical obstruction, glare, and animal in roadway. Most of fatal crashes in this database did not have any apparent environment conditions that contributed to the crashes. Weather condition was the major contributing environment condition to these crashes for about 4 percent to 18 percent of the crashes.

Table 4.19 Contributing Environment Circumstances (CEC) by State

CEC \ State	AL (%)	GA (%)	MS (%)	SC (%)	All States (%)
None	83	76	80	94	84
Weather Condition	11	18	18	4	12
Physical Obstruction	0	1	1	1	1
Glare	0	1	0	0	0
Animal in roadway	1	3	1	1	2
Other	4	1	0	0	1

Weather conditions are the prevailing atmospheric conditions that exist at the time of the crash. Table 4.20 displays the eight major classes of weather conditions and the percentage of time that the conditions occurred in each state. As indicated by the data, most of time, the fatal traffic crashes happened when the weather is clear.

Table 4.20 Weather Condition by State

	AL (%)		GA (%)		MS (%)		SC (%)	
Weather Condition	SV	MV	SV	MV	SV	MV	SV	MV
Clear	62	67	79	88	66	68	77	78
Cloudy	24	17	1	3	22	14	11	13
Fog, smog, smoke	3	2	2	0	4	4	2	2
Rain	9	12	18	9	8	14	10	8
Sleet, hail (freezing rain/drizzle)	1	2	0	0	0	0	0	0
Snow	0	0	0	0	0	0	0	0
Severe crosswinds	0	0	0	0	0	0	0	0
Blowing sand, soil, dirt, snow	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Not reported	0	0	0	0	0	0	0	0
Unknown	1	0	0	0	0	0	0	0

* SV = Single Vehicle Crashes
* MV = Multiple Vehicle Crashes

4.3.5.2. Ambient Light

Ambient light refers to the type of light that exists at the time of a vehicle crash. Table 4.21 presents six major classes of the light conditions. The percentages of single or multi-vehicle crashes are listed for each light condition. The single vehicle crashes tended to occur on roadways not lighted thus a dark light while the multi-vehicle crashes happened more often during day light conditions. Crash rate is time dependent based on the crash type because single vehicle crashes occur more frequently at night (or, more generally, in instances of reduced visibility) than during the daylight hours and vice versa for multi-vehicle crashes.

Table 4.21 Ambient Light Condition for Crashes by State

	AL (%)		GA (%)		MS (%)		SC (%)	
	SV	MV	SV	MV	SV	MV	SV	MV
Daylight	37	72	46	63	26	68	38	58
Dawn	1	2	0	1	2	0	0	2
Dusk	2	2	1	1	2	2	3	8
Dark - lighted roadway	1	0	1	0	4	4	2	2
Dark - roadway not lighted	59	24	51	35	66	26	57	31
Dark - Under roadway light	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Not reported	0	0	0	0	0	0	0	0
Unknown	0	0	0	0	0	0	0	0

* SV = Single Vehicle Crash
* MV = Multi-vehicle Crash

4.3.5.3. Time of day

Figure 4.5 depicts the percentage of fatal crashes that occurred during every hour for each of the four states. Overall, the predominance of the studied 550 fatal crashes occurred between the hours of approximately 2pm and 11pm, with the peak reached at 4pm to 7pm. Although the high and low percentage varied from state to state for every particular hour, the figure illustrates that the time period from 2pm to 11pm accounted for half of the fatal crashes whereas evening peak hours (3AM to 4AM, 13 to 19 percent) and morning peak hours (7AM to10AM, 10 to 20 percent) accounted for 30 percent of fatal crashes.

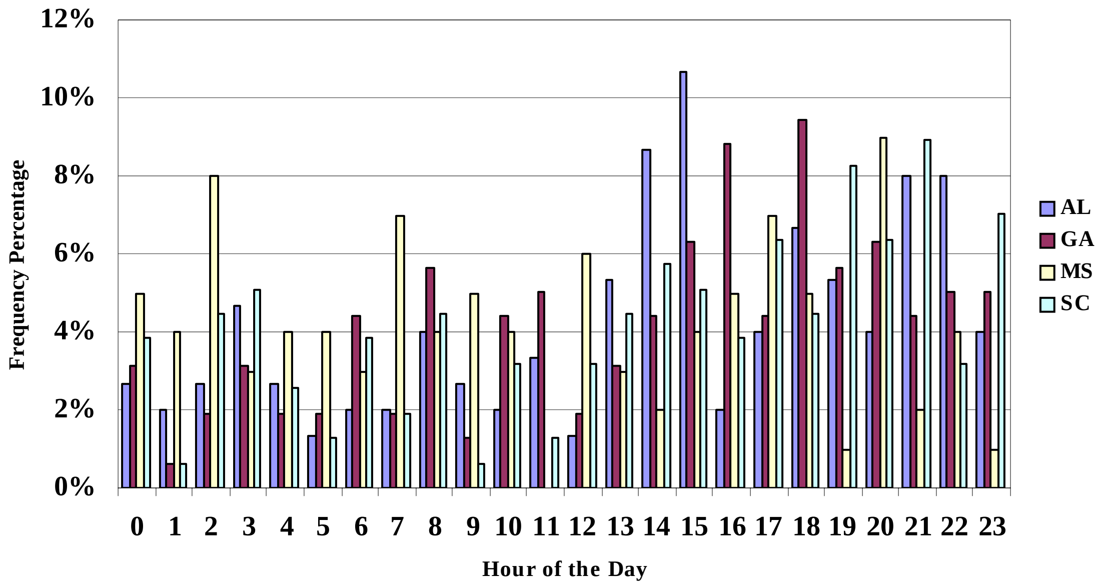


Figure 4.5 Crash Frequency Percentage by Hour of the Day

In most safety studies, "time of day" is defined as morning peak hours, midday, afternoon peak hours, and nighttime. However, there is no apparent pattern for this four-time period other than that the afternoon accounts for more crashes than the morning while noon has the lowest crash rate in the dataset used in this dissertation. Twenty-four hours were divided into 8 equal intervals in a 3-hour increment for this study, starting at 1 am midnight and ending at 00:59 p.m.

4.3.5.3. Day of week

Traffic variations occur at different time scales, e.g., time of day, day of week, and season of the year. Among the known temporal fluctuations of traffic stream, seasonal variation is probably of the most concern in traffic crashes. It is well known that traffic/crash fluctuates by time of day, day of week and season (month) of the year.

4.3.5.4. Contributing Road Circumstances and Road Surface Condition

Apparent condition of the road which contributes to the crash includes road surface condition, debris, work zone, etc. As shown in Table 4.22, most of fatal crashes in this database did not have apparent road conditions that contributed to the crashes. Road surface condition was the most frequent contributing condition, followed by the shoulder condition. Other conditions included but were not limited to debris, rut/hole/bump, work zone, worn surface, obstruction, inoperative traffic control device, non-highway work.

Table 4.22 Contributing Road Circumstances (CRC) by State

State / CRC	AL (%)	GA (%)	MS (%)	SC (%)	All (%)
None	89	73	79	88	83
Road Surface Condition	8	17	14	1	10
Shoulders	0	6	1	4	3
Other	3	4	6	6	5

Table 4.23 shows that the roadway surfaces were dry at the time and place of the most of the crashes. About 11 percent to 20 percent of the time the roadway surfaces were wet.

Table 4.23 Road Surface Condition by State

Road Surface Condition \ State	AL (%)	GA (%)	MS (%)	SC (%)	All (%)
Dry	79	81	84	89	83
Wet	20	19	15	11	16
Snow	1	0	0	0	0
Sand/Mud/Dirt/Oil	0	0	1	0	0

4.4. Data Issues

The peculiarities of highway safety data include the poor quality of crash data. Most fundamental crash information is typically collected from the police reports. Researchers conducting highway safety analyses have little influence over this process. The results are that data not critical to the police investigation are often of poor quality.

Not every factor is readily available for analysis even though it is of possible important for various reasons discussed in this section. Because of missing observations, a lack of variation in many factors, and strong correlations among many variables of interest, the resulting models do not contain all variables that were collected in the database.

4.4.1. Alcohol Data

Figure 4.6 illustrates alcohol and drug usage for every month. An interesting observation is that there were apparently more drivers involved in alcohol use during the first three quarters of the year than during the last quarter.

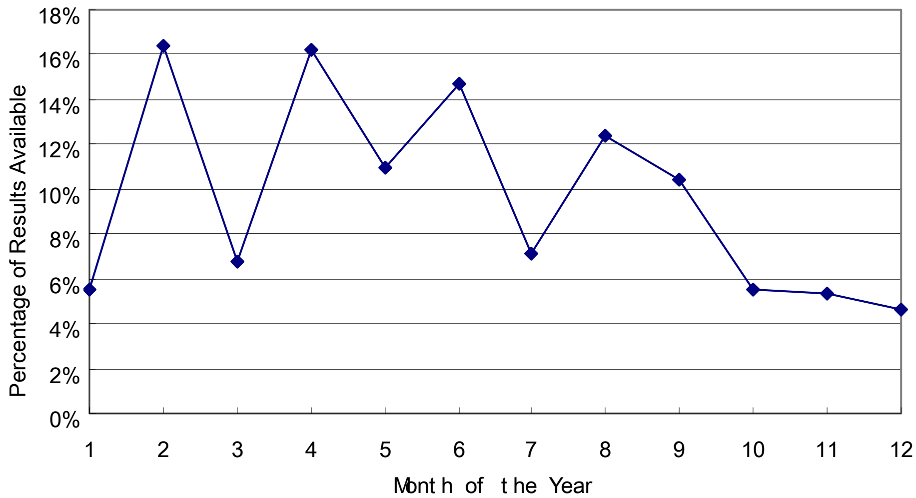


Figure 4.6 Alcohol use during the year

Is it because the drivers do not drink alcohol or use drugs during the fourth quarter? Not really. All the alcohol test results take four to five months to obtain. For this reason, anything that happened at the end of the year does not get included in state crash databases when they perform end-of-year close cuts. When the lab test results come in, it is too late to include them in the previous year crash. The alcohol and drug use is not tested in this dissertation since the information is not complete.

4.4.2. Data Availability

The variables collected for this dissertation are either identified in the crash literature as contributing factors to crashes or it is believed that it is probable that they contribute to fatal crashes. However, not all variables collected in this dissertation are well populated.

Table 4.24 SAS Output of Availability of Occupant Protection System Use

Occupant Protection System Use	Frequency	Percent (%)	Accumulated Frequency	Accumulated Percent (%)
None Used	593	54.35	593	54.35
Shoulder Belt Used Only	10	0.92	603	55.27
Lap Belt Used Only	28	2.57	631	57.84
Shoulder and Lap Belt Used	343	31.44	974	89.28
Child Safety Seat Used	22	2.02	996	91.29
Helmet Used	9	0.82	1005	92.12
Not reported	61	5.59	1066	97.71
Restraint Use Unknown	13	1.19	1079	98.9
Not Applicable	12	1.1	1091	100

Frequency Missing = 277

Table 4.24 is an example of the data availability for variable occupant protection system use. The occupant protection system use was not populated for any observations in the state of Mississippi. Because of the missing observations, the tested personal factors for the all state model did not include occupant protection system use.

4.4.3. Special Issues in Fatal Crash Dataset

Note that every crash record in the database includes at least one fatality of the people involved in that crash. When studying the severity of the crashes, the database with only fatal crashes can easily bias the comparisons. All coefficients, significance, and probabilities are estimated on the condition that a fatal crash has occurred. This fact needs to be taken into account when explaining the descriptive statistics and the model estimation. This model estimation process of the analysis and implications of the analysis are limited to fatal crashes, i.e. the sample is not representative of crashes in general. The inferences about the findings cannot be extended to non-fatal crashes.

4.4.4. Data Dictionary

Appendix A is a data dictionary for this dissertation, including five tables, one for each of the five categories of data elements: people, vehicle, crash, site, and environmental elements. All five tables have the same format. The first column is the sign for the corresponding variable, the second column is the data element name, the third column is the definition of the variable, the forth column is a list of the possible outcome of the variable, and the fifth to eighth columns are the indicators if the variable is well populated for state Alabama, Georgia, Mississippi, and South Carolina. The ninth column includes the indicator if the variable is well populated for all four studied states.

4.4.5. Correlations among Variables

Before the models are estimated, the correlations among the variables are checked to avoid the collinearity problem in the model. When an independent variable is nearly a linear combination of other independent variables in the model, the affected estimates of regression coefficients are unstable and have high standard errors. In this dissertation, if the correlation between two variables is greater than 0.60, then these two variables are not included in the model at the same time to avoid the collinearity problem.

The correlation between weather conditions and road surface conditions are a good example of the collinearity problem. These two variables are highly correlated with a correlation coefficient of 0.67. It is not hard to understand that these two variables are highly correlated since when the weather condition is rain, the road surface is wet. Weather condition includes more details in the prevailing environment such as severe crosswinds and blowing sand. Therefore, weather condition is included in the model and the road surface condition is excluded.

The correlations among the site variables are checked and the correlation coefficient values of the highly correlated pairs of variables are included in Table 4.25. The following two groups of variables are highly correlated.

A group of five variables, the general horizontal alignment, direction of curve, curve radius, crash curve location, and cross section are highly correlated with a correlation greater than 0.60. Of the five variables, the first three variables are all horizontal alignment related. Direction of the curve is related since direction of the curve is not applicable whenever the roadway is straight. Curve radius includes three categories: 1) not applicable, 2) sharp curve (if it requires the driver speed adjustment), 3) more detailed information about the general alignment of horizontal curve. If the general alignment is significant in the model, the curve radius will be included in the model instead of the general alignment. It is reasonable to have horizontal features highly related with cross sections because if the roadway is on a sharp curve, it is likely that the cross section is super-elevated to keep the vehicle from getting out of the lane. Crash curve location is not included since it is more or less a consequence of the crash, not a contributing factor.

Crest vertical curve is highly correlated with the sag vertical curve. These two variables are actually the same base information since the vertical curve can be flat, a crest, or sag. Only one of the variables will be included in the models that include the site factors.

Table 4.25 Correlation among Site Factors

	General Alignment	Direction of Curve	Curve Radius	Crash Curve Location	Cross Section Type	Crest Vertical Curve	Sag Vertical Curve
General Alignment	1.00	-0.90	-0.90	-0.84	0.76	-0.11	-0.17
Direction of Curve	-0.90	1.00	0.80	0.74	-0.67	0.16	0.19
Curve Radius	-0.90	0.80	1.00	0.75	-0.73	0.10	0.16
Crash Curve Location	-0.84	0.74	0.75	1.00	-0.69	0.12	0.19
Cross Section Type	0.76	-0.67	-0.73	-0.69	1.00	-0.08	-0.14
Crest Vertical Curve	-0.11	0.16	0.10	0.12	-0.08	1.00	0.71
Sag Vertical Curve	-0.17	0.19	0.16	0.19	-0.14	0.71	1.00

The vehicle related variables studied include vehicle configuration, the difference between travel speeds and the authorized speed limit, vehicle maneuver, vehicle model year, and crash avoidance maneuver. The correlations among the vehicle data elements are checked for the collinearity problems. None of the correlation between the variables has a correlation greater than 0.

In the rest of this dissertation, the correlation check has been performed for every model that has been tested. If there are no highly correlated variables, the correlation problem is not discussed for the sake of simplicity.

4.4.6. Data Representation

The dataset collected for this dissertation includes randomly drawn 150 crashes from four states (100 crashes from Mississippi). This dataset can be viewed as a random sample drawn from the fatality analysis reporting system (FARS) database. Chi-square test is used to test if there are any significant differences between the sample used in this dissertation and the data recorded in FARS.

The chi-square test is carried out on testing the distribution of the factors included in both FARS data base and the dataset used in this dissertation. A two way classification table is set up based on gender and age as shown in Table 4.46. The null hypothesis is that the sum of the sample proportion is not close to the sum of the population proportions. The total chi-square value for Table 4.26 is 162.30, which is greater than the critical value of $\chi^2_{91,0.005}$ =128.3. This proves that our dataset can be used to present the fatal crashes in the southeastern states.

Table 4.26 Comparison of FARS Data with Sample Data

Age	Male			Female		
	Sample	Population	Expected	Sample	Population	Expected
0	2	27	3.44	4	20	2.54
1	7	30	3.82	5	40	5.09
2	6	43	5.47	7	36	4.58
3	8	41	5.22	5	35	4.45
4	1	33	4.20	6	44	5.60
5	4	41	5.22	4	36	4.58
6	4	35	4.45	7	37	4.71
7	6	35	4.45	4	34	4.33
8	3	28	3.56	0	30	3.82
9	1	27	3.44	9	45	5.73
10	6	31	3.94	2	33	4.20
11	6	32	4.07	6	37	4.71
12	4	36	4.58	4	33	4.20
13	9	43	5.47	6	38	4.84
14	6	58	7.38	13	60	7.63
15	13	77	9.80	13	73	9.29
16	21	161	20.49	13	114	14.51
17	22	207	26.34	12	94	11.96
18	28	225	28.63	19	114	14.51
19	28	236	30.03	11	97	12.34
20	18	212	26.98	12	74	9.42
21	29	212	26.98	11	80	10.18
22	16	172	21.89	7	74	9.42
23	29	171	21.76	5	80	10.18
24	14	155	19.72	9	73	9.29
25	17	167	21.25	8	71	9.03
26	23	172	21.89	7	70	8.91
27	18	161	20.49	10	71	9.03
28	18	127	16.16	14	73	9.29
29	19	150	19.09	7	52	6.62
30	24	134	17.05	12	68	8.65
31	22	135	17.18	9	63	8.02
32	17	117	14.89	7	51	6.49
33	13	136	17.31	7	70	8.91
34	15	130	16.54	5	61	7.76
35	19	135	17.18	6	59	7.51
36	15	113	14.38	11	53	6.74
37	18	107	13.62	9	63	8.02
38	13	131	16.67	8	49	6.24
39	26	123	15.65	3	58	7.38
40	17	92	11.71	3	47	5.98
41	18	118	15.02	3	47	5.98
42	14	106	13.49	11	57	7.25

Table 4.26 Comparison of FARS Data with Sample Data (Continue)

Age	Male			Female		
	Sample	Population	Expected	Sample	Population	Expected
43	17	101	12.85	1	39	4.96
44	13	99	12.60	6	44	5.60
45	12	91	11.58	4	42	5.34
46	7	78	9.93	3	36	4.58
47	10	88	11.20	3	37	4.71
48	8	85	10.82	7	36	4.58
49	14	77	9.80	5	41	5.22
50	10	89	11.33	10	51	6.49
51	8	68	8.65	5	31	3.94
52	11	76	9.67	4	35	4.45
53	9	74	9.42	2	42	5.34
54	5	49	6.24	0	34	4.33
55	6	47	5.98	4	23	2.93
56	4	48	6.11	3	27	3.44
57	7	48	6.11	5	21	2.67
58	5	40	5.09	0	23	2.93
59	6	43	5.47	2	14	1.78
60	5	41	5.22	5	22	2.80
61	1	40	5.09	4	18	2.29
62	7	34	4.33	2	20	2.54
63	6	39	4.96	1	21	2.67
64	4	27	3.44	2	24	3.05
65	4	31	3.94	4	22	2.80
66	6	34	4.33	0	19	2.42
67	3	32	4.07	2	13	1.65
68	6	34	4.33	1	20	2.54
69	8	28	3.56	3	34	4.33
70	2	23	2.93	2	25	3.18
71	3	34	4.33	2	20	2.54
72	1	30	3.82	4	23	2.93
73	3	23	2.93	3	12	1.53
74	2	26	3.31	1	19	2.42
75	1	30	3.82	4	25	3.18
76	2	24	3.05	3	15	1.91
77	3	25	3.18	1	15	1.91
78	1	25	3.18	2	19	2.42
79	4	21	2.67	2	14	1.78
80	1	24	3.05	2	19	2.42
81	2	15	1.91	1	11	1.40
82	1	18	2.29	5	16	2.04
83	2	12	1.53	1	14	1.78
84	0	12	1.53	1	17	2.16

Table 4.26 Comparison of FARS Data with Sample Data (Continue)

Age	Male			Female		
	Sample	Population	Expected	Sample	Population	Expected
85	0	17	2.16	1	13	1.65
86	2	13	1.65	1	14	1.78
87	0	5	0.64	0	8	1.02
88	0	10	1.27	0	3	0.38
89	0	5	0.64	1	11	1.40
90	0	6	0.76	0	2	0.25
91	0	1	0.13	0	1	0.13
92	1	3	0.38	0	1	0.13

CHAPTER 5: CRASH SEVERITY

In Chapter 4, the descriptive statistics of the people, site, vehicle, and environmental factors have been examined. Although it is intuitively appealing to assume that these factors have an influence on the fatal crashes, it is not easy to get a clear view on their impacts on traffic safety. Given the large number of possible factors, it would be helpful to use statistical models to identify which factors are important determinants of fatal crashes and severity on rural roads.

The major objective of this chapter, the second objective of this dissertation, is to develop probabilistic models for explaining and predicting variations for fatal crash severity, quantify the impact of various factors on the crash severity in the southeastern United States, and predict variations in these fatal traffic crashes. These models should associate the probabilities of crash severity with a collection of person, vehicle, roadway, traffic, and environmental factors. The dependent variable for the models is crash severity. Independent variables include, but are not limited to, potential contributing factors such as lighting, pavement conditions, vehicle occupant characteristics, vehicle characteristics, and geometric features of the crash sites.

The crash severity models provide substantial insights into factors that contribute to fatal crash severity. The product of the crash severity analysis includes models that can be used to help transportation agencies better identify potential crash conditions, analyze the potential impact of changes in contributing factors on reduction of fatal crashes, and identify contributing factors for each individual state as well as the southeast region.

5.1. Introduction

The level of injury that a person sustains during a crash determines the severity of that specific person in the crash. The severity of a crash is measured as the most severe injury for a person involved in the crash (for this study, fatal injuries). For example, in a two-vehicle crash, if only one of the passengers in one car is fatally injured and all the other persons involved in the crash suffer minor injuries, the collision is classified as a fatal crash.

Crashes are also classified into five levels based on the injury status of people involved in the crashes. The five injury levels include the following:

- Fatal injury (K),
- Incapacitating nonfatal injury (A),
- Non-incapacitating nonfatal injury (B),
- Possible nonfatal injury (C), and
- No injury (O).

A total of 1359 people were involved in the 566 fatal crashes recorded in the database. Every crash included in the dataset had at least one fatality. Among these people there were 824 drivers, 526 passengers, and 16 non-motorists. Of all the people involved in these fatal crashes, approximately half of them were fatally injured. The percentages of fatal injury were 47.8 percent in Alabama, 48.6 percent in Georgia, 41.9 percent in Mississippi, and 48.1 percent in South Carolina. The other four categories, incapacitating nonfatal injury, non-incapacitating nonfatal injury, possible nonfatal injury, and no injury, had similar percentages for Georgia, Mississippi, and South

Carolina, ranging from 9 percent to 18 percent. Alabama had more than double the percentage of incapacitating non-fatal injury crashes than the other three states.

Figure 5.1 illustrates the percentage of drivers that sustained different levels of injury by state. The letters, K, A, B, C, and, O, on x axis represent the five injury levels mentioned earlier in this section. More than 50 percent of time, the drivers experience fatal injury.

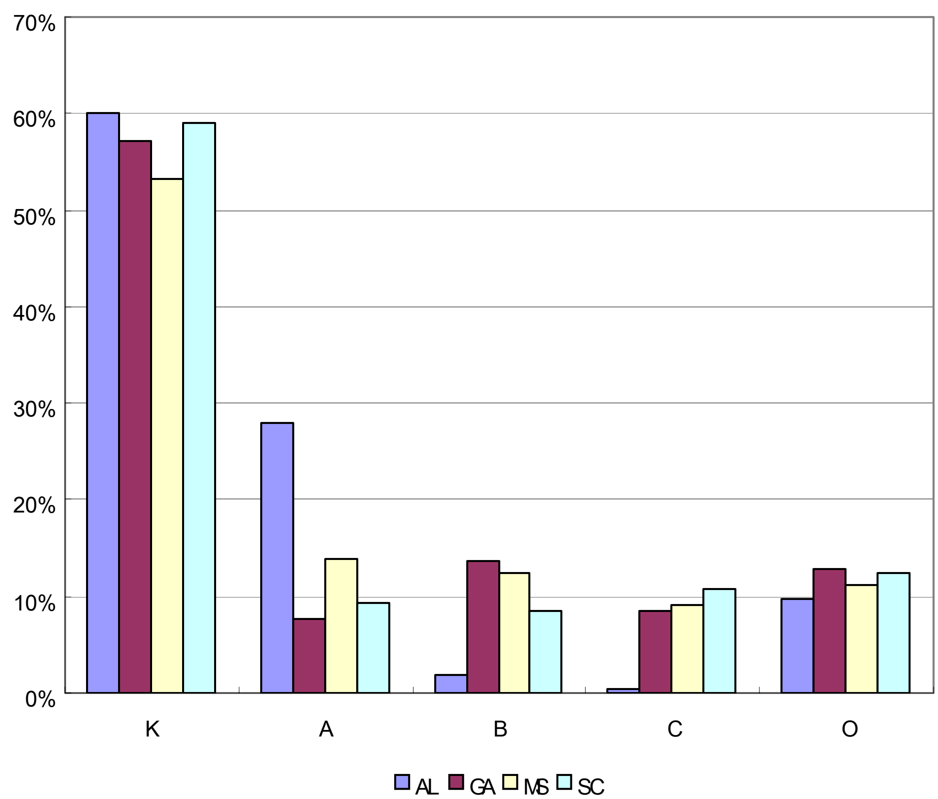


Figure 5.1 Crash Severity of Drivers by State

Figure 5.2 shows the crash severity of the passengers by state. The passengers in all states experienced about a 30 percent chance of fatal injury, which was about 20 percent less when compared to the drivers. Incapacitating nonfatal injury and non-incapacitating nonfatal injury were 20 percent to 26 percent in all states except in Alabama where this value was 50 percent. Possible nonfatal injury and no injury together were approximately 25 percent.

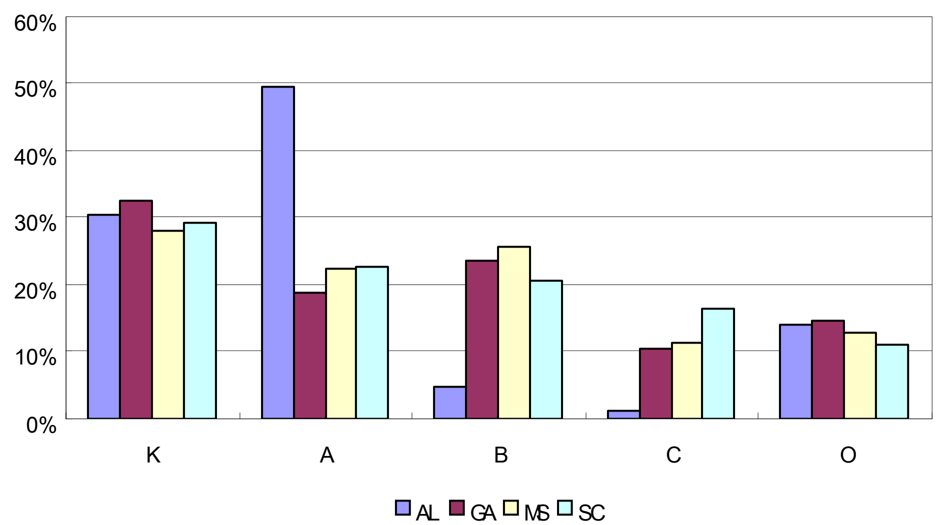


Figure 5.2 Crash Severity of Passengers by State

The higher percentage of the drivers who experienced a fatality may be due to the fact that all crash records in the database included at least one fatality and over 60 percent of the vehicles did not have any passengers. A comparison of Figures 5.1 and Figure 5.2 illustrates that both drivers and passengers in Alabama were more likely to experience incapacitating non-fatal injuries when compared to drivers and passengers in the other states.

5.2. Model Specification

Using data collected in the original FHWA pooled fund study, multinomial logit models were developed to relate probabilities of crash severity with the people, vehicle, environmental and site elements. With data from four participating states, including Georgia, South Carolina, Mississippi, and Alabama, the database included information for 1359 people.

5.2.1. State Specific Models versus All State Models

Rather than fitting one model for the entire Southeastern US, the crash severity models were developed not only for the original dataset that includes all four states, but also for state-specific datasets. Every model was estimated for the set of variables available for that state's dataset. Due to the availability of the data in some states, for the state specific models that are included in this chapter, the seat belt usage was included in the base model for the states of Georgia, South Carolina, and Alabama. The crash avoidance maneuver was included in the base model for the states of Georgia, Mississippi, and South Carolina.

5.2.2. Single Vehicle Crash versus Multi-vehicle Crash Model

Single vehicle crashes occur when a vehicle runs off the road and hits some fixed object, or the vehicle runs off the road and rolls over. Multi-vehicle crashes involve the collision between more than one vehicle. In the dataset for the four states, about 56 percent of the vehicle occupant deaths occurred for single vehicle crashes, 39 percent of the occupant deaths occurred for two vehicle crashes, 4 percent for three vehicle crashes, and 1 percent for four vehicle crashes.

The impact of potential causal factors on the injury severity for people involved in single vehicle and multi-vehicle crashes are estimated separately since these two types of crashes have different characteristics. For example, single vehicle crashes tended to occur more often at night on roads with poor or no lighting. Most of the multi-vehicle crashes occurred during daylight conditions. In 2002, an average of 48 percent of passenger vehicle occupant deaths occurred in single vehicle crashes nationwide, with the highest percentages close to 69 percent. On average, about half of passenger vehicle occupant deaths occurred at night for single vehicle crashes (NTHSA, 2003).

Due to the different characteristics of single vehicle crashes versus multi-vehicle crashes, separate models were estimated for people involved in single vehicle crashes and those involved in multi-vehicle crashes.

Most literature has focused on the severity of the at-fault drivers in the crash and the severity causation for not-at-fault drivers and passengers is often neglected in safety studies due to lack of data. The models in this dissertation are estimated for the dataset that includes information for the drivers and passengers in both at-fault vehicles and not-at-fault vehicles. All vehicles involved in single vehicle crashes are assumed to be at-fault vehicles. Whether the vehicles involved in multi-vehicle crashes are the at-fault vehicles is indicated by improper driving prior to the crashes. If there was no indication of improper driving, the vehicle was considered not-at-fault.

5.3. Crash Severity Model for All States

Crash severity models for all states were developed in three phases. In the first phase, only personal factors were included. In the second phase, the significant personal factors from the phase one and all vehicle-related factors were included. In the third phase, all significant factors from the phase two with site factors and environmental factors were included.

5.3.1. Crash Severity Models with Personal Factors Only

Ulfarsson and Mannering (2004) studied the differences in injury severities between male and female drivers in single and two vehicle crashes involving different sizes of vehicles. Their results suggest that there are important behavioral and physiological differences between male and female drivers which may affect crash injury severity. Physiological differences can arise from average differences in male/female size and weight and their interaction with vehicle safety design, as well as the differences in their body's ability withstand impacts. Behavior differences may arise from different responses to similar driving conditions.

In this dissertation, the author tested various personal factors including age, gender, driver contributing circumstances, and driver condition. The occupant protection system used was not tested in the model for all states since this information was not available for four states, but it was included in the state specific models whenever available. Table 5.1 presents the estimation results of both the single vehicle crash model and the multi-vehicle crash model and the personal factors determined as significant for all four states. It includes the coefficient estimates along with t-statistic and p value of the estimate for the models estimated using data that included all persons involved in the crashes. The base case in this multinomial logit model is the fatal injury category. As mentioned in the Chapter 3, the coefficients of these factors for the fatal injury outcome are restricted to 0. However, the interpretation of the coefficients is not intuitive due to the nonlinear nature of the logit model. If the t-statistic indicates that the variable is significant, it means that the change in the corresponding factor has a statistically significant effect on differentiating this injury severity from a fatal injury. All personal factors included in the table have a significance level greater than 90 percent for at least one level of injury.

Contrary to the coefficients, the elasticity of the factors is easy to interpret. The elasticity of a factor can be viewed as the one percentage change in one variable with respect to a one percentage change in another variable. Table 5.2 includes the corresponding elasticity of the factors in the model that contains personal factors only.

Many studies, such as Ulfarsson and Mannering (2004), have found that females have a significantly different probability of suffering severe injuries relative to males under the same circumstances. Similar results were observed in the single vehicle models in this dissertation. For example, gender was significant for the two most severe injury levels -- fatal and incapacitating nonfatal injury. The overall trend was that females are less likely to be killed and are more likely to experience less severe injuries compared to their male counterparts in single vehicle crashes.

Age is another personal factor that was significant in both the single vehicle crash severity model and the multi-vehicle crash model. Age was determined to be a significant factor for differentiate the fatal injury from most other level of injuries but also contribute to all levels of injuries significantly. Older people generally were more likely to be killed in a crash than younger people. Older people also experienced a slightly larger chance of experiencing the other degrees of injury than the people in the next younger age group. This increased injury level for older drivers may be due to the fact that older people are more fragile than young adults and may therefore be prone to suffer more severe injury.

The seating position was significant in the single vehicle crash model. As seating position is also an indicator of person type, the driver and passenger, there were more drivers who suffered fatal injuries than the passengers in the same vehicle for single vehicle crashes.

Ejection is defined as the location of each occupant's body being completely or partially thrown from the vehicle as a result of a crash. The estimates of the both the single vehicle crash model, and the multi-vehicle crash model proves that if an occupant was totally or partially ejected, the occupant was more likely to suffer fatal injury.

Although age, gender, seating position, and ejection were significant, their "explaining power" is not high, as suggested by a pseudo R^2 of 0.12 for the single vehicle crash model and 0.02 for the multi-vehicle crash model. The significant personal factors were tested along with vehicle characteristics and geometric features, and the results are discussed in Sections 5.3.2 and 5.3.3.

Table 5.1 Crash Severity Models for All States with Personal Factor Only

(SV: LL (0) = -557.25, LL (converge) = -487.32, Pseudo R^2 = 0.126, Number of obs = 517; MV: LL (0) = -1244.77, LL (converge) = -1217.37, Pseudo R^2 = 0.022, Number of obs = 825)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
SV	Gender	0.61	2.48	0.01	0.43	1.20	0.23	0.40	0.95	0.34	0.75	1.23	0.22
	Seating Position	0.44	3.88	0.00	0.42	3.35	0.00	0.44	3.29	0.00	0.23	1.50	0.13
	Age	-0.22	-3.00	0.00	-0.46	-5.25	0.00	-0.31	-3.20	0.00	-0.22	-1.43	0.15
	Ejection	-0.39	-2.07	0.04	-0.45	-2.00	0.05	-0.73	-2.09	0.04	-0.52	-1.29	0.20
MV	Age	-0.19	-4.26	0.00	-0.22	-4.41	0.00	-0.17	-3.04	0.00	-0.06	-0.83	0.41
	Ejection	-0.41	-2.18	0.03	-1.01	-3.11	0.00	-0.51	-1.90	0.06	-0.58	-1.58	0.11

Table 5.2 Elasticity of Crash Severity Models for All States with Personal Factor Only

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
SV	Gender	-0.24	-2.65	0.01	0.56	2.16	0.03	0.33	0.78	0.44	0.29	0.56	0.58	0.74	0.96	0.34
	Seating Position	-0.31	-3.50	0.00	0.68	3.93	0.00	0.65	3.10	0.00	0.68	2.92	0.00	0.22	0.72	0.47
	Age	0.67	5.20	0.00	-0.84	-2.05	0.04	-2.41	-4.76	0.00	-1.43	-2.37	0.02	-0.84	-0.82	0.41
	Ejection	0.23	3.02	0.00	-0.35	-1.56	0.12	-0.43	-1.50	0.13	-0.85	-1.81	0.07	-0.54	-0.93	0.35
MV	Age	0.71	4.03	0.00	-0.62	-2.53	0.01	-0.83	-2.98	0.00	-0.50	-1.54	0.13	0.26	0.62	0.53
	Ejection	0.46	3.27	0.00	-0.03	-0.19	0.85	-0.77	-2.27	0.02	-0.15	-0.53	0.60	-0.25	-0.72	0.47

5.3.2. Crash Severity Models with Personal and Vehicle Factors Only

The estimation results of the personal-factor-only models suggest that (1) gender, age, seating position, and ejection are significant for single vehicle crashes, and (2) age and ejection are significant for multi-vehicle crashes. In addition to these significant factors, the vehicle factors that capture vehicle characteristics are also important. Per discussion in Chapter 4, section 4.3.3 about the selection of the vehicle data elements, several vehicle related variables were added to the models. These variables include vehicle configuration, vehicle role (for multi-vehicle crash only), the authorized speed limit, vehicle maneuver, and vehicle model year. Note that vehicle configuration was not included in the all-state model because of data quality issues. For example, in Georgia, every vehicle involved in a single vehicle crash was recorded as a passenger car.

Table 5.3 summarizes the single vehicle crash model and multi-vehicle crash model with vehicle-related factors. The newly added variables improve the model performance proved with a higher log-likelihood at convergence and a higher pseudo R^2 of 0.14 for single vehicle crash and 0.05 for multi-vehicle crash. The p-values suggest that the newly added vehicle related factors are significant in terms of explaining the causation of the fatal crashes. Vehicle maneuver and vehicle model year have a p-value less than 0.10 in single vehicle crash model. Vehicle maneuver, vehicle model year, and crash avoidance maneuver were all significant in the multi-vehicle model. The elasticity of the variables in the crash severity models is presented in Table 5.4.

For single vehicle crashes, the significant vehicle related factors for differentiating fatal injury from all other levels included vehicle model year and crash avoidance maneuver. The older model year increases the chances of fatal injury for the vehicle occupants. Crash avoidance maneuvers, either braking or steering, can help reduce the chance of fatal injury.

For multi-vehicle crashes, the vehicle model year and crash avoidance maneuver were significant. Occupants in the newer model vehicles were less likely to be involved in the incapacitating nonfatal injury. Newer the vehicles include more safety improvement features in the vehicle design. Features such as airbags and anti-block brakes decrease the likelihood that occupants experience severe injury, including fatal injury, and may completely avoid an injury. The crash avoidance maneuver reduced the likelihood of a non-incapacitating non-fatal injury. The elasticity of the crash avoidance maneuver indicated that such a maneuver helped reduce the chances of fatal injuries, although only a small percentage of drivers executed actions to attempt to avoid a crash. The most frequent maneuvers by the drivers were steering and braking.

Table 5.3 Crash Severity Models for All States with Personal and Vehicle Factors Only

(SV: LL (0) = -554.99, LL (converge) = -474.84, Pseudo R^2 = 0.144, Number of obs = 517; MV: LL (0) = -1222.41, LL (converge) = -1159.89, Pseudo R^2 = 0.051, Number of obs = 808)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
SV	Gender	0.68	2.68	0.01	0.52	1.42	0.16	0.50	1.08	0.28	0.81	1.31	0.19
	Seating Position	0.43	3.75	0.00	0.42	3.44	0.00	0.44	3.44	0.00	0.23	1.46	0.14
	Age	-0.22	-2.88	0.00	-0.48	-5.48	0.00	-0.34	-3.82	0.00	-0.23	-1.52	0.13
	Ejection	-0.40	-1.99	0.05	-0.44	-1.95	0.05	-0.64	-2.02	0.04	-0.53	-1.34	0.18
	Vehicle Model Year	-0.02	-0.98	0.33	-0.04	-1.86	0.06	-0.01	-0.17	0.86	-0.03	-0.72	0.47
	Crash Avoidance Maneuver	0.05	1.20	0.23	-0.11	-1.82	0.07	-0.34	-2.71	0.01	0.04	0.45	0.65
MV	Age	-0.17	-3.92	0.00	-0.23	-4.34	0.00	-0.18	-2.94	0.00	-0.05	-0.66	0.51
	Ejection	-0.45	-2.26	0.02	-0.93	-2.87	0.00	-0.44	-1.66	0.10	-0.52	-1.45	0.15
	Vehicle Maneuver	-0.03	-0.86	0.39	-0.14	-2.74	0.01	-0.16	-2.37	0.02	-0.02	-0.36	0.72
	Vehicle Model Year	0.00	-7.39	0.00	0.00	0.62	0.54	0.00	0.69	0.49	0.00	1.00	0.32
	Crash Avoidance Maneuver	0.13	3.32	0.00	-0.16	-3.07	0.00	-0.11	-1.82	0.07	0.06	1.24	0.22

Table 5.4 Elasticity of Crash Severity Models for All States with Personal and Vehicle Factors Only

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
SV	Gender	-0.26	-2.94	0.00	0.62	2.32	0.02	0.42	0.98	0.33	0.40	0.70	0.49	0.79	1.02	0.31
	Seating Position	-0.29	-3.45	0.00	0.68	3.77	0.00	0.66	3.25	0.00	0.70	3.05	0.00	0.22	0.72	0.47
	Age	0.66	5.13	0.00	-0.85	-1.99	0.05	-2.60	-5.02	0.00	-1.66	-2.96	0.00	-0.92	-0.92	0.36
	Ejection	0.21	2.88	0.00	-0.38	-1.58	0.12	-0.44	-1.49	0.14	-0.73	-1.70	0.09	-0.57	-1.01	0.31
	Vehicle Model Year	17.30	1.83	0.07	-27.22	-0.70	0.48	-71.39	-1.63	0.10	3.69	0.05	0.96	-45.51	-0.54	0.59
	Crash Avoidance Maneuver	0.04	1.23	0.22	0.20	1.71	0.09	-0.31	-1.75	0.08	-0.99	-2.68	0.01	0.15	0.63	0.53
MV	Age	0.66	3.74	0.00	-0.56	-2.20	0.03	-0.96	-3.15	0.00	-0.62	-1.68	0.09	0.30	0.72	0.47
	Ejection	0.43	3.03	0.00	-0.12	-0.61	0.54	-0.70	-2.07	0.04	-0.11	-0.39	0.70	-0.21	-0.62	0.53
	Vehicle Maneuver	0.09	2.62	0.01	0.03	0.40	0.69	-0.21	-2.13	0.03	-0.27	-1.97	0.05	0.06	0.77	0.44
	Vehicle Model Year	0.02	0.05	0.96	-1.78	-3.10	0.00	0.68	1.08	0.28	0.76	1.20	0.23	1.36	1.52	0.13
	Crash Avoidance Maneuver	-0.03	-0.52	0.60	0.35	4.18	0.00	-0.52	-3.67	0.00	-0.36	-2.30	0.02	0.15	1.43	0.15

5.3.3. Crash Severity Models with Crash, Personal, Vehicle, Environmental and Site Factors

Other than personal and vehicle factors, crash and ambient environmental factors such as time of day, day of the week, weather condition, ambient light, and road surface condition may contribute to a crash. These variables used in the model help identify the unobserved effects that would cause the estimation bias.

The various site factors were also added to the crash severity models and the effects of the geometric features of the crash sites were tested thoroughly. One primary concern of traffic engineers is the impact of site factors on the crash condition. This information helps provide crash reduction knowledge concerning the safety effects of roadway improvements. Most existing knowledge regarding the geometric features is associated with crash frequency not crash severity. To date, highway safety engineers have little substantial information regarding the crash injury outcomes of choices in geometric design features.

Table 5.5 summarizes the estimation results of the severity models for all states, including all five categories of factors. Due to the data availability issues, some variables such as seat belt usage were only available in some states and were not included in the all-state models.

Table 5.6 summarizes the elasticity of the causal factors in the crash severity models. Contrary to the coefficients, the elasticity of the factors is easy to interpret. The elasticity of a factor can be viewed as the ratio of the incremental percentage of change in the probability for a particular outcome with respect to when there is an incremental change in the causal factor.

For single vehicle crashes, the significant factors for differentiating fatal injury from all other levels included time of day, vertical curve, cross section type, shoulder type, number of intersections, RHR, raised pavement reflectors, terrain, cross road involvement, first harmful event, relation to roadway, weather condition, ambient light, road surface condition, contributing environment condition, and contributing road condition. The RHR is a subjective measure of the hazard associated with the roadside environment. The rating values indicate the crash damage likely to be sustained by errant vehicles on a scale from one to seven, where seven is the most dangerous roadside condition.

For the multi-vehicle crash model, horizontal curve, direction of the vertical slope, percent of slope, cross road type, lane width, number of driveways/intersections, RHR, terrain, and crossroad involvement were significant. Other than site factors, time of day, first harmful event, relation to roadway, manner of impact, and ambient light were also significant factors in the multi-vehicle crash model.

The elasticity of ambient light indicates that the nighttime conditions can contribute to more fatal crashes than daylight conditions for single vehicle crashes. This observation is consistent with those in Chapter 4. Drivers generally take longer time to react to roadway situations on a poorly-lit roadway than during daylight conditions. In the case that something unexpected happens on a dark road, the driver may not have enough time to respond resulting in more single vehicle crashes and greater injury severity. The "unexpected event" could be a road feature such as a sharp horizontal curve.

Road surface condition is also very important as variations in surface condition can cause as much as 32 percent more likelihood of a fatality. Note that road surface condition for the studied fatal crashes was dry for 79 percent to 89 percent of time and wet for the rest 10 percent to 20 percent of time. Rain can reduce the visibility of the roadway and limit the visible sight distance. Wet pavement is more likely to cause vehicle to skid than dry conditions and makes it more difficult for drivers.

The strongest and most consistent influencing factor for driver fatigue and alertness was the time of day (The Hartford, 2002). Time of day decreases the chances of fatal injury and non-incapacitating nonfatal injury, and possible nonfatal injury while increasing the likelihood of an incapacitating nonfatal injury or no injury. People are more likely to feel drowsy during night driving than during daytime driving. This can be explained by the fact that the biological clock of most people is programmed to sleep during periods of darkness.

Site factors are discussed in detail in section 5.8.4.

The following are the equations that can be used to predict the probability of different severity levels for single vehicle crashes. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

= 1/M

P(Y = Incapacitating Non-fatal Injury)

= EXP (0.62 Gender + 0.41 Seating Position – 0.21Age -0.50 Ejection + 0.15 Time of Day + 0.88 Crest Vertical Curve + 0.56 Number of Intersections – 0.65RaisedPavementReflectors – 0.10 Relation to Roadway - 0.46 Road Surface Condition)/M

P(Y = Non-Incapacitating Injury)

= EXP (0.40 Seating Position – 0.48 Age -0.73 Ejection -0.15 Crash Avoidance Maneuver + 0.44 Number of Intersections – 0.25 RHR + 2.02 Crossroad Involvement – 0.11 First Harmful Event – 0.20 Ambient Light + 0.23 Environment Circumstances + 0.11 Road Circumstances) / M

P(Y = Possible Injury)

= EXP (0.31 Seating Position – 0.34 Age -0.58 Ejection -0.41 Crash Avoidance Maneuver +0.26 Time of Day + 0.44 Shoulder Type + 0.63 Number of Intersections – 1.18 Pavement Reflectors + 1.21 Terrain – 39.73 Cross Street Involvement – 2.66 Environment Circumstances + 0.52 Road Circumstances) / M

P(Y = No Injury)

= exp (0.93 Gender - 0.56 Ejection -1.60 Cross Section + 0.99 Number of Intersections + 1.09 Terrain -39.65 Cross Street Involvement – 0.26 Relation to Roadway – 18.80 Weather Condition – 16.62 Road Surface Condition) / M

where,

M = 1 + exp(0.62 Gender + 0.41 Seating Position – 0.21Age -0.50 Ejection + 0.15 Time of Day + 0.88 Crest Vertical Curve + 0.56 Number of Intersections – 0.65RaisedPavementReflectors – 0.10 Relation to Roadway - 0.46 Road Surface Condition) + exp(0.40 Seating Position – 0.48 Age -0.73 Ejection - 0.15 Crash Avoidance Maneuver+ 0.44 Number of Intersections – 0.25 RHR + 2.02 Crossroad Involvement – 0.11 First Harmful Event – 0.20 Ambient Light + 0.23 Environment Circumstances + 0.11 Road Circumstances) + exp(0.31 Seating Position – 0.34 Age -0.58 Ejection -0.41 Crash Avoidance Maneuver +0.26 Time of Day + 0.44 Shoulder Type + 0.63 Number of Intersections – 1.18 Pavement Reflectors + 1.21 Terrain – 39.73 Cross Street Involvement – 2.66 Environment Circumstances + 0.52 Road Circumstances) + exp (0.93 Gender - 0.56 Ejection -1.60 Cross Section + 0.99 Number of Intersections + 1.09 Terrain -39.65 Cross Street Involvement – 0.26 Relation to Roadway – 18.80 Weather Condition – 16.62 Road Surface Condition)

The following are the equations that can be used to predict the probability of different severity level of multi-vehicle crashes for all-four southeastern states. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

=1 / M

P(Y = Incapacitating Non-fatal Injury)

=EXP (-0.16 Age – 0.49 Ejection + 0.12 Crash Avoidance Maneuver + 0.56 Curve Radius + 0.48 Cross Section Type + 0.48 Cross Section Type + 0.10 Number of Driveways + 0.52Crossstreet Involvement) / M

P(Y = Non-incapacitating Non-fatal Injury)

= EXP (-0.21 Age – 0.90 Ejection – 0.18 Vehicle Maneuver - 0.16 Crash Avoidance Maneuver + 0.18 Day of Week + 0.52 Terrain – 0.52RelationtoRoadway) / M

P(Y = Possible Injury)

= EXP (-0.19 Age – 0.60 Ejection – 0.20 Vehicle Maneuver – 0.12 Time of Day – 1.00 Cross Section Type + 0.28 Lane Width + 0.34 Number of Intersections +0.25 RHR + 0.31 Manner of Impact + 0.19 Ambient Light) / M

P(Y = No Injury)

= EXP (0.18 Seating Position - 0.58 Ejection -0.86 Direction of Slope + 0.29 Percent of Slope – 0.55 Cross Section Type + 0.10 Number of Driveways – 0.57 Terrain – 0.26 First Harmful Event) / M

where,

M
=1 + *exp (-0.16 Age – 0.49 Ejection + 0.12 Crash Avoidance Maneuver + 0.56 Curve Radius + 0.48 Cross Section Type + 0.48 Cross Section Type + 0.10 Number of Driveways + 0.52Crossstreet Involvement) + exp (-0.21 Age – 0.90 Ejection – 0.18 Vehicle Maneuver - 0.16 Crash Avoidance Maneuver + 0.18 Day of Week + 0.52 Terrain – 0.52RelationtoRoadway) + exp (-0.19 Age – 0.60 Ejection – 0.20 Vehicle Maneuver – 0.12 Time of Day – 1.00 Cross Section Type + 0.28 Lane Width + 0.34 Number of Intersections +0.25 RHR + 0.31 Manner of Impact + 0.19 Ambient Light) + exp (0.18 Seating Position - 0.58 Ejection -0.86 Direction of Slope + 0.29 Percent of Slope – 0.55 Cross Section Type + 0.10 Number of Driveways – 0.57 Terrain – 0.26 First Harmful Event)*

Table 5.5 Crash Severity Models for All States with Personal, Vehicle, Environmental, and Site Factors

(SV: LL (0) = -532.30, LL (converge) = -387.11, Pseudo R^2 = 0.273, Number of obs = 500; MV: LL (0) = -1211.56, LL (converge) = -1066.09, Pseudo R^2 = 0.121, Number of obs = 800)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
SV	Gender	0.62	2.23	0.03	0.33	0.75	0.46	0.52	1.06	0.29	0.93	1.61	0.11
	Seating Position	0.41	3.03	0.00	0.40	2.51	0.01	0.31	2.36	0.02	0.17	0.91	0.36
	Age	-0.21	-2.41	0.02	-0.48	-4.71	0.00	-0.34	-3.21	0.00	-0.29	-1.45	0.15
	Ejection	-0.50	-2.82	0.01	-0.73	-2.64	0.01	-0.58	-1.53	0.13	-0.56	-1.56	0.12
	Crash Avoidance Maneuver	0.07	1.37	0.17	-0.15	-2.23	0.03	-0.41	-2.72	0.01	0.17	1.26	0.21
	Time of Day	0.15	2.30	0.02	0.11	1.35	0.18	0.26	2.46	0.01	0.12	0.81	0.42
	Crest Vertical Curve	0.88	3.28	0.00	-0.01	-0.04	0.97	0.25	0.53	0.60	0.04	0.07	0.94
	Cross Section Type	0.28	0.99	0.32	-0.30	-0.79	0.43	-0.02	-0.04	0.96	-1.60	-2.19	0.03
	Shoulder Type	0.06	0.47	0.64	-0.08	-0.39	0.70	0.44	2.40	0.02	-0.13	-0.32	0.75
	Number of Intersections	0.56	2.34	0.02	0.44	1.46	0.14	0.63	1.64	0.10	0.99	2.43	0.02
	RHR	0.09	0.69	0.49	-0.25	-1.69	0.09	-0.33	-1.25	0.21	0.06	0.36	0.72
	Raised Pavement Reflectors	-0.65	-2.33	0.02	0.36	0.94	0.35	-1.18	-1.83	0.07	0.07	0.10	0.92
	Terrain	0.33	1.05	0.29	0.41	1.12	0.27	1.21	2.84	0.01	1.09	2.38	0.02
	Cross-street Involvement	-0.34	-0.45	0.66	2.02	3.25	0.00	-39.73	-49.35	0.00	-39.65	-57.83	0.00
	First Harmful Event	-0.03	-1.01	0.31	-0.11	-3.99	0.00	-0.04	-0.78	0.44	-0.06	-0.90	0.37
	Relation to Roadway	-0.10	-2.35	0.02	-0.08	-1.43	0.15	0.07	0.77	0.44	-0.26	-2.31	0.02
	Weather Condition	0.21	1.06	0.29	0.18	0.76	0.45	0.32	0.77	0.44	-18.80	-9.24	0.00
	Ambient Light	-0.04	-0.52	0.60	-0.20	-2.01	0.05	0.16	1.08	0.28	0.21	1.16	0.25
	Road Surface Condition	-0.46	-1.69	0.09	-0.98	-1.30	0.19	-2.66	-1.66	0.10	-16.62	-11.60	0.00
	Contributing Circumstances, Environment	-0.09	-0.67	0.50	0.23	1.65	0.10	0.52	3.50	0.00	0.09	0.31	0.76
	Contributing Circumstances, Road	-0.02	-0.35	0.73	0.11	2.21	0.03	-0.05	-0.46	0.64	0.08	0.52	0.60

Table 5.5 Crash Severity Models for All States with Personal, Vehicle, Environmental, and Site Factors (Continue)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
MV	Seating Position	0.04	0.60	0.55	0.03	0.40	0.69	0.02	0.26	0.79	0.18	2.07	0.04
	Age	-0.16	-3.16	0.00	-0.21	-3.69	0.00	-0.19	-2.93	0.00	-0.03	-0.48	0.63
	Ejection	-0.49	-2.29	0.02	-0.90	-2.50	0.01	-0.60	-2.20	0.03	-0.58	-1.47	0.14
	Vehicle Maneuver	-0.05	-1.25	0.21	-0.18	-3.40	0.00	-0.20	-2.29	0.02	-0.05	-0.95	0.34
	Vehicle Model Year	0.00	-5.20	0.00	0.00	0.73	0.47	0.00	0.29	0.77	0.00	1.06	0.29
	Crash Avoidance Maneuver	0.12	3.21	0.00	-0.16	-2.70	0.01	-0.10	-1.44	0.15	0.07	1.27	0.20
	Day of Week	0.05	1.00	0.32	0.18	2.32	0.02	0.04	0.61	0.54	-0.06	-0.89	0.37
	Time of Day	0.08	1.23	0.22	-0.05	-0.78	0.44	-0.12	-1.84	0.07	0.00	-0.08	0.94
	Curve Radius	0.56	2.60	0.01	0.05	0.22	0.83	-0.26	-0.73	0.47	-0.17	-0.65	0.52
	Direction of Slope	0.11	0.75	0.45	-0.21	-1.08	0.28	-0.01	-0.06	0.95	-0.86	-3.81	0.00
	Percent of Slope	0.03	0.27	0.79	0.17	1.17	0.24	0.20	1.16	0.25	0.29	1.66	0.10
	Cross Section Type	0.48	1.85	0.06	-0.30	-0.75	0.45	-1.00	-1.89	0.06	-0.55	-1.70	0.09
	Lane Width	-0.04	-0.38	0.71	0.09	0.76	0.45	0.28	1.50	0.13	0.13	1.20	0.23
	Number of Driveways	0.10	2.02	0.04	0.05	0.59	0.55	-0.03	-0.43	0.67	0.10	1.56	0.12
	Number of Intersections	-0.07	-0.32	0.75	0.09	0.29	0.77	0.34	1.60	0.11	0.26	1.41	0.16
	RHR	0.00	0.00	1.00	0.01	0.05	0.96	0.25	1.82	0.07	-0.04	-0.37	0.72
	Terrain	-0.05	-0.18	0.85	0.52	1.55	0.12	0.03	0.06	0.95	-0.57	-2.20	0.03
	Cross-street Involvement	0.52	1.95	0.05	0.26	0.70	0.49	-0.42	-1.11	0.27	-0.14	-0.48	0.63
	First Harmful Event	0.10	0.69	0.49	0.22	1.28	0.20	0.03	0.24	0.81	-0.26	-1.94	0.05
	Relation to Roadway	-0.10	-0.52	0.60	-0.52	-2.75	0.01	-0.43	-1.17	0.24	0.19	1.34	0.18
	Manner of Impact	-0.08	-0.86	0.39	-0.11	-1.05	0.29	0.31	2.92	0.00	0.09	0.99	0.32
	Ambient Light	-0.04	-0.69	0.49	-0.10	-1.26	0.21	0.19	2.60	0.01	0.05	0.74	0.46

Table 5.6 Elasticity of Crash Severity Models for All States with Personal, Vehicle, Environmental, and Site Factors

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
SV	Gender	-0.15	-2.04	0.04	0.66	2.19	0.03	0.27	0.53	0.60	0.53	0.84	0.40	1.06	1.42	0.16
	Seating Position	-0.20	-2.96	0.00	0.73	3.00	0.00	0.69	2.32	0.02	0.51	1.92	0.06	0.19	0.49	0.63
	Age	0.42	3.49	0.00	-1.00	-2.07	0.04	-2.83	-4.54	0.00	-1.90	-2.77	0.01	-1.52	-1.13	0.26
	Ejection	0.18	3.39	0.00	-0.57	-2.56	0.01	-0.90	-2.39	0.02	-0.68	-1.24	0.22	-0.65	-1.24	0.22
	Crash Avoidance Maneuver	0.00	-0.04	0.97	0.21	1.60	0.11	-0.45	-2.36	0.02	-1.26	-2.71	0.01	0.53	1.25	0.21
	Time of Day	-0.14	-2.81	0.01	0.56	2.13	0.03	0.37	1.03	0.31	1.11	2.17	0.03	0.43	0.60	0.55
	Crest Vertical Curve	-0.32	-3.14	0.00	1.76	3.19	0.00	-0.35	-0.46	0.65	0.28	0.25	0.80	-0.23	-0.20	0.85
	Cross Section Type	-0.04	-0.51	0.61	0.38	1.05	0.29	-0.49	-0.90	0.37	-0.07	-0.09	0.93	-2.43	-2.22	0.03
	Shoulder Type	-0.01	-0.28	0.78	0.13	0.49	0.63	-0.21	-0.44	0.66	1.00	2.35	0.02	-0.32	-0.34	0.74
	Number of Intersections	-0.04	-2.68	0.01	0.16	2.18	0.03	0.12	1.16	0.25	0.19	1.34	0.18	0.32	2.14	0.03
	RHR	0.01	0.13	0.90	0.42	0.83	0.40	-1.14	-1.74	0.08	-1.47	-1.23	0.22	0.30	0.37	0.71
	Raised Pavement Reflectors	0.12	1.69	0.09	-0.83	-2.36	0.02	0.64	1.22	0.22	-1.59	-1.70	0.09	0.22	0.21	0.83
	Terrain	-0.12	-1.53	0.13	0.39	0.94	0.35	0.52	0.95	0.34	1.75	2.64	0.01	1.57	2.19	0.03
	Cross-street Involvement	0.00	0.58	0.57	-0.01	-0.40	0.69	0.08	3.68	0.00	-1.51	-45.86	0.00	-1.50	-51.32	0.00
	First Harmful Event	0.13	2.59	0.01	-0.19	-0.70	0.48	-1.15	-3.65	0.00	-0.29	-0.54	0.59	-0.55	-0.72	0.47
	Relation to Roadway	0.13	2.85	0.00	-0.54	-2.17	0.03	-0.37	-1.10	0.27	0.60	0.97	0.33	-1.59	-2.13	0.03
	Weather Condition	-0.07	-1.23	0.22	0.25	1.00	0.32	0.21	0.62	0.54	0.43	0.67	0.50	-29.09	-9.26	0.00
	Ambient Light	0.06	1.30	0.19	-0.07	-0.33	0.74	-0.62	-1.96	0.05	0.58	1.20	0.23	0.77	1.25	0.21
	Road Surface Condition	0.17	2.31	0.02	-0.39	-1.38	0.17	-1.03	-1.18	0.24	-3.07	-1.57	0.12	-20.11	-11.51	0.00
	Contributing Circumstances, Environment	0.00	-0.06	0.95	-0.14	-0.81	0.42	0.34	1.74	0.08	0.77	3.66	0.00	0.13	0.30	0.76
	Contributing Circumstances, Road	0.00	-0.24	0.81	-0.05	-0.45	0.65	0.18	2.19	0.03	-0.10	-0.48	0.63	0.14	0.50	0.62

Table 5.6 Elasticity of Crash Severity Models for All States with Personal, Vehicle, Environmental, and Site Factors (Coutinue)

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
MV	Seating Position	-0.10	-1.17	0.24	0.00	-0.03	0.97	-0.03	-0.20	0.84	-0.05	-0.31	0.76	0.29	2.29	0.02
	Age	0.59	3.28	0.00	-0.55	-1.96	0.05	-0.93	-2.67	0.01	-0.75	-1.80	0.07	0.35	0.83	0.41
	Ejection	0.44	2.99	0.00	-0.15	-0.77	0.44	-0.65	-1.75	0.08	-0.29	-1.00	0.32	-0.27	-0.71	0.48
	Vehicle Maneuver	0.12	3.15	0.00	0.01	0.21	0.84	-0.27	-2.61	0.01	-0.32	-1.81	0.07	0.02	0.19	0.85
	Vehicle Model Year	0.21	0.84	0.40	-1.59	-3.56	0.00	0.68	1.56	0.12	0.39	0.96	0.34	1.14	1.70	0.09
	Crash Avoidance Maneuver	-0.04	-0.68	0.50	0.31	3.73	0.00	-0.51	-3.29	0.00	-0.33	-1.81	0.07	0.16	1.38	0.17
	Day of Week	-0.13	-1.38	0.17	0.12	0.59	0.56	0.71	2.12	0.03	0.08	0.24	0.81	-0.39	-1.55	0.12
	Time of Day	-0.02	-0.15	0.88	0.36	1.49	0.14	-0.25	-0.89	0.37	-0.57	-1.98	0.05	-0.04	-0.17	0.87
	Curve Radius	-0.23	-1.10	0.27	1.17	2.73	0.01	-0.09	-0.16	0.88	-0.88	-1.02	0.31	-0.65	-1.21	0.23
	Direction of Slope	0.31	2.28	0.02	0.55	2.13	0.03	-0.16	-0.41	0.68	0.27	0.57	0.57	-1.58	-3.71	0.00
	Percent of Slope	-0.21	-2.02	0.04	-0.15	-0.77	0.44	0.20	0.60	0.55	0.26	0.68	0.50	0.48	1.35	0.18
	Cross Section Type	0.12	0.81	0.42	0.76	2.82	0.01	-0.28	-0.59	0.56	-1.22	-1.81	0.07	-0.62	-1.64	0.10
	Lane Width	-0.47	-1.28	0.20	-0.94	-0.92	0.36	0.48	0.41	0.68	2.65	1.34	0.18	0.93	0.84	0.40
	Number of Driveways	-0.08	-1.94	0.05	0.11	1.52	0.13	0.01	0.10	0.92	-0.15	-1.02	0.31	0.11	1.05	0.30
	Number of Intersections	-0.04	-0.85	0.39	-0.08	-0.76	0.45	0.01	0.09	0.93	0.17	1.43	0.15	0.12	1.18	0.24
	RHR	-0.06	-0.37	0.71	-0.06	-0.18	0.86	-0.03	-0.07	0.94	0.99	1.83	0.07	-0.23	-0.56	0.58
	Terrain	0.07	0.45	0.65	-0.01	-0.02	0.98	0.88	1.77	0.08	0.11	0.18	0.86	-0.83	-2.44	0.02
	Cross-street Involvement	-0.02	-1.03	0.30	0.11	1.95	0.05	0.04	0.46	0.64	-0.13	-1.41	0.16	-0.06	-0.94	0.35
	First Harmful Event	-0.06	-0.17	0.87	0.72	0.82	0.41	1.75	1.18	0.24	0.21	0.21	0.83	-2.21	-2.39	0.02
	Relation to Roadway	0.11	1.50	0.13	-0.02	-0.09	0.93	-0.56	-2.28	0.02	-0.45	-1.00	0.32	0.36	2.03	0.04
	Manner of Impact	-0.03	-0.28	0.78	-0.32	-1.20	0.23	-0.46	-1.24	0.21	1.14	2.79	0.01	0.32	0.99	0.32
	Ambient Light	0.00	-0.07	0.94	-0.10	-0.99	0.32	-0.25	-1.42	0.16	0.46	2.72	0.01	0.12	0.91	0.36

5.4. Crash Severity Model for Alabama

Tables 5.7 and 5.8 summarize the crash severity model estimation results for the state of Alabama.

For single vehicle crashes, the significant factors for differentiating fatal injury from all other levels included seating position, age, ejection, direction of the slope, average daily traffic, and contributing environment circumstances. Increase in age group increased the likelihood of more fatal injuries. Age, ejection and average daily traffic had the highest elasticity for single vehicle crashes.

For multi-vehicle crashes, the final multi-vehicle crash severity model for Alabama includes: age, seat belt usage, vehicle configuration, vehicle role, direction of the slope, direction of the slope, shoulder type, number of driveways/intersections, delineator presence, RHR, and terrain. Half of the at-fault drivers did not use seat belts. In Alabama, fewer not-at-fault drivers did not use seat belts compared to at-fault drivers. Promoting the usage of the seat belts can reduce the severity of crashes. About one-third of the vertical slopes were considered mild, one-third were steep, and the other one-third were flat. Vertical slope was significant in differentiating fatal injury and incapacitating injury.

The following are the equations that can be used to predict the probability of different severity levels for single vehicle crashes in the state of Alabama. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

= 1 / M

P(Y = Incapacitating Non-fatal Injury)

= EXP (0.28 Seating Position-0.51 Age-1.37 Ejection-0.52 Direction of Slope-0.28 Environment Circumstances)/M

P(Y = Non-Incapacitating Non-fatal Injury)

=EXP (-0.79 Age-1.32 Ejection-19.71 Environment Circumstances)/M

The author was unable to estimate *P(Y = Possible Injury)* due to the small number of observations in this category.

P(Y = No Injury)

=EXP (0.64 Seating Position - 23.31 Ejection - 18.79 Environment Circumstances) / M

where

M

=1 + EXP (0.28 Seating Position - 0.51 Age - 1.37 Ejection - 0.52 Direction of Slope - 0.28 Environment Circumstances) + EXP (-0.79 Age-1.32 Ejection-19.71 Environment Circumstances) + EXP (0.64 Seating Position - 23.31 Ejection - 18.79 Environment Circumstances)

The following are the equations that can be used to predict the probability of different severity levels of multi-vehicle crashes in the state of Alabama. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

=1 / M

P(Y = Incapacitating Non-fatal Injury)

=EXP (0.29 Occupant Protection System Use - 0.23 Age + 0.33 Vehicle Configuration -0.85 Vehicle Role + 0.31 Percent of Slope - 0.22 Shoulder Type + 0.16 Number of Driveways - 0.65 Terrain) / M

P(Y = Non – Incapacitating Non-fatal Injury)

= EXP (0.70 Occupant Protection System Use - 0.42 Age + 0.56 Vehicle Configuration - 1.06 Percent of Slope - 1.02 Shoulder Type + 0.50 Number of Driveways + 2.37 Number of Intersections - 17.80 Delineator Presence + 0.88 RHR) / M

The author was unable to estimate *P(Y = Possible Injury)* due to the small number of observations in this category

P(Y = No Injury)

= EXP (0.80 Occupant System Use + 0.29 Age + 0.66 Vehicle Configuration - 1.50 Vehicle Role - 1.63 Direction of Slope - 0.45 Shoulder Type + 1.34 Number of Intersections - 19.56 Delineator Presence + 0.49 RHR - 1.54 Terrain) / M

where,

M

=1+ EXP (0.29 Occupant Protection System Use - 0.23 Age + 0.33 Vehicle Configuration -0.85 Vehicle Role + 0.31 Percent of Slope - 0.22 Shoulder Type + 0.16 Number of Driveways - 0.65 Terrain) + EXP (0.70 Occupant Protection System Use - 0.42 Age + 0.56 Vehicle Configuration - 1.06 Percent of Slope - 1.02 Shoulder Type + 0.50 Number of Driveways + 2.37 Number of Intersections - 17.80 Delineator Presence + 0.88 RHR) + EXP (0.80 Occupant System Use + 0.29 Age + 0.66 Vehicle Configuration - 1.50 Vehicle Role - 1.63 Direction of Slope - 0.45 Shoulder Type + 1.34 Number of Intersections - 19.56 Delineator Presence + 0.49 RHR - 1.54 Terrain)

Table 5.7 Crash Severity Models for Alabama

(SV: LL (0) = -108.11, LL (converge) = -79.151, Pseudo R^2 = 0.68, Number of obs = 139; MV: LL (0) = -266.48, LL (converge) = -178.18, Pseudo R^2 = 0.331, Number of obs = 221)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
SV	Seating Position	0.28	1.99	0.05	0.10	0.43	0.67				0.64	1.77	0.08
	Age	-0.51	-2.95	0.00	-0.79	-2.76	0.01				-0.09	-0.19	0.85
	Ejection	-1.37	-3.55	0.00	-1.32	-1.56	0.12				-23.31	-3.10	0.00
	Direction of Slope	-0.52	-1.56	0.12	0.89	0.97	0.33				-0.18	-0.39	0.70
	Contributing Circumstances, Environment	-0.28	-2.55	0.01	-19.71	-6.10	0.00				-18.79	-3.60	0.00
MV	Occupant Protection System Use	0.29	2.72	0.01	0.70	2.79	0.01	14.06	41.17	0.00	0.80	5.11	0.00
	Age	-0.23	-3.11	0.00	-0.42	-2.08	0.04	0.13	0.38	0.70	0.29	2.02	0.04
	Vehicle Configuration	0.33	3.59	0.00	0.56	2.07	0.04	6.41	21.55	0.00	0.66	3.81	0.00
	Vehicle Role	-0.85	-2.59	0.01	-2.33	-1.40	0.16	-1.34	-2.31	0.02	-1.50	-1.86	0.06
	Direction of Slope	-0.12	-0.46	0.65	0.14	0.19	0.85	11.70	12.44	0.00	-1.63	-4.48	0.00
	Percent of Slope	0.31	2.19	0.03	-1.06	-1.80	0.07	-26.97	-64.82	0.00	0.15	0.56	0.58
	Shoulder Type	-0.22	-2.46	0.01	-1.02	-1.87	0.06	-86.20	.	.	-0.45	-1.89	0.06
	Number of Driveways	0.16	1.85	0.06	0.50	2.42	0.02	-3.75	-13.38	0.00	-0.09	-0.61	0.54
	Number of Intersections	0.11	0.53	0.60	2.37	2.69	0.01	60.04	.	.	1.34	3.42	0.00
	Delineator Presence	-0.24	-1.15	0.25	-17.80	-2.64	0.01	-72.33	.	.	-19.56	-6.47	0.00
	RHR	0.03	0.19	0.85	0.88	1.78	0.08	59.58	118.44	0.00	0.49	2.32	0.02
	Terrain	-0.65	-1.88	0.06	1.04	0.74	0.46	-53.27	-32.98	0.00	-1.54	-2.60	0.01

Table 5.8 Elasticity of Crash Severity Models for Alabama

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
SV	Seating Position	-0.14	-2.00	0.05	0.50	1.94	0.05									
	Age	0.76	2.90	0.00	-2.76	-2.83	0.01									
	Ejection	0.45	4.06	0.00	-1.62	-3.23	0.00									
	Direction of Slope	0.26	1.48	0.14	-0.93	-1.56	0.12									
	Contributing Circumstances, Environment	0.09	2.42	0.02	-0.34	-2.50	0.01									
MV	Occupant Protection System Use	-0.50	-2.74	0.01	0.27	2.46	0.01							1.64	4.66	0.00
	Age	0.92	2.75	0.01	-0.76	-3.40	0.00							2.98	3.04	0.00
	Vehicle Configuration	-0.44	-3.31	0.00	0.26	3.63	0.00							0.96	3.34	0.00
	Vehicle Role	1.71	2.50	0.01	-1.05	-2.56	0.01							-3.14	-1.26	0.21
	Direction of Slope	0.24	0.70	0.49	-0.03	-0.13	0.90							-3.39	-4.36	0.00
	Percent of Slope	-0.40	-2.22	0.03	0.29	2.08	0.04							-0.08	-0.15	0.88
	Shoulder Type	0.30	2.51	0.01	-0.18	-2.22	0.03							-0.67	-1.30	0.19
	Number of Driveways	-0.19	-1.70	0.09	0.15	2.00	0.05							-0.39	-1.39	0.16
	Number of Intersections	-0.06	-0.79	0.43	0.01	0.15	0.88							0.75	3.31	0.00
	Delineator Presence	0.66	3.48	0.00	0.41	2.28	0.02							-20.23	-6.21	0.00
	RHR	-0.12	-0.34	0.74	0.00	0.00	1.00							1.80	2.16	0.03
	Terrain	0.57	1.99	0.05	-0.33	-1.66	0.10							-1.58	-2.18	0.03

5.5. Crash Severity Model for Georgia

Tables 5.9 and Table 5.10 summarize the crash severity model estimation results for the state of Georgia.

For single vehicle crashes, the significant factors for differentiating fatal injury from all other levels include sex, seating position, age, ejection, vehicle model year, crash avoidance maneuver, time of day, and first harmful event. Site and environmental factors were not significant for the Georgia model. Among the significant factors, vehicle model year exhibited the highest elasticity. As around 70 of the vehicles involved in the single vehicle fatal crashes were models more than 5 years old, the lack of safety features on these vehicles contributed to the severe single vehicle crashes.

For multi-vehicle crashes, the final model includes age, seat belt usage, vehicle configuration, vehicle authorized speed limit, vehicle maneuver, most harmful event for the vehicle, day of the week, number of intersections, delineator presence, raised pavement reflectors, first harmful event, weather condition, ambient light, contributing environment circumstances, and contributing road circumstances. The older person was more likely to experience a fatal injury. Vehicle configuration indicates if the vehicle involved in the crash is a passenger car, a light truck, or others. Involvement of a light truck, for example, decreased the probability of the three most severe levels of injury, including fatal injury, incapacitating nonfatal injury, and non-incapacitating nonfatal injury over that of a passenger car. It also decreased the probability of injury in all other crash severity categories.

The following are the equations that can be used to predict the probability of different severity levels for single vehicle crashes in the state of Georgia. The factors with a p value less than or equal to 0.15 are included in the equations.

$P(Y = Fatal\ Injury)$

$= 1 / M$

P(Y = Incapacitating Non-fatal Injury)

=EXP (1.77 Gender + 0.50 Seating Position - 0.19 Age - 0.14 Vehicle Model Year + 0.32 Time of Day - 0.13 First Harmful Event) / M

P(Y = Non-incapacitating Non-fatal Injury)

=EXP (-0.35 Age - 1.74 Ejection - 0.07 Vehicle Model Year + 0.29 Crash Avoidance Maneuver + 0.25 Time of Day -0.11 First Harmful Event) / M

P(Y = Possible Injury)

=EXP (0.53 Seating Position - 0.51 Age + 0.46 Crash Avoidance Maneuver) / M

The author was unable to estimate *P(Y = No Injury)* due to limited number of observations in this category.

where

M

=1 + EXP (1.77 Gender + 0.50 Seating Position - 0.19 Age - 0.14 Vehicle Model Year + 0.32 Time of Day - 0.13 First Harmful Event) + EXP (-0.35 Age - 1.74 Ejection - 0.07 Vehicle Model Year + 0.29 Crash Avoidance Maneuver + 0.25 Time of Day -0.11 First Harmful Event) + EXP (0.53 Seating Position - 0.51 Age + 0.46 Crash Avoidance Maneuver)

The following are the equations that can be used to predict the probability of different severity level of multi-vehicle crash in the state of Georgia. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

=1 / M

P(Y = Incapacitating Non-fatal Injury)

=EXP (- 0.24 Age + 0.16 Day of Week - 0.72 Number of Intersections + 5.54 First Harmful Event + 0.41 Weather Condition) / M

P(Y = Non – Incapacitating Non-fatal Injury)

=EXP (-0.29 Age + 0.05 Speed Limit - 0.26 Vehicle Maneuver + 0.24 Day of Week - 0.79 Pavement Reflectors - 0.28 Ambient Light + 0.82 Environment Circumstances) / M

P(Y = Possible Injury)

=EXP (0.24 Occupant Protection System Use - 0.53 Age + 1.61 Vehicle Configuration + 0.31 Ambient Light - 0.74 Road Circumstances) / M

P(Y = No Injury)

=EXP (0.28 Occupant Protection System Use - 0.42 Age + 1.29 Vehicle Configuration - 0.09 Speed Limit - 0.36 Vehicle Maneuver - 6.60 Delineator Presence - 2.25 Pavement Reflectors - 0.54 First Harmful Event + 0.26 Ambient Light + 0.77 Environment Circumstances - 0.41 Road Circumstances) / M

where,

M

=1 + EXP (- 0.24 Age + 0.16 Day of Week - 0.72 Number of Intersections + 5.54 First Harmful Event + 0.41 Weather Condition) + EXP (-0.29 Age + 0.05 Speed Limit - 0.26 Vehicle Maneuver + 0.24 Day of Week - 0.79 Pavement Reflectors - 0.28 Ambient Light + 0.82 Environment Circumstances) + EXP (0.24 Occupant Protection System Use - 0.53 Age + 1.61 Vehicle Configuration + 0.31 Ambient Light - 0.74 Road Circumstances) + EXP (0.28 Occupant Protection System Use - 0.42 Age + 1.29 Vehicle Configuration - 0.09 Speed Limit - 0.36 Vehicle Maneuver - 6.60 Delineator Presence - 2.25 Pavement Reflectors - 0.54 First Harmful Event + 0.26 Ambient Light + 0.77 Environment Circumstances - 0.41 Road Circumstances)

Table 5.9 Crash Severity Models for Georgia

(SV: LL (0) = -120.87, LL (converge) = -79.72, Pseudo R^2 = 0.340, Number of obs = 131; MV: LL (0) = -344.41, LL (converge) = -262.25, Pseudo R^2 = 0.239, Number of obs = 226)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
SV	Gender	1.77	2.64	0.01	0.70	1.02	0.31	1.11	1.24	0.22	-79.76	-55.72	0.00
	Seating Position	0.50	2.39	0.02	0.22	1.01	0.32	0.53	1.87	0.06	454.04	1793.40	0.00
	Age	-0.19	-1.55	0.12	-0.35	-2.51	0.01	-0.51	-2.57	0.01	113.78	547.89	0.00
	Ejection	-0.52	-0.86	0.39	-1.74	-2.45	0.01	-23.59	-0.16	0.88	311.13	508.16	0.00
	Vehicle Model Year	-0.14	-3.47	0.00	-0.07	-2.01	0.05	0.09	1.13	0.26	-1.79	-767.90	0.00
	Crash Avoidance Maneuver	-0.43	-1.52	0.13	0.29	1.97	0.05	0.46	2.31	0.02	120.95	408.92	0.00
	Time of Day	0.32	1.99	0.05	0.25	1.83	0.07	-0.19	-0.51	0.61	738.49	.	.
	First Harmful Event	-0.13	-2.20	0.03	-0.11	-2.24	0.03	-0.05	-0.52	0.61	27.19	143.30	0.00
MV	Occupant Protection System Use	0.06	0.55	0.58	0.02	0.24	0.81	0.24	1.93	0.05	0.28	2.33	0.02
	Age	-0.24	-2.69	0.01	-0.29	-2.81	0.01	-0.53	-2.89	0.00	-0.42	-3.95	0.00
	Vehicle Configuration	-16.60	.	.	-0.22	-0.40	0.69	1.61	3.83	0.00	1.29	3.49	0.00
	Vehicle Authorized Speed Limit	0.01	0.24	0.81	0.05	1.54	0.12	0.05	1.13	0.26	-0.09	-3.73	0.00
	Vehicle Maneuver	0.03	0.41	0.68	-0.26	-2.92	0.00	-0.21	-1.11	0.27	-0.36	-2.49	0.01
	Day of Week	0.16	1.52	0.13	0.24	1.79	0.07	0.06	0.36	0.72	0.09	0.63	0.53
	Number of Intersections	-0.72	-2.11	0.03	-0.15	-0.45	0.65	-0.37	-0.74	0.46	0.60	1.24	0.21
	Delineator Presence	-0.03	-0.18	0.86	0.18	0.96	0.34	0.08	0.34	0.73	-6.60	-2.41	0.02
	Raised Pavement Reflectors	-0.47	-1.11	0.27	-0.79	-2.05	0.04	0.55	0.90	0.37	-2.25	-2.46	0.01
	First Harmful Event	5.54	17.89	0.00	-0.15	-0.76	0.45	-0.02	-0.12	0.90	-0.54	-2.28	0.02
	Weather Condition	0.41	1.87	0.06	-0.06	-0.29	0.77	-0.17	-0.47	0.64	-0.14	-0.41	0.68
	Ambient Light	0.08	0.67	0.50	-0.28	-2.03	0.04	0.31	2.40	0.02	0.26	1.78	0.08
	Contributing Circumstances, Environment	-0.34	-0.71	0.48	0.81	1.98	0.05	0.69	0.77	0.44	0.77	2.60	0.01
	Contributing Circumstances, Road	0.09	0.76	0.44	-0.10	-0.67	0.50	-0.75	-2.20	0.03	-0.41	-2.40	0.02

Table 5.10 Elasticity of Crash Severity Models for Georgia

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
SV	Gender	-0.19	-1.60	0.11	2.14	2.49	0.01	0.73	0.91	0.36						
	Seating Position	-0.09	-1.35	0.18	0.93	2.35	0.02	0.36	0.93	0.35						
	Age	0.30	3.15	0.00	-0.94	-1.24	0.21	-2.05	-2.31	0.02						
	Ejection	0.32	2.68	0.01	-0.49	-0.55	0.58	-2.37	-2.29	0.02						
	Vehicle Model Year	25.62	2.51	0.01	-261.71	-3.07	0.00	-109.58	-1.80	0.07						
	Crash Avoidance Maneuver	-0.03	-0.69	0.49	-0.93	-1.59	0.11	0.57	2.06	0.04						
	Time of Day	-0.19	-2.00	0.05	1.35	1.80	0.07	1.00	1.73	0.08						
	First Harmful Event	0.20	2.95	0.00	-1.41	-1.96	0.05	-1.06	-2.02	0.04						
MV	Occupant Protection System Use	-0.23	0.13	-1.70	-0.02	-0.07	0.95	-0.16	-0.74	0.46	0.55	1.71	0.09	0.68	2.21	0.03
	Age	1.27	0.34	3.69	-0.41	-0.71	0.48	-0.74	-1.48	0.14	-2.44	-2.30	0.02	-1.64	-2.73	0.01
	Vehicle Configuration	-0.43	0.27	-1.61	-23.27	-45.36	0.00	-0.73	-1.32	0.19	1.78	4.42	0.00	1.35	4.26	0.00
	Vehicle Authorized Speed Limit	-0.24	0.55	-0.44	0.30	0.14	0.89	2.24	1.69	0.09	2.51	1.17	0.24	-5.08	-4.45	0.00
	Vehicle Maneuver	0.27	0.09	3.02	0.34	1.96	0.05	-0.27	-1.79	0.07	-0.17	-0.51	0.61	-0.48	-1.87	0.06
	Most Harmful Event	-0.32	0.18	-1.74	0.40	0.77	0.44	0.73	1.55	0.12	-0.07	-0.11	0.91	0.10	0.17	0.86
	Day of Week	0.00	0.07	-0.01	-0.41	-2.09	0.04	-0.08	-0.56	0.57	-0.21	-0.85	0.40	0.34	1.43	0.15
	Number of Intersections	0.89	0.42	2.10	0.86	1.90	0.06	1.09	2.47	0.01	0.98	2.09	0.04	-6.32	-2.36	0.02
	Delineator Presence	0.54	0.28	1.92	-0.08	-0.13	0.89	-0.52	-1.20	0.23	1.27	1.81	0.07	-2.46	-2.32	0.02
	Raised Pavement Reflectors	0.82	0.54	1.53	43.60	18.28	0.00	-0.35	-0.27	0.79	0.63	0.48	0.63	-3.33	-2.20	0.03
	First Harmful Event	0.07	0.12	0.57	0.61	2.23	0.03	-0.01	-0.03	0.98	-0.16	-0.41	0.68	-0.12	-0.31	0.76
	Weather Condition	-0.02	0.12	-0.20	0.18	0.61	0.54	-0.76	-2.64	0.01	0.78	2.70	0.01	0.66	2.08	0.04
	Ambient Light	-0.46	0.27	-1.71	-0.88	-1.35	0.18	0.57	1.77	0.08	0.41	0.47	0.64	0.52	1.70	0.09
	Contributing Circumstances, Environment	0.24	0.11	2.13	0.37	2.13	0.03	0.10	0.74	0.46	-0.84	-2.11	0.03	-0.36	-1.78	0.07
	Contributing Circumstances, Road	-0.23	0.13	-1.70	-0.02	-0.07	0.95	-0.16	-0.74	0.46	0.55	1.71	0.09	0.68	2.21	0.03

5.6. Crash Severity Model for Mississippi

Tables 5.11 and Table 5.12 summarize the crash severity model estimation results for the state of Mississippi.

For single vehicle crashes, the significant factors for differentiating fatal injury from all other levels include most harmful event for this vehicle, vehicle model year, crash avoidance maneuver, time of day, vertical curve, number of driveways/intersections, RHR, terrain, first harmful event, and ambient light. In the sample used in this dissertation, eighty percent of the drivers in Mississippi were fatally injured in the crashes and over 70 percent of them were male. The presence of the driveway and intersections did not increase the likelihood of fatal injuries significantly and the elasticity of them was lower when compared to other factors in the model. Similar to the state of Georgia, the age of the vehicles contributed significantly to the single vehicle crashes as 60 of the vehicles were more than 5 years old.

For multi-vehicle crashes, age, ejection, vehicle configuration, vehicle model year, horizontal alignment (curve radius), percent of slope, crest vertical curve, cross section type, number of intersections, RHR, raised pavement reflectors, terrain, crossroad involvement, manner of impact, contributing environment circumstances, and contributing road circumstances were significant. Age and ejection were the two factors with the largest elasticity, followed by manner of impact and contributing environmental circumstances.

The following are the equations that can be used to predict the probability of different severity levels for single vehicle crashes in the state of Mississippi. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

=1 / M

P(Y = Incapacitating Non-fatal Injury)

=EXP (-0.19 Vehicle Model Year - 1.71 Crash Avoidance Maneuver + 1.80 Crest Vertical Curve + 0.78 Number of Driveways + 2.42 Number of Intersections - 0.57 Ambient Light) / M

P(Y = Non-incapacitating Non-fatal Injury)

=EXP (-0.07 Most Harmful Event + 0.30 Vehicle Model Year -0.76 Crash Avoidance Maneuver + 0.43 Time of Day + 1.32 Crest Vertical Curve - 1.00 RHR + 3.79 Terrain - 0.2 First Harmful Event) / M

The author was unable to estimate *P(Y = Possible Injury)* and *P(Y = No Injury)* due to the limited number of observations in this category.

where,

M
=1 + EXP (-0.19 Vehicle Model Year - 1.71 Crash Avoidance Maneuver + 1.80 Crest Vertical Curve + 0.78 Number of Driveways + 2.42 Number of Intersections - 0.57 Ambient Light) + EXP (-0.07 Most Harmful Event + 0.30 Vehicle Model Year -0.76 Crash Avoidance Maneuver + 0.43 Time of Day + 1.32 Crest Vertical Curve - 1.00 RHR + 3.79 Terrain - 0.2 First Harmful Event)

The following are the equations that can be used to predict the probability of different severity levels for multi-vehicle crashes in the state of Mississippi. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

=1 / M

P(Y = Incapacitating Non-fatal Injury)

=EXP (-0.21 Age - 20.07 Crash Avoidance Maneuver + 0.96 Crest Vertical Curve + 0.75 RHR - 4.78 Pavement Reflectors + 1.42 Cross Street Involvement - 0.54 Manner of Impact + 0.64 Road Circumstances) / M

P(Y = Non-incapacitating Non-fatal Injury)

=EXP (-0.35 Age - 2.57 Ejection + 0.24 Vehicle Configuration + 0.82 Percent of Slope - 0.29 Manner of Impact + 1.49 Environment Circumstances) / M

P(Y = Possible Injury)

=EXP (1.33 Crash Avoidance Maneuver + 4.69 Curve Radius + 1.44 Percent of Slope + 4.59 Cross Section Type -3.28 Number of Intersections - 0.47 RHR + 3.89 Pavement Reflectors + 6.09 Terrain + 3.43 Cross Street Involvement - 0.36 Manner of Impact + 2.34 Road Circumstances) / M

P(Y = No Injury)

=EXP (-0.63 Age - 3.10 Ejection + 0.58 Vehicle Configuration + 0.84 Crash Avoidance Maneuver + 2.34 Curve Radius + 2.30 Pavement Reflectors - 3.52 Terrain + 0.58 Manner of Impact - 2.29 Environment Circumstances) / M

where,

M

=1 + EXP (-0.21 Age - 20.07 Crash Avoidance Maneuver + 0.96 Crest Vertical Curve + 0.75 RHR - 4.78 Pavement Reflectors + 1.42 Cross Street Involvement - 0.54 Manner of Impact + 0.64 Road Circumstances) + EXP (-0.35 Age - 2.57 Ejection + 0.24 Vehicle Configuration + 0.82 Percent of Slope - 0.29 Manner of Impact + 1.49 Environment Circumstances) + EXP (1.33 Crash Avoidance Maneuver + 4.69 Curve Radius + 1.44 Percent of Slope + 4.59 Cross Section Type -3.28 Number of Intersections - 0.47 RHR + 3.89 Pavement Reflectors + 6.09 Terrain + 3.43 Cross Street Involvement - 0.36 Manner of Impact + 2.34 Road Circumstances) + EXP (-0.63 Age - 3.10 Ejection + 0.58 Vehicle Configuration + 0.84 Crash Avoidance Maneuver + 2.34 Curve Radius + 2.30 Pavement Reflectors - 3.52 Terrain + 0.58 Manner of Impact - 2.29 Environment Circumstances)

Table 5.11 Crash Severity Models for Mississippi

(SV: LL (0) = -66.62, LL (converge) = -40.23, Pseudo R^2 = 0.396, Number of obs = 79; MV: LL (0) = -287.53, LL (converge) = -179.38, Pseudo R^2 = 0.376, Number of obs = 185)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
SV	Most Harmful Event	-0.05	-1.02	0.31	-0.07	-1.88	0.06						
	Vehicle Model Year	-0.19	-1.92	0.06	0.30	2.74	0.01						
	Crash Avoidance Maneuver	-1.71	-3.77	0.00	-0.76	-1.53	0.13						
	Time of Day	0.27	1.36	0.17	0.43	2.82	0.01						
	Crest Vertical Curve	1.80	2.39	0.02	1.32	1.71	0.09						
	Number of Driveways	0.78	2.37	0.02	-0.24	-0.62	0.53						
	Number of Intersections	2.42	2.40	0.02	0.40	0.57	0.57						
	RHR	0.21	0.51	0.61	-1.00	-2.01	0.04						
	Terrain	0.57	0.44	0.66	3.79	3.12	0.00						
	First Harmful Event	-0.11	-0.90	0.37	-0.20	-2.93	0.00						
	Ambient Light	-0.57	-1.94	0.05	-0.33	-0.98	0.33						
MV	Age	-0.21	-1.53	0.13	-0.35	-2.61	0.01	-0.31	-1.45	0.15	-0.63	-3.39	0.00
	Ejection	-0.44	-0.74	0.46	-2.57	-3.68	0.00	-18.61	-0.10	0.92	-3.10	-3.21	0.00
	Vehicle Configuration	-0.15	-0.92	0.36	0.24	2.15	0.03	0.22	1.26	0.21	0.58	3.99	0.00
	Vehicle Model Year	0.00	-2.16	0.03	0.01	0.30	0.77	0.08	0.88	0.38	0.00	-0.18	0.86
	Crash Avoidance Maneuver	-20.07	-2.90	0.00	0.38	1.42	0.15	1.33	3.65	0.00	0.84	2.40	0.02
	Curve Radius	1.17	0.76	0.45	1.05	1.19	0.24	4.69	3.01	0.00	2.34	2.08	0.04
	Percent of Slope	0.04	0.16	0.87	0.82	2.96	0.00	1.44	3.48	0.00	0.25	0.78	0.44
	Crest Vertical Curve	0.96	2.40	0.02	-0.27	-0.75	0.46	0.38	0.71	0.48	0.11	0.20	0.84
	Cross Section Type	-0.85	-0.67	0.50	0.66	0.56	0.57	4.59	1.90	0.06	2.36	1.24	0.21
	Number of Intersections	0.16	0.14	0.89	-0.55	-0.73	0.47	-3.28	-2.41	0.02	-1.08	-0.81	0.42
	RHR	0.75	2.09	0.04	0.22	0.56	0.57	-0.47	-1.58	0.12	0.27	0.83	0.41
	Raised Pavement Reflectors	-4.78	-3.38	0.00	0.00	0.01	1.00	3.89	3.04	0.00	2.30	1.96	0.05
	Terrain	-0.47	-0.53	0.60	19.67	0.49	0.62	6.09	2.63	0.01	-3.52	-2.49	0.01
	Cross-street Involvement	1.42	1.65	0.10	0.08	0.09	0.93	3.43	2.78	0.01	1.30	0.88	0.38
	Manner of Impact	-0.54	-2.99	0.00	-0.29	-1.54	0.12	-0.36	-2.31	0.02	0.58	2.86	0.00
	Contributing Circumstances, Environment	-0.30	-0.39	0.70	1.49	1.49	0.14	0.21	0.11	0.91	-2.29	-2.19	0.03
	Contributing Circumstances, Road	0.64	2.74	0.01	-1.29	-1.09	0.28	2.34	1.64	0.10	-0.28	-0.65	0.52

Table 5.12 Elasticity of Crash Severity Models for Mississippi

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
SV	Most Harmful Event	0.09	2.05	0.04	-1.02	-0.96	0.34	-1.67	-1.74	0.08						
	Vehicle Model Year	-5.26	-0.34	0.74	-392.67	-1.94	0.05	594.05	2.59	0.01						
	Crash Avoidance Maneuver	0.15	1.80	0.07	-3.11	-3.60	0.00	-1.30	-1.39	0.16						
	Time of Day	-0.08	-1.31	0.19	0.87	1.31	0.19	1.46	2.78	0.01						
	Crest Vertical Curve	-0.23	-1.92	0.06	4.06	2.31	0.02	2.91	1.58	0.11						
	Number of Driveways	-0.03	-0.79	0.43	1.07	2.28	0.02	-0.37	-0.70	0.48						
	Number of Intersections	-0.04	-1.89	0.06	1.09	2.28	0.02	0.15	0.46	0.64						
	RHR	0.11	0.73	0.47	1.17	0.59	0.56	-4.86	-1.95	0.05						
	Terrain	-0.23	-1.15	0.25	0.77	0.36	0.72	6.44	2.94	0.00						
	First Harmful Event	0.10	1.25	0.21	-1.04	-0.85	0.39	-2.01	-2.78	0.01						
	Ambient Light	0.10	2.12	0.03	-2.00	-1.85	0.06	-1.14	-0.91	0.36						
MV	Age	0.62	2.57	0.01	-0.85	-0.92	0.36	-1.76	-2.19	0.03	-1.51	-1.08	0.28	-3.71	-3.14	0.00
	Ejection	0.57	2.00	0.05	0.04	0.05	0.96	-2.55	-3.69	0.00	-22.06	-0.10	0.92	-3.20	-3.28	0.00
	Vehicle Configuration	-0.20	-2.24	0.03	-0.59	-1.41	0.16	0.41	1.72	0.09	0.36	0.85	0.39	1.28	3.91	0.00
	Vehicle Model Year	-0.75	-0.26	0.79	-2.49	-0.83	0.41	22.07	0.30	0.77	151.76	0.88	0.38	-1.15	-0.37	0.71
	Crash Avoidance Maneuver	-0.20	-1.63	0.10	-34.37	-2.91	0.00	0.44	1.21	0.23	2.06	3.65	0.00	1.24	2.44	0.02
	Curve Radius	-0.82	-1.55	0.12	2.13	0.55	0.59	1.82	0.85	0.39	10.98	2.78	0.01	5.07	2.11	0.04
	Percent of Slope	-0.14	-1.09	0.28	-0.04	-0.07	0.94	1.71	2.94	0.00	3.10	3.31	0.00	0.44	0.71	0.48
	Crest Vertical Curve	-0.01	-0.06	0.95	2.26	2.37	0.02	-0.64	-0.78	0.44	0.87	0.69	0.49	0.25	0.22	0.83
	Cross Section Type	-0.41	-1.09	0.28	-1.53	-0.93	0.35	0.46	0.30	0.76	5.60	1.76	0.08	2.68	1.25	0.21
	Number of Intersections	0.09	0.80	0.43	0.19	0.29	0.78	-0.24	-0.57	0.57	-1.89	-2.34	0.02	-0.56	-0.80	0.42
	RHR	-0.19	-0.92	0.36	3.32	1.93	0.05	0.86	0.49	0.63	-2.38	-1.80	0.07	1.06	0.80	0.42
	Raised Pavement Reflectors	-0.35	-1.65	0.10	-6.19	-3.64	0.00	-0.34	-0.43	0.66	4.41	2.88	0.00	2.46	1.93	0.05
	Terrain	-0.49	-0.19	0.85	-1.38	-0.52	0.61	37.04	0.50	0.62	11.14	2.23	0.03	-7.21	-1.78	0.08
	Cross-street Involvement	-0.06	-0.78	0.44	0.46	1.43	0.15	-0.03	-0.09	0.93	1.20	2.64	0.01	0.42	0.89	0.37
	Manner of Impact	-0.27	-2.23	0.03	-2.60	-3.33	0.00	-1.54	-1.98	0.05	-1.81	-2.66	0.01	2.26	2.67	0.01
	Contributing Circumstances, Environment	0.27	1.80	0.07	-0.08	-0.09	0.93	2.03	1.77	0.08	0.52	0.23	0.82	-2.42	-2.11	0.04
	Contributing Circumstances, Road	0.10	1.49	0.14	0.92	3.02	0.00	-1.55	-1.05	0.30	3.10	1.71	0.09	-0.26	-0.50	0.62

5.7. Crash Severity Model for South Carolina

Tables 5.13 and Table 5.14 summarize the crash severity model estimation results for the state of South Carolina.

For single vehicle crashes, the significant factors for differentiating fatal injury from all other levels include seating position, age, vehicle configuration, speed limit, time of day, direction of slope, ADT, number of driveways, RHR, and contributing road circumstances. About 75 percent of the crash sites had a roadside hazard rating (RHR) of 5 and the rest of them had a rating greater than 4. Only 20 percent of the occupants used their seat belt.

For multi-vehicle crashes, the final model includes age, time of day, speed limit, vehicle maneuver, direction of slope, cross-section type, lane width, shoulder type, RHR, terrain, cross-road involvement, manner of impact, road surface condition, and contributing road circumstances. Age was the leading factor contributing to fatal injury, with the high elasticity and high significance level for multi-vehicle crashes. Cross-road involvement, direction of slope, cross-section type, and terrain increased the chance of an incapacitating nonfatal injury as shown by their high elasticity. Wider lanes decreased the chance of non-incapacitating nonfatal injury.

The following are the equations that can be used to predict the probability of different severity levels for single vehicle crashes in the state of South Carolina. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

=1 / M

P(Y = Incapacitating Non-fatal Injury)

=EXP (0.84 Seating Position - 1.60 Vehicle Configuration + 0.14 Speed Limit + 0.39 Time of Day -0.81 Number of Driveways - 1.46 Road Circumstances) / M

P(Y = Non-incapacitating Non-fatal Injury)

=EXP (0.95 Seating Position - 0.42 Age - 0.23 Time of Day + 0.12 Road Circumstances) / M

P(Y = Possible Injury)

=EXP (0.71 Seating Position - 0.30 Age - 0.78 Direction of Slope – 17.73 Road Circumstances) / M

P(Y =No Injury)

=EXP (0.53 Number of Driveways - 3.01 RHR - 18.93 Road Circumstances) / M

where,

M

=1 + EXP (0.84 Seating Position - 1.60 Vehicle Configuration + 0.14 Speed Limit + 0.39 Time of Day - 0.81 Number of Driveways - 1.46 Road Circumstances) + EXP (0.95 Seating Position - 0.42 Age - 0.23 Time of Day + 0.12 Road Circumstances) + EXP (0.71 Seating Position - 0.30 Age - 0.78 Direction of Slope – 17.73 Road Circumstances) + EXP (0.53 Number of Driveways - 3.01 RHR - 18.93 Road Circumstances)

The following are the equations that can be used to predict the probability of different severity levels for multi-vehicle crashes in the state of South Carolina. The factors with a p value less than or equal to 0.15 are included in the equations.

P(Y = Fatal Injury)

=1 / M

P(Y = Incapacitating Non-fatal Injury)

=EXP (0.35 Time of Day - 0.08 Speed Limit - 0.17 Vehicle Maneuver + 0.86 Direction of Slope + 1.43 Cross Section Type + 0.67 Lane Width + 1.28 Terrain + 1.13 Cross Street Involvement - 0.47 Manner of Impact - 0.30 Road Circumstances) / M

P(Y = Non-incapacitating Non-fatal Injury)

=EXP (-0.16 Age - 0.19 Time of Day - 0.31 Vehicle Maneuver - 1.09 Cross Section Type + 1.10 Cross Street Involvement - 2.57 Road Surface Condition) / M

P(Y = Possible Injury)

=EXP (-0.40 Age + 0.27 Speed Limit - 1.94 Cross Section Type + 0.60 Lane Width - 0.43 Number of Driveways + 1.21 RHR + 1.03 Cross Street Involvement + 0.83 Manner of Impact) / M

P(Y = No Injury)

=EXP (-0.35 Age - 1.33 Direction of Slope - 1.18 Shoulder Type + 0.33 Number of Driveways - 0.84 RHR - 2.42 Terrain + 0.33 Manner of Impact) / M

where,

M

=1 + EXP (0.35 Time of Day - 0.08 Speed Limit - 0.17 Vehicle Maneuver + 0.86 Direction of Slope + 1.43 Cross Section Type + 0.67 Lane Width + 1.28 Terrain + 1.13 Cross Street Involvement - 0.47 Manner of Impact - 0.30 Road Circumstances) + EXP (-0.16 Age - 0.19 Time of Day - 0.31 Vehicle Maneuver - 1.09 Cross Section Type + 1.10 Cross Street Involvement - 2.57 Road Surface Condition) + EXP (-0.40 Age + 0.27 Speed Limit - 1.94 Cross Section Type + 0.60 Lane Width - 0.43 Number of Driveways + 1.21 RHR + 1.03 Cross Street Involvement + 0.83 Manner of Impact) + EXP (-0.35 Age - 1.33 Direction of Slope - 1.18 Shoulder Type + 0.33 Number of Driveways - 0.84 RHR - 2.42 Terrain + 0.33 Manner of Impact)

Table 5.13 Crash Severity Models for South Carolina

(SV: LL (0) = -188.23, LL (converge) = -122.38, Pseudo R^2 = 0.350, Number of obs = 156; MV: LL (0) = -277.93, LL (converge) = -212.85, Pseudo R^2 = 0.234, Number of obs = 183)

		Incapacitating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value	Coef.	t stat	p value
SV	Seating Position	0.84	3.23	0.00	0.95	3.77	0.00	0.71	2.46	0.01	0.40	0.99	0.32
	Age	-0.11	-0.60	0.55	-0.42	-1.81	0.07	-0.30	-1.62	0.10	-0.15	-0.43	0.66
	Vehicle Configuration	-1.60	-2.94	0.00	-0.13	-0.33	0.74	-0.08	-0.35	0.73	0.07	0.59	0.55
	Vehicle Authorized Speed Limit	0.14	2.91	0.00	0.01	0.12	0.90	0.02	0.57	0.57	0.08	0.76	0.45
	Time of Day	0.39	2.64	0.01	-0.23	-1.65	0.10	0.45	1.44	0.15	-0.21	-1.11	0.27
	Direction of Slope	-0.38	-1.31	0.19	0.37	0.84	0.40	-0.78	-1.88	0.06	-0.45	-1.01	0.31
	ADT	0.00	-2.98	0.00	0.00	-0.33	0.74	0.00	0.20	0.84	0.00	-2.66	0.01
	Number of Driveways	-0.81	-3.11	0.00	0.12	0.76	0.45	-0.05	-0.22	0.83	0.53	2.55	0.01
	RHR	-1.46	-2.37	0.02	-0.14	-0.34	0.73	-0.87	-1.25	0.21	-3.01	-2.69	0.01
	Contributing Circumstances, Road	0.02	0.29	0.77	0.12	1.56	0.12	-17.73	-2.96	0.00	-18.93	-3.78	0.00
MV	Age	-0.08	-0.57	0.57	-0.16	-1.50	0.13	-0.40	-2.82	0.01	-0.35	-2.71	0.01
	Time of Day	0.35	2.38	0.02	-0.19	-1.49	0.14	-0.07	-0.52	0.60	-0.06	-0.43	0.67
	Vehicle Authorized Speed Limit	-0.08	-1.67	0.10	0.00	0.06	0.95	0.27	2.57	0.01	-0.03	-0.61	0.54
	Vehicle Maneuver	-0.17	-1.88	0.06	-0.31	-1.52	0.13	-0.31	-1.29	0.20	-0.02	-0.15	0.88
	Direction of Slope	0.86	1.66	0.10	0.22	0.40	0.69	-0.57	-0.97	0.33	-1.33	-2.55	0.01
	Cross Section Type	1.43	2.07	0.04	-1.09	-1.59	0.11	-1.94	-3.60	0.00	-0.78	-1.27	0.20
	Lane Width	0.67	1.91	0.06	-0.13	-0.32	0.75	0.60	1.63	0.10	-0.22	-0.62	0.54
	Shoulder Type	-0.28	-0.54	0.59	0.09	0.11	0.91	0.09	0.15	0.88	-1.18	-2.26	0.02
	Number of Driveways	0.19	1.18	0.24	0.00	0.03	0.98	-0.43	-2.95	0.00	0.33	2.03	0.04
	RHR	-0.39	-0.78	0.44	-0.41	-0.65	0.51	1.21	1.85	0.06	-0.84	-1.73	0.08
	Terrain	1.28	1.65	0.10	0.72	0.65	0.52	-0.58	-0.59	0.56	-2.42	-2.66	0.01
	Cross-street Involvement	1.13	2.61	0.01	1.10	1.70	0.09	1.03	1.90	0.06	-0.51	-0.72	0.47
	Manner of Impact	-0.47	-1.92	0.06	0.06	0.26	0.80	0.83	3.50	0.00	0.33	2.16	0.03
	Road Surface Condition	-0.44	-0.64	0.52	-2.57	-2.61	0.01	-1.37	-1.32	0.19	-0.51	-0.56	0.58
	Contributing Circumstances, Road	-0.30	-2.76	0.01	-0.08	-0.48	0.63	-0.25	-0.95	0.34	-0.02	-0.17	0.87

Table 5.14 Elasticity of Crash Severity Models for South Carolina

		Fatal Injury			Incapacitiating Nonfatal Injury			Nonincapacitating Nonfatal Injury			Possible Injury			No Injury		
		Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
SV	Seating Position	-0.37	-2.28	0.02	1.66	3.27	0.00	1.91	3.91	0.00	1.33	2.34	0.02	0.59	0.64	0.52
	Age	0.35	1.57	0.12	-0.40	-0.37	0.71	-2.44	-1.78	0.08	-1.64	-1.44	0.15	-0.64	-0.28	0.78
	Vehicle Configuration	0.16	1.64	0.10	-2.38	-2.88	0.00	-0.05	-0.08	0.93	0.04	0.11	0.91	0.28	1.30	0.19
	Vehicle Authorized Speed Limit	-0.41	-1.17	0.24	6.49	2.83	0.01	-0.11	-0.05	0.96	0.76	0.35	0.73	3.67	0.67	0.51
	Time of Day	0.03	0.28	0.78	2.09	2.72	0.01	-1.22	-1.77	0.08	2.42	1.45	0.15	-1.11	-1.08	0.28
	Direction of Slope	-0.04	-0.39	0.70	-0.85	-1.42	0.16	0.74	0.89	0.38	-1.71	-1.91	0.06	-1.00	-1.06	0.29
	ADT	0.09	2.02	0.04	-1.42	-2.75	0.01	0.00	0.00	1.00	0.13	0.63	0.53	-1.26	-2.46	0.01
	Number of Driveways	0.04	1.05	0.30	-1.07	-3.05	0.00	0.21	1.04	0.30	-0.03	-0.08	0.93	0.76	2.75	0.01
	RHR	0.47	1.65	0.10	-6.66	-2.20	0.03	-0.24	-0.13	0.90	-3.77	-1.09	0.27	-14.20	-2.61	0.01
	Contributing Circumstances, Road	-0.02	-1.59	0.11	0.00	0.04	0.97	0.17	1.51	0.13	-29.80	-2.96	0.00	-31.82	-3.78	0.00
MV	Age	0.85	2.39	0.02	0.25	0.28	0.78	-0.34	-0.61	0.55	-2.07	-2.48	0.01	-1.72	-2.42	0.02
	Time of Day	0.03	0.16	0.87	1.66	2.33	0.02	-0.86	-1.77	0.08	-0.30	-0.48	0.63	-0.23	-0.45	0.65
	Vehicle Authorized Speed Limit	-0.25	-0.32	0.75	-4.34	-1.74	0.08	-0.10	-0.05	0.96	13.72	2.55	0.01	-1.86	-0.85	0.40
	Vehicle Maneuver	0.18	1.94	0.05	-0.16	-0.96	0.34	-0.41	-1.27	0.20	-0.42	-0.97	0.33	0.14	0.88	0.38
	Direction of Slope	0.28	0.66	0.51	2.33	1.94	0.05	0.81	0.77	0.44	-1.08	-0.89	0.37	-2.90	-2.84	0.01
	Cross Section Type	0.37	1.52	0.13	2.32	2.23	0.03	-1.12	-1.43	0.15	-2.28	-3.48	0.00	-0.69	-0.95	0.34
	Lane Width	-0.63	-0.47	0.64	6.83	1.66	0.10	-2.10	-0.56	0.58	6.05	1.77	0.08	-3.07	-0.99	0.32
	Shoulder Type	0.38	0.99	0.32	-0.17	-0.19	0.85	0.57	0.43	0.67	0.56	0.57	0.57	-1.94	-2.14	0.03
	Number of Driveways	-0.08	-1.17	0.24	0.27	0.99	0.32	-0.08	-0.35	0.73	-0.89	-3.30	0.00	0.54	1.85	0.06
	RHR	0.74	1.19	0.24	-1.07	-0.48	0.64	-1.16	-0.46	0.64	6.41	2.12	0.03	-3.18	-1.55	0.12
	Terrain	0.23	0.56	0.57	2.04	2.02	0.04	1.25	0.96	0.34	-0.59	-0.49	0.63	-3.21	-2.87	0.00
	Cross-street Involvement	-0.08	-1.56	0.12	0.23	2.00	0.05	0.22	1.51	0.13	0.20	1.64	0.10	-0.21	-1.34	0.18
	Manner of Impact	-0.28	-1.19	0.23	-2.24	-2.12	0.03	0.00	-0.01	1.00	3.21	3.08	0.00	1.10	1.96	0.05
	Road Surface Condition	0.70	3.66	0.00	0.21	0.27	0.79	-2.13	-2.15	0.03	-0.81	-0.69	0.49	0.13	0.14	0.89
	Contributing Circumstances, Road	0.11	1.55	0.12	-0.38	-2.18	0.03	-0.03	-0.12	0.91	-0.30	-0.74	0.46	0.07	0.36	0.72

5.8. Severity Model Discussion

In general, state specific crash severity models performed better than the overall crash severity model for all four states. Each state had its own set of significant factors that contributed to the severity of the injuries of the vehicle occupants involved in the fatal crashes. Among the significant factors, the same personal factors, environmental factors, and vehicle factors are significant across the models for people involved in the crash in different states. However, a variety of site variables were found in the models for different groups of people in each state.

Table 5.15 summarizes the significant factors for single vehicle crashes.

Table 5.15 Summary of Significant Factors in Single Vehicle Crash Model

	AL	GA	MS	SC	All
Gender		x			x
Seating Position	x	x		x	x
Age	x	x		x	x
Ejection	x	x			x
Crash Avoidance Maneuver		x	x		x
Time of Day		x	x	x	x
Crest Vertical Curve			x		x
Cross Section Type					x
Shoulder Type					x
Number of Intersections			x		x
RHR			x	x	x
Raised Pavement Reflectors					x
Terrain			x		x
Cross-street Involvement					x
First Harmful Event		x	x		x
Relation to Roadway					x
Weather Condition					x
Ambient Light			x		x
Road Surface Condition					x
Contributing Circumstances, Environment	x				x
Contributing Circumstances, Road				x	x
Vehicle Model Year		x	x		
Number of Driveways			x	x	
Vehicle Configuration				x	
Vehicle Authorized Speed Limit				x	
ADT				x	
Direction of Slope	x			x	
Most Harmful Event			x		

Table 5.16 summarizes the significant factors for multi-vehicle crashes for the four state specific models as well as the all-state model.

Table 5.16 Summary of Significant Factors in Multi-vehicle Crash Models

	AL	GA	MS	SC	All
Seating Position					x
Age	x	x	x	x	x
Ejection			x		x
Vehicle Maneuver		x		x	x
Vehicle Model Year			x		x
Crash Avoidance Maneuver			x		x
Day of Week					x
Time of Day				x	x
Curve Radius			x		x
Direction of Slope	x			x	x
Percent of Slope	x		x		x
Cross Section Type			x	x	x
Lane Width				x	x
Number of Driveways	x			x	x
Number of Intersections	x	x	x		x
RHR	x		x	x	x
Terrain	x		x	x	x
Cross-street Involvement			x	x	x
First Harmful Event		x			x
Relation to Roadway					x
Manner of Impact			x	x	x
Ambient Light		x			x
Occupant Protection System Use	x	x			
Vehicle Configuration	x	x	x		
Vehicle Role	x				
Shoulder Type	x			x	
Delineator Presence	x	x			
Vehicle Authorized Speed Limit		x		x	
Day of Week		x			
Raised Pavement Reflectors		x	x		
Contributing Circumstances, Environment		x	x		
Contributing Circumstances, Road		x	x	x	
Crest Vertical Curve			x		
Road Surface Condition				x	
Weather Condition		x			

5.8.1. Personal Factors

The common personal factor for most of the models was age. It was significant across all southeastern states included in the analysis. The impact of the age is consistent in different states; that is, increase in age increases the chances of suffering from fatal injury more than any other injury severity levels. Many studies have been conducted on the impact of age and our results make the same conclusion as in the existing literature.

Gender is another frequently studied personal factor and it is found significant in the overall model and Georgia model. It has a smaller value of elasticity compared to age.

5.8.2. Vehicle Related Factors

Three vehicle-related factors, the authorized speed limit, vehicle maneuver, and seat belt usage, were found to be significant in the single vehicle crashes models. In particular, speed was significant for the overall model, the Alabama model, and the South Carolina model. Vehicle configuration was important in the Georgia model; and vehicle maneuver prior to the crash was important in the Mississippi model.

The elasticity of the vehicle configuration indicates that driving a light truck reduces the likelihood of fatal injury compared to that of drivers for a passenger car but increases chances for suffering other levels of injury in multi-vehicle crashes. Passenger cars by their nature weigh less than light trucks including sports utility vehicles (SUV) and trucks, therefore passenger car occupants have greater likelihood of severe injury when involved in a collision with SUVs or trucks.

Given the fact that the majority of the vehicles are traveling straight ahead prior to the crashes, the next common vehicle maneuver differed by crash severity: negotiating a curve for fatal crashes, turning left for injury crashes, and stopped in traffic lane for property damage only crashes (NTHSA, 2003). Vehicle maneuver is important for differentiating incapacitating nonfatal injury, non-incapacitating nonfatal injury, and possible nonfatal injury from fatal injury.

5.8.3. Environmental Factors

Ambient light was significant for the single vehicle crash model and the multi-vehicle crash model for all states. In addition, it was significant in the Mississippi single vehicle crash model and the Georgia multi-vehicle crash model. Road surface condition is significant in the single vehicle crash model for all states and the South Carolina multi-vehicle crash model.

5.8.4. Site Factors

Although most personal factors, vehicle factors and environmental factors are similar between states, site factors differed from state to state as summarized in Tables 5.15 and 5.16. The overall model includes all the site factors categories that appeared in the state specific models but not necessarily the exact the same site factor. Specifically, lane width, shoulder width, vertical slope, number of intersections, and RHR are the most influencing site factors in the southeastern states.

5.8.4.1. RHR

Roadside design begins at the edge of the travel lane and includes features such as side slope, ditch, drainage channel, fixed objects. The cause of a crash is the vehicle, driver or roadway factor, or combination of factors that causes the vehicle to lose control or leave the roadway. After it exits the road, the vehicle may hit fixed objects on the roadside such as trees and utility poles or the vehicle could roll over due to the roadside features. The characteristics of the roadside affect the ability to regain control of an errant vehicle and the associated crash severity. RHR is the most frequently studied significant site factor for single vehicle crash severity. Severe RHR does not cause severe crashes but influences the severity level once the crash occurred.

5.8.4.2. Lane Width

Lane width plays an important role in multi-vehicle crashes. The narrow lanes and shoulders do not provide an adequate lateral clearance and recovery area for the vehicles that are in trouble and therefore contribute to the likelihood and the severity of the crashes. Wider lanes reduce the chance of severe injury. However, wider lanes that are not compatible with the other geometric features of the roadway may cause safety problems since they can enable the drivers to drive at a higher speed.

5.8.4.3. Number of Driveways

The number of driveways was found to be important for the single vehicle crashes. This factor is an indicator of the potential conflicts between vehicles. The interaction with other vehicles does not necessarily cause collisions, but this interaction may be a contributing factor for severe single vehicle crashes.

5.8.4.4. Vertical Slope and Crest Vertical Curve

Vertical slope and crest vertical curve are the new additions to crash literature. The greater the vertical slope, the faster the vehicle speed is when the vehicle travels down grade. This could be the reason that this variable contributed to the level of severity when the percentage of vertical slope increased or there is a crest vertical curve.

5.8.4.5. Shoulder Width

Road shoulder increases the effective width of the traffic lanes and increases lateral clearance, provides a recovery area for errant vehicles, and allows a stopped vehicle to stand clear of the traffic lanes. In other words, shoulders provide a greater recovery and maneuvering space. Shoulder width and type may vary significantly. For instance, in South Carolina, 96 percent of the shoulders were graded shoulders, and the shoulder was as wide as 12 feet while most other states had a shoulder between 2 and 4 feet. Having a shoulder reduces the severity of the crash, but there is little extra benefit of having a shoulder wider than needed other than the impaired RHR traceability. Paved shoulders reduce the potential for vehicles that stray from the paved driving lane to lose control in loose shoulder material or at pavement drop-offs.

5.8.4.6. Intersections

About thirty to forty percent of the fatal crashes included in the dataset used in this dissertation occurred near or at intersections. The information is represented by the number of intersections within 250 feet upstream and downstream of the crash sites. Since most of observation has a value of 0 if there is an intersection close by or 1 if not, this variable works as an indicator if there is an intersection at or close to the crash sites in the crash severity model. No information regarding sight distance was collected.

Crashes at or close to intersections often involve more than one vehicle. As shown in the estimates from both the state specific model and the all state model, the number of intersections was significant in more multi-vehicle crash models than in the single vehicle crash models. The majority of the crashes at intersections involved head-on or side impacts into other vehicles. Vehicle occupants involved in intersection crashes are comparatively vulnerable to severe injury and death since there is a high likelihood of severe injury associated with head-on impacts or side impacts where vehicles generally have less protective structure.

Vehicle conflicts at intersections also create a dangerous environment to pedestrians. Due to the limited number of observations of pedestrians, no statistical conclusion was drawn for the effect in this dissertation.

5.9. Crash Severity Model Validation

Table 5.17 summarizes the predicted probabilities of each level of injury severity by the crash severity models and the actual probabilities of each level of injury severity in the database for single vehicle crashes. Table 5.18 summarizes the predicted probabilities of each level of injury severity by the crash severity models and the actual probabilities of each level of injury severity in the database for multi-vehicle crashes. The numbers indicate that the predicted probabilities are close to the actual probabilities and thus indicate the crash severity models developed in this dissertation are a good representation of actual conditions. However, there is an over-prediction trend of "no injury" and an under-prediction trend of "non-incapacitating non-fatal injury". This suggests the need for improved specification with respect to the specification of the levels of crash severity.

Table 5.17 Predicted versus Actual Probability of Level of Injury in Single Vehicle Crashes

		Fatal injury	Incapacitating Nonfatal Injury	Non-incapacitating Nonfatal Injury	Possible Injury	No Injury
All	Predicted	0.68	0.15	0.06	0.05	0.06
	Actual	0.65	0.16	0.10	0.06	0.03
AL	Predicted	0.75	0.22	0.02	0.00	0.01
	Actual	0.68	0.28	0.03	0.00	0.01
GA	Predicted	0.75	0.05	0.18	0.02	0.00
	Actual	0.70	0.08	0.16	0.05	0.01
MS	Predicted	0.64	0.13	0.14	0.05	0.04
	Actual	0.60	0.15	0.13	0.04	0.07
SC	Predicted	0.63	0.15	0.11	0.09	0.02
	Actual	0.60	0.14	0.10	0.11	0.04

Table 5.18 Predicted versus Actual Probability of Level of Injury in Multi-vehicle Crashes

		Fatal injury	Incapacitating Nonfatal Injury	Non-incapacitating Nonfatal Injury	Possible Injury	No Injury
All	Predicted	0.40	0.24	0.11	0.08	0.16
	Actual	0.36	0.23	0.14	0.10	0.17
AL	Predicted	0.40	0.48	0.00	0.02	0.10
	Actual	0.36	0.42	0.03	0.01	0.18
GA	Predicted	0.42	0.10	0.23	0.11	0.14
	Actual	0.38	0.14	0.17	0.11	0.20
MS	Predicted	0.44	0.10	0.24	0.10	0.12
	Actual	0.33	0.20	0.21	0.13	0.13
SC	Predicted	0.51	0.11	0.16	0.07	0.16
	Actual	0.40	0.14	0.14	0.14	0.18

CHAPTER 6: CRASH TYPE

This chapter addresses the third objective of this dissertation by focusing on the relationship between the crash type and the various causal factors. In this chapter, the crashes are classified into seven types based on the manner of impact. The identification of a crash is the manner in which two or more vehicles in transport initially came together without regard to the direction of force when the crash occurred. The seven types include:

- Runoff the road (Single vehicle crash),
- Rear end collision,
- Head-on collision,
- Rear to rear collision
- Angle collision,
- Sideswipe with same direction of travel, and
- Sideswipe with opposite direction of travel

Figure 6.1 illustrates percentages of all seven types of fatal crashes in each of the four southern states. Note that there were no rear to rear crashes in the database. The three major fatal crash types in the southeastern region were single vehicle crash, head-on, and angle crash. These three types together account for 88 percent to 99 percent of the total fatal crashes in each state. The analysis in this chapter will focus on these three major crash types.

The major type of the study fatal crashes was the single vehicle crashes, which ranged from 50 percent to 63 percent of the fatal crashes in every state. Specifically, 63 percent of the fatal crashes were single vehicle crashes in Alabama, 58 percent in Georgia, 50 percent in Mississippi, and 61 percent in South Carolina. Thus the overall percentage of single vehicle fatal crashes was 59 percent.

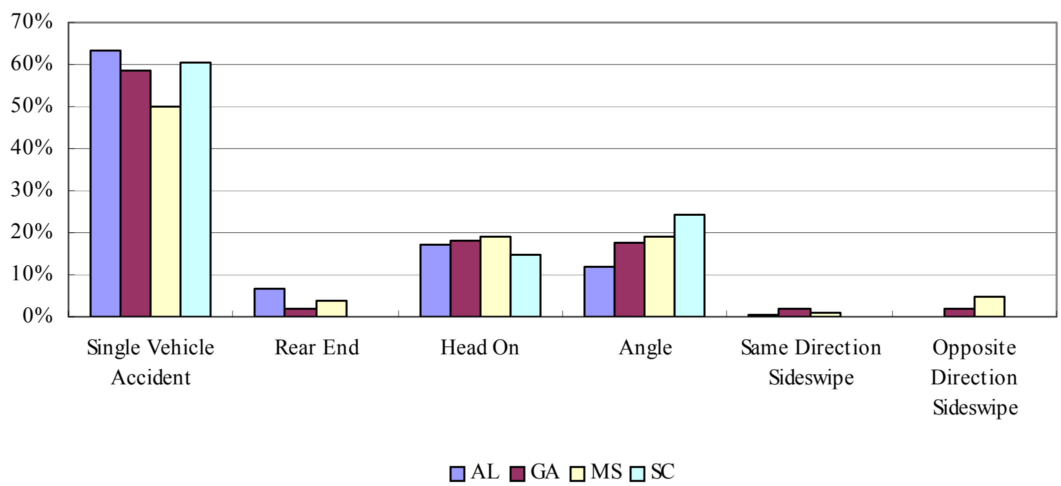


Figure 6.1 Crash Type by State

Head-on and Angle are the two major types of multi-vehicle crashes. Head-on crashes were about 17 percent of all fatal crashes in Alabama, 18 percent in Georgia, 19 percent in Mississippi, and 15 percent in South Carolina. The angle crashes were 12 percent, 18 percent, 19 percent and 24 percent in Alabama, Georgia, and Mississippi, and South Carolina respectively.

Generally, the most common crash type cited was not often the most dangerous. Table 6.1 illustrates the different percentage of fatal crash type percentages in the four states versus crash type on rural two lane highways in other states (Harwood et al., 2000).

Table 6.1 Fatal Crash Type Percentage in Four States versus Crash Type in Other States*

	AL (%)	GA (%)	MS (%)	SC (%)	Other States
Single Vehicle Crash	63	58	51	61	67
Rear End	7	2	4	0	15
Head On	17	18	19	15	2
Angle	12	18	19	24	10
Same Direction Sideswipe	1	2	1	0	3
Opposite Direction Sideswipe	0	2	5	0	3

* Based on HSIS data for Michigan (1995) and Minnesota (1996)

A single vehicle crash is a very common rural crash type. It accounted for 30 percent of the study crashes, but accounted for about 60 percent of fatalities on two-lane rural roads in southeastern states. In addition, head-on crashes only account for 2 percent of the crashes in the U.S., but one out of five fatalities on two-lane rural roads in southeastern states is a head-on crashes. The probability of a fatal injury is higher for vehicle occupants involved in a single vehicle crash or a head-on crash than for any other type of crash. As some types of crashes usually result in more severe injuries than others, the investigation of the occurrence of a certain crash type helps highway engineers and safety legislators to understand what can be done to improve highway safety. Moreover, there is some indication that the safety effects of the changes in cross-section might not clearly be discovered by focusing on the severity of all crashes, but an effect could be detected when concentrating on specific crash types that are more likely to cause fatal injuries, such as run-off-road, head-on and angle crashes. The roadway variables that appear to be associated with these related crashes types include lane width, shoulder width and type, roadside condition, terrain condition and traffic volume.

6.1. Model Specification

Using data collected in the original FHWA pooled fund study, the research team developed multinomial logit models for crash type. These models relate probabilities of crash type occurrence with numerous roadway, traffic, and environmental factors. Using data from Georgia, South Carolina, Mississippi, and Alabama, each with 150 fatal crashes (MS has 100), the sample size available for analysis was 550 crashes.

The analysis goals of this chapter are as follows:

- Estimate multinomial logit models for different crash types.
- Identify factors that affect the probability of the type including roadway, traffic, and environmental factors.

These models will provide substantial insights into factors contributing to the type of fatal crash. By including information from the various categories, a relationship between possible countermeasures that highway engineers can apply and the crash event may be established.

Similar to the dataset used to develop the crash severity models, the database used in the analysis for crash types includes the crash, personal, vehicle, environmental, and site information. The difference lies in the personal information. The data used to develop crash type models only included the at-fault driver information since the driver was the one who presumably caused the crashes. In general, the attributes of the not-at-fault drivers and passengers do not affect the occurrence nor the severity and the type of the crash. Therefore, the not-at-fault drivers and passengers' information are not included in the database for testing crash types.

Crash type models were estimated for all four states as well as for each individual state. The dataset, which includes the at-fault driver only information, was divided by state, thus there are a total of 5 datasets: a complete dataset, which include all four states, and one dataset for each state. For details, please refer to each state specific model in Sections 6.3 to 6.6.

The model estimation results for crash type models are presented in the subsequent sections in a similar format to the crash severity models. Not all crash type categories have estimation results due to the limited number of observations. Blank columns in Table 6.8 to 6.15 are examples of the lack of estimation results. Specifically, the limited number of observations on the same direction and opposite direction sideswipe crashes can cause difficulties in estimating standard error for these two types of crashes. It is also difficult to draw any statistical conclusions of the effects of the studied factors on these two types of crashes.

6.2. Crash Type Models for All States

Similar to crash severity model development, crash type models for all states were also developed in three phases. In the first phase, only personal factors were included. In the second phase, the significant personal factors from the phase one and all vehicle-related factors were included. In the third phase, all significant factors from the phase two with site factors and environmental factors were included. Note that only the at-fault drivers' information for each crash was included in the data used to develop crash type models.

6.2.1. Crash Type Models with Personal Factors Only

In the first phase, the crash type model only included personal factors. Person factors describe the characteristics of the person who was responsible for the traffic crash. The tested personal variables were age, gender, contributing circumstances, and driver condition. Occupant protection system use was not tested in the model for all states since this information was not available in Mississippi. Some of the factors such as age and gender have been widely studied in the literature and are proven to have significant effects on traffic crashes.

The significant personal variables included in this phase were driver's age and gender. These variables were used in the model to capture the unobserved effects that would cause an estimation bias. Table 6.2 displays the coefficients for the estimated multinomial logit model for crash types including only personal data. It contains the list of the coefficient estimates of all tested variables, along with their t-statistics for the test of the significance of a coefficient from zero, and the corresponding p-values. As mentioned in the methodology section, for estimation of the coefficients, the coefficients of one outcome (the base outcome) should be restricted to 0. In this model, the base case is the single vehicle crash. If a coefficient is significant, it means that the factor can make a significantly different impact on this outcome than from the base case. Note that the coefficient estimates from the multinomial logit regression was allowed to vary. The positive and negative sign of the coefficient estimate does not mean an increase or decrease of the probability of an outcome.

Table 6.3 presents the elasticity of the estimated multinomial logit estimates for the crash type model with personal data only. It contains the elasticity of the all tested variables for all outcomes, along with the t-statistics for the test of the significance of a coefficient from zero, and the corresponding p-values. As elasticity is the change in the probability of an outcome with the one unit change in the variable, the positive sign of the elasticity means an increase in the probability of the outcome and a negative sign means a decrease in the probability.

Only the variables that can significantly differentiate these crash types are kept and will be included in the models of the next phase. Any variables with a p-value less than or equal to 0.15 are considered significant for differentiating the various types of crashes from the base type, single vehicle crash. The results of the two tables indicate that age and gender are two personal traits important for differentiating crash types and they have an actual impact on occurrence of a certain type of crash. These two significant factors will be kept in the crash type model and will be tested along with additional vehicle related factors in the next phase. Note that the overall model fit is low with a pseudo R^2 of 0.02. This indicates that although age and gender make a difference in the crash type, their impacts are relatively low.

Age has a significant effect on separating the single vehicle crashes with the head-on and angle crashes. Older drivers are less likely to be involved in single vehicle crashes as the driving experience evolves over the year.

Gender is also significant and a female is less likely to be involved in a single vehicle crash and head-on crash.

Table 6.2 Crash Type Model for All States with Personal and Vehicle Factors Only

(LL (0) = -1086.15, LL (converge) = -1005.13, Pseudo R^2 = 0.075, Number of obs = 815)

	Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value
Gender	0.70	1.48	0.14	0.08	0.36	0.72	0.53	2.43	0.02	-0.87	-0.80	0.42	-1.46	-1.39	0.16
Age	0.13	0.86	0.39	0.09	1.32	0.19	0.27	3.95	0.00	-0.28	-1.15	0.25	0.17	0.90	0.37

Table 6.3 Elasticity of Crash Type Model for All States with Personal and Vehicle Factors Only

	Single Vehicle			Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p
Gender	-0.16	-1.37	0.17	0.74	1.28	0.20	-0.05	-0.22	0.83	0.53	2.56	0.01	-1.26	-0.93	0.35	-2.02	-1.53	0.13
Age	-0.63	-3.19	0.00	0.36	0.33	0.74	0.05	0.12	0.91	1.41	3.64	0.00	-2.68	-1.51	0.13	0.60	0.45	0.65

* E = Elasticity
* t = t value
* p = p value

6.2.2. Crash Type Models with Personal and Vehicle Related Factors Only

In addition to the significant personal factors, the vehicle factors are added to the model so that vehicle characteristics can be captured. Per the election of the variables discussion in Chapter 4 Data 4.3.3, the following additional variables were added to the crash type model. The vehicle related factors are:

- vehicle configuration,
- vehicle role,
- vehicle authorized speed limit,
- vehicle maneuver/action,
- underride/override,
- most damaged area,
- extent of damage,
- vehicle model year,
- vehicle body type,
- vehicle towed, and
- crash avoidance maneuver.

Table 6.4 and Table 6.5 summarize the model estimate for the crash type model that includes both personal and vehicle factors. The overall model fit has been increased by the newly added vehicle factors. The ρ^2 for the crash type model has been increased to 0.07 from 0.02. The results suggest that among the vehicle related factors, vehicle configuration, speed, vehicle maneuver/action, and the crash avoidance maneuver have significant effects on crash types.

Vehicle configuration is significant in differentiating the single vehicle crashes and the angle crashes. Change in vehicle configuration increases the likelihood of angle crashes but decreases the likelihood of single vehicle crashes. This seems to initially contradict the literature since most studies indicate that vans and sports utility vehicles (SUV) tend to be more frequently involved in single vehicle crashes. Since the study subjects are fatal crashes, the extra protection of the SUVs can reduce the chance of the fatal single vehicle crashes.

Speed increases the chance of head-on and angle fatal crashes. The elasticity numbers indicate that these two crash types more likely to occur than single vehicle crashes when speed increases.

Vehicle maneuver/action differentiates the single vehicle crash from the head-on and angle crashes. Change in vehicle maneuver increases the likelihood of angle vehicle crashes but decreases the likelihood of single vehicle crashes.

The crash avoidance maneuver differentiates the single vehicle crashes from the head-on crash and angle crash. Changes in the crash avoidance maneuver increase the likelihood of single vehicle crashes and head-on crashes significantly.

Table 6.4 Crash Type Model for All States with Personal and Vehicle Factors Only

(LL (0) = -1059.26, LL (converge) = -967.20,, Pseudo R^2 = 0.087, Number of obs = 792)

	Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value
Gender	0.79	1.64	0.10	0.12	0.48	0.63	0.54	2.37	0.02	-0.78	-0.72	0.47	-1.41	-1.34	0.18
Age	0.10	0.63	0.53	0.07	1.02	0.31	0.23	3.25	0.00	-0.29	-1.18	0.24	0.12	0.65	0.52
Vehicle Configuration	0.10	1.08	0.28	0.06	1.16	0.25	0.11	2.21	0.03	-0.04	-0.16	0.87	0.19	2.15	0.03
Vehicle Authorized Speed Limit	0.09	1.91	0.06	0.05	2.78	0.01	0.01	0.81	0.42	0.15	1.49	0.14	2.39	68.17	0.00
Vehicle Maneuver	0.04	0.58	0.56	-0.08	-1.79	0.07	0.10	3.03	0.00	0.14	1.61	0.11	0.01	0.10	0.92
Crash Avoidance Maneuver	0.09	1.16	0.25	-0.01	-0.19	0.85	-0.19	-4.16	0.00	-0.02	-0.11	0.91	-0.14	-1.00	0.32

Table 6.5 Elasticity of Crash Type Model for All States with Personal and Vehicle Factors Only

	Single Vehicle			Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p
Gender	-0.20	-1.81	0.07	0.81	1.37	0.17	-0.06	-0.24	0.81	0.49	2.26	0.02	-1.21	-0.88	0.38	-2.01	-1.50	0.13
Age	-0.50	-2.55	0.01	0.26	0.22	0.82	0.04	0.11	0.91	1.22	3.06	0.00	-2.64	-1.47	0.14	0.43	0.31	0.76
Vehicle Configuration	-0.07	-1.95	0.05	0.11	0.70	0.49	0.04	0.57	0.57	0.13	2.03	0.04	-0.15	-0.34	0.74	0.26	1.77	0.08
Vehicle Authorized Speed Limit	-0.79	-2.91	0.00	3.62	1.61	0.11	1.49	2.36	0.02	-0.25	-0.48	0.63	6.79	1.34	0.18	119.30	67.69	0.00
Vehicle Maneuver	-0.01	-0.39	0.69	0.08	0.53	0.60	-0.21	-2.48	0.01	0.22	3.73	0.00	0.31	1.58	0.12	0.01	0.05	0.96
Crash Avoidance Maneuver	0.11	2.74	0.01	0.38	1.74	0.08	0.09	1.14	0.25	-0.42	-4.18	0.00	0.07	0.18	0.86	-0.28	-0.71	0.48

* E = Elasticity
* t = t value
* p = p value

6.2.3. Crash Type Models with Personal, Vehicle, Site, and Environmental Factors

Site, crash, and environmental factors are included in the crash type models along with the significant personal and vehicle factors. The results are summarized in Table 6.6 and 6.7. The crash type model in this last phase includes the following significant variables:

- ambient light,
- vehicle configuration,
- the authorized speed limit,
- vehicle maneuver,
- crash avoidance maneuver,
- general horizontal alignment (curve radius),
- vertical slope,
- crest or sag vertical curve,
- average daily traffic,
- lane width,
- shoulder type,
- number of intersections surrounding crash sites,
- surface type,
- terrain, and
- crossroads involvement.

The estimated significance of the coefficients indicates that ADT, paved/graded shoulder width, number of driveways, and raised pavement reflectors significantly differentiate the single vehicle crashes from the head-on crashes. The significance of the coefficients also indicates that horizontal alignment, shoulder type, paved shoulder width, raised pavement reflectors, and cross street involved significantly differentiate the single vehicle crashes from the angle crashes. Among the significant variables, shoulder width is significant for differentiating both head-on and angle crashes from single vehicle crashes.

The probability of single vehicle crash decreases with the speed limit. The likelihood of head-on crash increases with the speed limit, but decreases with vehicle maneuver. The likelihood of angle crashes increases with vehicle maneuver, but decreases with crash avoidance maneuver. Vehicle configuration significantly differentiates the likelihood of angle crashes and single vehicle crash.

The likelihood of head-on crashes increase with the average daily traffic, type of the shoulder, and the number of intersection. The higher average daily traffic on the roadway indicates more vehicles, and therefore more conflicts among the vehicles on the road. The increased number of intersections increases the probability of conflicts among the vehicles as well. The head-on crashes are more likely to happen on the roadway with the graded shoulder than the roadway with paved shoulders. The graded shoulder usually indicates lower design standards than the roadway with paved shoulders.

Environmental factors capture the prevailing conditions at the time of the traffic crashes. The estimation results of crash type model suggest that ambient light plays a significant role in contributing to different types of fatal crashes. Ambient light indicates the light condition exists at the time of a motor vehicle crash. Daylight and dark – roadway not lighted are two major types of light condition in this dissertation. Ambient light condition is still significant in differentiating the single vehicle crashes and the other types of crashes.   Change in ambient light has a statistically different impact on single vehicle crashes and all other types of crashes. Change in ambient light increases the probability of single vehicle crashes while decreasing most other types of crashes.

The following are the equations that can be used to predict the probability of different crash types in the four southeastern states.

P(Y = Single Vehicle Crash)
=1/ M

P(Y = Rear End)
=EXP (-0.30 Ambient Light + 0.79 Curve Radius + 0.43 Lane Width + 0.85 Terrain) / M

P(Y = Head On)
=EXP (-0.30 Ambient Light + 0.04 Speed Limit - 0.10 Vehicle Maneuver + 0.42 ADT + 0.23 Lane Width + 0.28 Shoulder Type + 0.48 Number of Intersections) / M

P(Y = Angle)
=EXP (-0.65 Ambient Light + 0.10 Vehicle Configuration + 0.14 Vehicle Maneuver -0.12 Crash Avoidance Maneuver + 0.44 Curve Radius - 0.26 Percent of Slope - 0.71 Crest Vertical Curve + 0.21 ADT + 0.65 Lane Width - 0.34 Shoulder Type + 0.59 Number of Intersection+ 3.91 Cross Street Involvement) / M

P(Y = Same Direction Side Swipe)
=EXP (0.19 Vehicle Maneuver + 1.96 Curve Radius + 0.78 Percent of Slope + 2.30 Terrain) / M

P(Y = Opposite Direction Side Swipe)
=EXP (-0.64 Ambient Light + 0.19 Vehicle Configuration + 2.46 Speed Limit + 1.09 Surface Type + 5.46 Terrain) / M

where,

M
=1 + EXP (-0.30 Ambient Light + 0.79 Curve Radius + 0.43 Lane Width + 0.85 Terrain) + EXP (-0.30 Ambient Light + 0.04 Speed Limit - 0.10 Vehicle Maneuver + 0.42 ADT + 0.23 Lane Width + 0.28 Shoulder Type+ 0.48 Number of Intersections) + EXP (-0.65 Ambient Light + 0.10 Vehicle Configuration

+ 0.14 Vehicle Maneuver -0.12 Crash Avoidance Maneuver + 0.44 Curve Radius - 0.26 Percent of Slope - 0.71 Crest Vertical Curve + 0.21 ADT + 0.65 Lane Width - 0.34 Shoulder Type + 0.59 Number of Intersection+ 3.91 Cross Street Involvement) + EXP (0.19 Vehicle Maneuver + 1.96 Curve Radius + 0.78 Percent of Slope + 2.30 Terrain) + EXP (-0.64 Ambient Light + 0.19 Vehicle Configuration + 2.46 Speed Limit + 1.09 Surface Type + 5.46 Terrain)

Table 6.6 Crash Type Model for All States with Personal, Vehicle, Environmental, and Site Factors

(LL (0) = -1029.52, LL (converge) = -708.88,, Pseudo R^2 = 0.311, Number of obs = 766)

	Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value
Ambient Light	-0.30	-2.28	0.02	-0.30	-4.79	0.00	-0.65	-6.71	0.00	0.18	0.79	0.43	-0.64	-2.78	0.01
Vehicle Configuration	0.07	0.71	0.48	0.05	0.96	0.34	0.10	1.48	0.14	-0.03	-0.10	0.92	0.19	1.76	0.08
Vehicle Authorized Speed Limit	0.07	1.40	0.16	0.04	1.88	0.06	0.01	0.44	0.66	0.14	1.31	0.19	2.46	16.23	0.00
Vehicle Maneuver	0.05	0.62	0.54	-0.10	-1.96	0.05	0.14	3.06	0.00	0.19	1.93	0.05	0.02	0.18	0.86
Crash Avoidance Maneuver	0.08	0.88	0.38	0.01	0.18	0.86	-0.12	-2.06	0.04	-0.02	-0.16	0.87	-0.26	-1.41	0.16
Curve Radius	0.79	1.79	0.07	-0.14	-0.86	0.39	0.44	1.87	0.06	1.96	1.87	0.06	0.63	1.07	0.28
Percent of Slope	0.28	1.17	0.24	0.12	0.99	0.32	-0.26	-1.94	0.05	0.78	1.69	0.09	0.03	0.07	0.94
Crest Vertical Curve	0.13	0.30	0.77	-0.23	-1.17	0.24	-0.71	-2.94	0.00	-0.25	-0.42	0.68	-0.37	-0.75	0.45
ADT	0.10	0.47	0.64	0.42	3.83	0.00	0.21	1.54	0.12	0.08	0.20	0.84	0.37	1.04	0.30
Lane Width	0.43	1.57	0.12	0.23	1.63	0.10	0.65	3.49	0.00	0.47	1.08	0.28	0.79	1.36	0.17
Shoulder Type	0.12	0.47	0.64	0.28	2.38	0.02	-0.34	-1.90	0.06	0.01	0.03	0.98	0.41	0.90	0.37
Number of Intersections	0.36	0.86	0.39	0.48	2.41	0.02	0.59	2.29	0.02	0.59	0.84	0.40	-0.20	-0.27	0.79
Surface Type	-0.04	-0.09	0.93	0.21	1.10	0.27	0.07	0.29	0.77	-0.12	-0.14	0.89	1.09	1.99	0.05
Terrain	0.85	1.48	0.14	0.26	0.93	0.35	-0.12	-0.36	0.72	2.30	2.23	0.03	5.46	3.12	0.00
Cross-street Involvement	1.17	1.31	0.19	0.49	0.85	0.39	3.91	7.80	0.00	-31.56	0.00	1.00	-30.02	0.00	1.00

Table 6.7 Elasticity of Crash Type Model for All States with Personal, Vehicle, Environmental, and Site Factors

	Single Vehicle			Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p
Ambient Light	0.48	6.70	0.00	-0.35	-1.01	0.31	-0.35	-2.78	0.01	-1.33	-5.46	0.00	0.98	1.57	0.12	-1.30	-2.04	0.04
Vehicle Configuration	-0.05	-1.39	0.17	0.08	0.46	0.65	0.04	0.64	0.52	0.12	1.30	0.19	-0.10	-0.21	0.84	0.28	1.56	0.12
Vehicle Authorized Speed Limit	-0.66	-1.88	0.06	2.80	1.18	0.24	1.21	1.68	0.09	-0.17	0.00	1.00	6.34	1.18	0.24	122.73	16.16	0.00
Vehicle Maneuver	0.01	0.00	1.00	0.12	0.73	0.46	-0.22	-2.51	0.01	0.34	3.79	0.00	0.46	2.00	0.05	0.06	0.22	0.82
Crash Avoidance Maneuver	0.03	0.71	0.48	0.26	1.07	0.28	0.06	0.63	0.53	-0.32	-2.24	0.03	-0.04	-0.08	0.93	-0.69	-1.35	0.18
Curve Radius	-0.12	0.00	1.00	1.76	1.74	0.08	-0.46	-1.65	0.10	0.92	1.99	0.05	4.56	1.82	0.07	1.38	1.00	0.32
Percent of Slope	-0.01	0.00	1.00	0.67	1.22	0.22	0.28	1.36	0.17	-0.65	-2.37	0.02	1.88	1.69	0.09	0.07	0.00	1.00
Crest Vertical Curve	0.34	1.99	0.05	0.63	0.69	0.49	-0.19	-0.60	0.55	-1.26	-2.85	0.00	-0.22	-0.17	0.87	-0.50	-0.46	0.65
ADT	-0.42	-3.37	0.00	-0.11	-0.17	0.87	0.86	3.53	0.00	0.22	0.65	0.52	-0.20	-0.17	0.86	0.71	0.66	0.51
Lane Width	-1.74	-3.06	0.00	2.91	1.04	0.30	0.72	0.67	0.50	5.30	3.11	0.00	3.44	0.72	0.47	6.89	1.09	0.28
Shoulder Type	-0.06	-0.61	0.54	0.22	0.38	0.70	0.57	2.98	0.00	-0.84	-2.48	0.01	-0.03	-0.02	0.98	0.87	0.84	0.40
Number of Intersections	-0.10	-2.77	0.01	0.07	0.37	0.71	0.12	1.92	0.06	0.18	1.81	0.07	0.18	0.54	0.59	-0.19	-0.57	0.57
Surface Type	-0.13	-0.85	0.40	-0.22	-0.22	0.82	0.30	1.09	0.28	0.03	0.00	1.00	-0.37	-0.21	0.83	2.12	1.91	0.06
Terrain	-0.12	0.00	1.00	1.20	1.41	0.16	0.29	0.00	1.00	-0.31	-0.72	0.47	3.46	2.16	0.03	8.39	3.08	0.00
Cross-street Involvement	-0.10	0.00	1.00	0.07	0.00	1.00	-0.03	0.00	1.00	0.48	7.81	0.00	-4.79	0.00	1.00	-4.56	0.00	1.00

* E = Elasticity
* t = t value
* p = p value

6.3. Crash Type Model for Alabama

Table 6.8 and Table 6.9 summarize the significant factors for crash types in Alabama.

The overall model fit, R^2, for Alabama is improved from 0.31 to 0.36. For head-on crashes in the state of Alabama, age, designation of national highway system, ambient light, and number of driveway are significant variables for differentiating them from single vehicle crashes. For angle crashes, gender, crash avoidance maneuver, general horizontal alignment (curve radius), national highway system, terrain, and ambient light are significant while differentiating them from single vehicle crashes.

The following are the equations that can be used to predict the probability of different crash types in the state of Alabama. Only the factors with a p-value less than or equal to 0.15 are included in the equations.

P(Y = Single Vehicle Crash)

=1/ M

P(Y = Rear End)

=EXP (-1.11 Ambient Light + 1.55 Lane Width + 0.73 Number of Driveways + 4.16 Cross Street Involvement) / M

P(Y = Head On)

=EXP (-0.38 Age - 0.36 Ambient Light + 0.78 Curve Radius - 0.49 Percent of Slope + 0.59 ADT - 0.57 Number of Driveways) / M

P(Y = Angle)

=EXP (0.37 Crash Avoidance Maneuver - 1.43 Ambient Light + 2.23 Curve Radius + 1.38 Lane Width + 0.40 Number of Driveways - 1.86 Terrain + 5.30 Cross Street Involvement) / M

The author unable to estimate *P(Y = Same Direction Sideswipe)* and *P(Y = Opposite Direction Sideswipe)* due to the limited number of observations in these categories.

where,

M
=1 + EXP (-1.11 Ambient Light + 1.55 Lane Width + 0.73 Number of Driveways + 4.16 Cross Street Involvement) + EXP (-0.38 Age - 0.36 Ambient Light + 0.78 Curve Radius - 0.49 Percent of Slope + 0.59 ADT -0.57 Number of Driveways) + EXP (0.37 Crash Avoidance Maneuver - 1.43 Ambient Light + 2.23 Curve Radius + 1.38 Lane Width + 0.40 Number of Driveways - 1.86 Terrain + 5.30 Cross Street Involvement)

Table 6.8 Crash Type Model for Alabama

(LL (0) = -275.18, LL (converge) = -138.66, Pseudo R^2 = 0.496, Number of obs = 214)

	Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value
Age	0.13	0.39	0.70	-0.38	-2.12	0.03	-0.05	-0.13	0.89	-36.64	0.00	1.00			
Crash Avoidance Maneuver	-0.05	-0.26	0.80	0.15	1.05	0.29	0.37	1.58	0.11	-10.13	0.00	1.00			
Ambient Light	-1.11	-2.76	0.01	-0.36	-2.52	0.01	-1.43	-3.27	0.00	7.91	0.00	1.00			
Curve Radius	0.31	0.42	0.67	0.78	2.04	0.04	2.23	2.31	0.02	31.45	.	.			
Percent of Slope	0.11	0.27	0.78	-0.49	-2.02	0.04	-0.44	-1.27	0.20	25.78	0.00	1.00			
ADT	-0.43	-1.03	0.30	0.59	2.01	0.05	-0.30	-0.74	0.46	-12.69	0.00	1.00			
Lane Width	1.55	2.25	0.02	-0.04	-0.14	0.89	1.38	2.35	0.02	-6.94	0.00	1.00			
Number of Driveways	0.73	2.82	0.01	-0.57	-2.82	0.01	0.40	1.66	0.10	-34.38	0.00	1.00			
Terrain	-0.55	-0.53	0.60	0.27	0.53	0.60	-1.86	-1.82	0.07	33.33	0.00	1.00			
Cross-street Involvement	4.16	2.47	0.01	-44.35	.	.	5.30	3.15	0.00	21.64	.	.			

Table 6.9 Elasticity of Crash Type Model for Alabama

	Single Vehicle			Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p
Age	-0.01	-0.14	0.89	1.00	0.39	0.70	-2.85	-2.13	0.03	-0.35	-0.14	0.89						
Crash Avoidance Maneuver	-0.03	-0.72	0.47	-0.35	-0.29	0.77	0.99	1.03	0.30	2.50	1.59	0.11						
Ambient Light	0.11	1.86	0.06	-3.13	-2.61	0.01	-0.93	-2.25	0.02	-4.06	-3.13	0.00						
Curve Radius	-0.09	-1.29	0.20	0.68	0.38	0.71	1.82	1.96	0.05	5.40	2.28	0.02						
Percent of Slope	0.01	0.47	0.64	0.29	0.29	0.77	-1.20	-2.02	0.04	-1.07	-1.28	0.20						
ADT	0.03	0.92	0.36	-1.18	-1.03	0.31	1.68	2.06	0.04	-0.82	-0.73	0.47						
Lane Width	-0.49	-1.70	0.09	16.27	2.19	0.03	-0.98	-0.28	0.78	14.45	2.27	0.02						
Number of Driveways	-0.03	-1.64	0.10	1.28	2.74	0.01	-1.06	-2.91	0.00	0.69	1.59	0.11						
Terrain	0.05	1.09	0.28	-0.72	-0.50	0.62	0.43	0.60	0.55	-2.54	-1.80	0.07						
Cross-street Involvement	-0.01	-0.99	0.32	0.47	2.38	0.02	-5.07	-112.61	0.00	0.59	3.03	0.00						

* E = Elasticity
* t = t value
* p = p value

6.4. Crash Type Model for Georgia

Table 6.10 and Table 6.11 summarize the crash type model for the state of Georgia.

The overall model fit, R^2, has been slightly improved from 0.31to 0.32. General horizontal alignment (curve radius) and average daily traffic are significant factors in differentiating head-on from single vehicle crashes. For differentiating angle crashes from single vehicle crashes, driver contributing circumstances, vehicle maneuver/action, average daily traffic, light condition, and weather condition are all significant.

For single vehicle crashes, vehicle maneuver/action, average daily traffic, ambient light, and weather condition are significant. Again, the darker the surrounding environment is, the more likely the single vehicle crash. If the weather condition is not clear, the road surface may be slippery compared to the clear days and this may contribute to vehicles departing the roadway.

For head-on crashes, average daily traffic and general horizontal alignment (curve radius) are significant. The head-on crashes are related to the traffic volume; the higher volume of vehicles on the highway, the greater the likelihood of head-on crashes. Sharp horizontal curves reduce the sight distance and increase the probability of run-off-road crashes.

For angle crashes, other than the environmental factors, light condition and weather condition, the factors related to driver maneuver, driver contributing circumstances, and vehicle maneuver are important.

The following are the equations that can be used to predict the probability of different crash types in the state of Georgia. Only the factors with a p-value less than or equal to 0.15 are included in the equations.

P(Y = Single Vehicle Crash)
=1/ M
P(Y = Rear End)
= EXP (1.77 Speed Limit + 0.46 Vehicle Maneuver + 0.98 ADT) / M

P(Y = Head On)
=EXP (-0.53 Curve Radius + 0.61 ADT) / M

P(Y = Angle)
=EXP (-0.46 Driver Circumstances + 0.53 Vehicle Maneuver + 0.49 ADT - 0.34 Ambient Light - 1.16 Weather Condition) / M

P(Y = Same Direction Sideswipe)
=EXP(2.26 Speed Lmit + 0.70 Vehicle Maneuver + 1.14 ADT) / M

P(Y = OppositeDirectionSideSwipe)
=EXP (2.42 Speed Limit) / M

where,

M
=1 + EXP (1.77 Speed Limit + 0.46 Vehicle Maneuver + 0.98 ADT) + EXP (-0.53 Curve Radius + 0.61 ADT) + EXP (-0.46 Driver Circumstances + 0.53 Vehicle Maneuver + 0.49 ADT - 0.34 Ambient Light - 1.16 Weather Condition) + EXP (2.26 Speed Lmit + 0.70 Vehicle Maneuver + 1.14 ADT) + EXP(2.42 Speed Limit)

Table 6.10 Crash Type Model for Georgia

(LL (0) = -293.38, LL (converge) = -199.68, Pseudo R^2 = 0.319, Number of obs = 213)

	Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value
Contributing Circumstances, Driver	-0.29	-1.33	0.19	0.08	0.79	0.43	-0.46	-4.47	0.00	-0.01	-0.09	0.93	-0.09	-0.50	0.62
Vehicle Authorized Speed Limit	1.77	27.44	0.00	-0.01	-0.37	0.71	-0.02	-0.42	0.67	2.26	25.56	0.00	2.42	41.18	0.00
Vehicle Maneuver	0.46	1.79	0.07	0.18	0.96	0.34	0.53	3.05	0.00	0.70	2.74	0.01	-7.16	.	.
Curve Radius	0.01	0.01	0.99	-0.53	-1.95	0.05	0.33	0.69	0.49	1.06	1.04	0.30	0.22	0.31	0.76
ADT	0.98	1.67	0.10	0.61	3.31	0.00	0.49	1.93	0.05	1.14	1.87	0.06	-0.13	-0.28	0.78
Ambient Light	-17.53	.	.	-0.14	-1.12	0.26	-0.34	-1.92	0.06	0.29	0.95	0.34	-0.06	-0.20	0.84
Weather Condition	-15.84	.	.	-0.32	-1.32	0.19	-1.16	-2.16	0.03	-21.99	.	.	-18.67	.	.

Table 6.11 Elasticity of Crash Type Model for Georgia

	Single Vehicle			Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p
Contributing Circumstances, Driver	0.17	0.71	0.48				0.91	1.22	0.22	-4.21	-4.36	0.00						
Vehicle Authorized Speed Limit	0.20	0.50	0.62				-0.38	-0.32	0.75	-0.73	-0.36	0.72						
Vehicle Maneuver	-0.16	-1.57	0.12				0.19	0.70	0.48	0.88	2.93	0.00						
Curve Radius	0.21	1.23	0.22				-0.98	-2.04	0.04	0.95	0.98	0.33						
ADT	-0.54	-3.19	0.00				1.36	2.94	0.00	0.98	1.38	0.17						
Ambient Light	0.15	1.68	0.09				-0.21	-0.85	0.40	-0.77	-1.73	0.08						
Weather Condition	0.23	2.21	0.03				-0.22	-0.83	0.41	-1.43	-1.97	0.05						

* E = Elasticity
* t = t value
* p = p value

6.5. Crash Type Model for Mississippi

Table 6.12 and Table 6.13 summarize the crash type model for the state of Mississippi.

The overall model fit, R^2, increased to 0.53. For differentiating head-on crashes with single vehicle crashes, the general horizontal alignment (curve radius), light condition, and average daily traffic are significant factors. For differentiating angle crashes with single vehicle crashes, factors such as roadside hazard rating, light condition, and the number of driveways are significant.

For single vehicle crashes, the following factors including the horizontal alignment (curve radius), ADT, roadside hazard rating, ambient light, and cross road involved have a significant impact on the likelihood of its occurrence. The likelihood of single vehicle crashes increases with the curve radius, roadside hazard rating, and the darkness of the ambient light. The sharper the horizontal curve, the more likely a vehicle is to run off the road. The darker light condition reduces the visibility of the road condition, and generally nighttime is also the time period that the drivers are less alert and tired.

For head-on crashes, horizontal alignment (curve radius) and ADT are significant factors. The higher the traffic volume, the greater the chance that a vehicle will not stay properly in its lane and could hit on another vehicle.

For angle crashes, ADT, roadside hazard rating, cross road involved, and ambient light are significant. Interactions and conflicts between vehicles can be introduced by not only high ADT but also the cross roads involved. The more conflicts or interactions among the vehicles, the more likely angle-crashes occur.

The following are the equations that can be used to predict the probability of different crash types in the state of Mississippi. Only the factors with a p-value less than or equal to 0.15 are included in the equations.

P(Y = Single Vehicle Crash)
=1/ M

P(Y = Rear End)
= EXP (21.78 Curve Radius + 0.95 Grade Shoulder Width) / M

P(Y = Head On)
= EXP (-1.11 Curve Radius + 1.29 ADT - 0.58 Ambient Light) / M

P(Y = Angle)
= EXP (-1.54 RHR + 6.20 Cross Street Involvement - 0.95 Ambient Light) / M

The author unable to estimate *P(Y = Same Direction Sideswipe)* and *P(Y = Opposite Direction Sideswipe)* due to the limited number of observations in these categories

where,

M
=1 + EXP (21.78 Curve Radius + 0.95 Grade Shoulder Width) + EXP (-1.11 Curve Radius + 1.29 ADT - 0.58 Ambient Light) + EXP (-1.54 RHR + 6.20 Cross Street Involvement - 0.95 Ambient Light)

Table 6.12 Crash Type Model for Mississippi

(LL (0) = -215.84, LL (converge) = -109.17, Pseudo R^2 = 0.494, Number of obs = 147)

	Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value
Curve Radius	21.78	22.33	0.00	-1.11	-2.23	0.03	0.06	0.10	0.92						
ADT	-0.68	-1.08	0.28	1.29	4.02	0.00	-0.07	-0.17	0.86						
Graded Shoulder Width	0.95	2.03	0.04	-0.19	-1.27	0.21	-0.18	-0.85	0.40						
RHR	-0.45	-1.10	0.27	-0.26	-0.82	0.42	-1.54	-3.66	0.00						
Cross-street Involvement	-32.83	0.00	1.00	1.22	0.98	0.33	6.20	4.56	0.00						
Ambient Light	0.24	0.79	0.43	-0.58	-3.66	0.00	-0.95	-3.65	0.00						

Table 6.13 Elasticity of Crash Type Model for Mississippi

	Single Vehicle			Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p	E	t	p
Curve Radius	0.91	1.59	0.11	52.05	22.32	0.00	-1.69	-2.07	0.04	1.06	0.94	0.35						
ADT	-1.38	-2.56	0.01	-3.45	-1.80	0.07	2.54	3.22	0.00	-1.59	-1.69	0.09						
Graded Shoulder Width	0.41	1.18	0.24	4.24	2.24	0.03	-0.34	-1.03	0.31	-0.33	-0.54	0.59						
RHR	1.79	2.04	0.04	-0.32	-0.17	0.87	0.54	0.60	0.55	-5.49	-3.16	0.00						
Cross-street Involvement	-0.40	-2.18	0.03	-8.67	0.00	1.00	-0.09	-0.51	0.61	1.16	3.84	0.00						
Ambient Light	1.09	3.44	0.00	1.78	2.01	0.04	-0.56	-1.86	0.06	-1.60	-2.55	0.01						

* E = Elasticity
* t = t value
* p = p value

6.6. Crash Type Model for South Carolina

Table 6.14 and Table 6.15 summarize the crash type model for the state of South Carolina.

The overall fit, R^2, for the final model is 0.40. The driver's age, vehicle configuration, crash avoidance maneuver, vertical slope, shoulder type, and the number of intersections are significant factors for differentiating head-on crashes from single vehicle crashes. Driver's age, crash avoidance maneuver, vertical curve, lane width, shoulder type, number of driveways, number of intersections, and ambient light are significant factors for differentiating angle crashes from single vehicle crashes.

For single vehicle crashes, driver's age, seat belt usage, crash avoidance maneuver, and number of intersections are significant contributing factors.

For head-on crashes, driver's age, seat belt usage, light condition, vehicle configuration, crash avoidance maneuver, vertical slope, lane width, shoulder type, and the number of intersections are significant factors.

For angle crashes, crash avoidance maneuver, vertical slope, lane width, shoulder type, the number of driveways, the number of intersections, and the ambient light are the significant factors.

The following are the equations that can be used to predict the probability of different crash types in the state of South Carolina. Only the factors with a p-value less than or equal to 0.15 are included in the equations.

P(Y = Single Vehicle Crash)

$$= 1/M$$

P(Y = Head On)

= EXP (1.24 Gender + 0.39 Age + 0.26 Vehicle Configuration - 0.56 Lane Width + 1.83 Shoulder Type + 1.30 Number of Intersections - 1.63 Crest Vertical Curve + 0.54 ADT - 1.22 Terrain) / M

P(Y = Angle)

= EXP (0.41 Age - 14.20 Crash Avoidance Maneuver + 0.90 Lane Width - 3.36 Shoulder Type + 0.44 Number of Driveways+ 1.37 Number o f Intersections - 0.74 Ambient Light -2.05 Crest Vertical Curve + 0.65 ADT + 1.93 Terrain + 23.89 Cross Street Involvement) / M

The author unable to estimate *P=(Y = Rear End)*, *P=(Y = Same Direction Sideswipe)* and *P=(Y = Opposite Direction Sideswipe)* due to the limited number of observations in these categories

where,

M

=1 + EXP (1.24 Gender + 0.39 Age + 0.26 Vehicle Configuration - 0.56 Lane Width + 1.83 Shoulder Type + 1.30 Number of Intersections - 1.63 Crest Vertical Curve + 0.54 ADT - 1.22 Terrain) + EXP (0.41 Age - 14.20 Crash Avoidance Maneuver + 0.90 Lane Width - 3.36 Shoulder Type + 0.44 Number of Driveways+ 1.37 Number o f Intersections - 0.74 Ambient Light -2.05 Crest Vertical Curve + 0.65 ADT + 1.93 Terrain + 23.89 Cross Street Involvement)

Table 6.14 Crash Type Model for South Carolina

(LL (0) = -204.93, LL (converge) = -106.86, Pseudo R^2 = 0.479, Number of obs = 192)

	Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value	Coeff.	t stat	p value
Gender				1.24	2.00	0.05	0.35	0.51	0.61						
Age				0.39	1.79	0.07	0.41	1.65	0.10						
Vehicle Configuration				0.26	2.36	0.02	-0.09	-0.57	0.57						
Crash Avoidance Maneuver				-0.29	-0.63	0.53	-14.20	-2.34	0.02						
Lane Width				-0.56	-1.89	0.06	0.90	1.78	0.08						
Shoulder Type				1.83	2.91	0.00	-3.36	-2.59	0.01						
Number of Driveways				0.05	0.25	0.81	0.44	1.98	0.05						
Number of Intersections				1.30	2.52	0.01	1.37	2.26	0.02						
Ambient Light				-0.11	-0.71	0.48	-0.74	-3.85	0.00						
Crest Vertical Curve				-1.63	-1.60	0.11	-2.05	-2.15	0.03						
ADT				0.54	2.06	0.04	0.65	2.16	0.03						
Terrain				-1.22	-1.85	0.07	1.93	2.64	0.01						
Cross-street Involvement				21.55	.	.	23.89	21.70	0.00						

Table 6.15 Elasticity of Crash Type Model for South Carolina

	Single Vehicle			Rear End			Head-on			Angle			Same Direction Sideswipe			Opposite Direction Sideswipe		
	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value	Elasticity	t stat	p value
Gender	-0.26	-1.13	0.26				0.91	1.55	0.12	-0.37	-0.59	0.56						
Age	-1.01	-2.14	0.03				2.06	1.70	0.09	1.86	1.46	0.14						
Occupant Protection System Use	-0.45	-3.06	0.00				0.94	2.92	0.00	0.77	2.36	0.02						
Vehicle Configuration	-0.07	-1.03	0.30				0.32	1.80	0.07	-0.26	-1.24	0.21						
Crash Avoidance Maneuver	2.07	4.12	0.00				1.17	1.98	0.05	-15.73	-3.72	0.00						
Percent of Slope	-0.18	-1.02	0.31				0.99	1.93	0.05	-1.06	-2.21	0.03						
Lane Width	-0.60	-0.88	0.38				-2.27	-1.10	0.27	8.87	2.81	0.01						
Shoulder Type	0.18	0.43	0.67				1.93	2.05	0.04	-5.45	-3.43	0.00						
Number of Driveways	-0.05	-0.52	0.60				-0.08	-0.36	0.72	0.48	2.15	0.03						
Number of Intersections	-0.25	-2.91	0.00				0.46	2.67	0.01	0.54	2.82	0.01						
Ambient Light	0.20	1.49	0.14				-0.05	-0.15	0.88	-1.15	-3.22	0.00						

6.7. Crash Type Model Discussion

Single vehicle crashes are usually a result of too high operating speeds for the design of the road. Most geometric features of the crash sites do not directly contribute to the severity of the crashes, especially single vehicle crashes. Among the limited significant geometric features of the sites, roadside hazard increases the severity of the single vehicle crashes, and the number of intersections increases the severity of multi-vehicle crashes. The list of significant factors for multi-vehicle crash severity is similar to the list of the significant factors for two major types of multi-vehicle crashes: head-on and angle crashes.

Table 6.16 summarizes the significant factors that contribute to three major crash types including single vehicle crash, head-on crash, and angle crash.

Table 6.16 Summary of Significant Factors for Crash Type Models

	AL	GA	MS	SC	All
Ambient Light	x	x	x	x	x
Vehicle Configuration				x	x
Vehicle Authorized Speed Limit		x			x
Vehicle Maneuver		x			x
Crash Avoidance Maneuver	x			x	x
Curve Radius	x	x	x		x
Percent of Slope	x				x
Crest Vertical Curve				x	x
ADT	x	x	x	x	x
Lane Width	x			x	x
Shoulder Type				x	x
Number of Intersections				x	x
Surface Type					x
Terrain	x			x	x
Cross-street Involvement	x		x	x	x
Age	x			x	
Contributing Circumstances, Driver		x			
Weather Condition		x			
Graded Shoulder Width			x		
Gender				x	
Number of Driveways	x			x	
RHR			x		

The following highlights are identified from the crash type model development:

- Significant factors are different for each type of crashes. In other words, if one factor is significant for one crash type, it is not necessarily significant for the other crash types. For instance, the average daily traffic volume is significant for head-on crashes, but the number of intersections is significant for angle crashes.
- The person factors such as age and gender are not significant for crash types.
- Ambient light is the only environmental factor that has a significant effect on crash type. The darker the surrounding environment, the more likely that the drivers will run off the road.
- Vehicle configuration and vehicle maneuver are the significant effects on crash types. However, the vehicle configuration has a negative sign for single vehicle crashes, which is contrary to literature.
- Ambient light and ADT are significant in all four state specific models. Curve Radius and cross street involvement are significant in three state specific models. Due to the data availability, the speed difference and roadside hazard are significant in states wherever they are available.
- Other than the factors that are significant for all states, some factors are only significant in some states. For example, the lane width is not a significant factor in Alabama.
- Of all the factors that have a significant effect on differentiating various types of crashes, one unit change of some factors causes a greater magnitude of change in

crash types in different states. The values of the elasticity of the significant variables range from –31 percent to 46 percent.

6.8. Crash Type Model Validation

Table 6.17 summarizes the predicted probabilities of each crash type by the crash type models and the actual probabilities of each crash type in the database. The numbers indicate that the predicted probabilities are close to the actual probabilities and thus indicate the crash type models adequately predict actual conditions.

Table 6.17 Predicted versus Actual Probability of Crash Types

		Single Vehicle Crash	Rear End	Head On	Angle	Same Direction Sideswipe	Opposite Direction Sideswipe
All	Predicted	0.48	0.04	0.22	0.27	0.00	0.00
	Actual	0.50	0.03	0.21	0.23	0.01	0.02
AL	Predicted	0.67	0.00	0.15	0.18	0.00	0.00
	Actual	0.63	0.07	0.17	0.12	0.01	0.00
GA	Predicted	0.47	0.01	0.33	0.17	0.02	0.01
	Actual	0.58	0.02	0.18	0.18	0.02	0.02
MS	Predicted	0.48	0.00	0.42	0.10	0.00	0.00
	Actual	0.51	0.04	0.19	0.19	0.01	0.05
SC	Predicted	0.56	0.00	0.35	0.09	0.00	0.00
	Actual	0.61	0.00	0.15	0.24	0.00	0.00

CHAPTER 7: CONCLUSION

This dissertation provides an empirical and methodological framework for analyzing crash severity and type. It also provides an example to compare crash analysis across different states. Moreover, the results provide valuable insights on how to improve highway design to reduce the probability of severe crashes and the injury severity.

7.1. Key findings

In the southeastern region, single vehicle crashes account for approximately sixty percent of rural two-lane highway fatal crashes, followed by head-on and angle crashes which account for 20 percent each. Roadside improvements are generally perceived as measures resulting in less severe run-off road crashes. Head-on and angle crashes, in turn, do not seem directly affected by geometric design; however, this study found that many site factors have significant impacts on the occurrence of head-on crashes and angle crash severity. Improvement of these geometric features may help reduce severe crashes such as head-on and angle crashes.

Single vehicle crash severity is mostly determined by the age and gender of the person involved in the crash, vehicle configuration, and roadside hazard rating. Multi-vehicle crash severity is determined by more site factors and more variation among different states and different people involved.

Despite the number and severity of fatal crashes on rural two lane highways, quantification of the effect of possible countermeasures has been surprisingly limited due to the absence of data. This study addressed this data deficiency in the following manner:

1. Compared detailed intra-region characteristics of vehicle / person / environment from different states in the same region;
2. Identified critical variables not commonly included in existing literature and police crash reports;
3. Identified significant intervention for crash reduction; and
4. Developed detailed site information on geometric design characteristics.

7.2. How to Apply the Models

The major goal of developing crash severity models and crash type models is to identify the effective countermeasures for reducing severe crashes. This section covers how to identify the countermeasures with the models developed in Chapter 5: Crash Severity Models and Chapter 6: Crash Type Models using an example. The example is the how to identify the countermeasures to improve geometric design features for reducing the probability of head-on crashes in the state of Georgia. The identification is a two step process.

The first step is to locate the correct model for the safety issue you are interested in. If you are interested in head-on crashes in Georgia, you can use the following equation presented in Section 6.4. Crash Type Model for Georgia. If you are interested in any other crash severity or crash type related safety issues, corresponding equations are available in Chapters 5 and 6. Each chapter includes models developed for all four states as well as for an individual state. For the states that were not included in the dataset, Section 4.2 Data Transferability includes information on how to look for possible solutions from other states in the region. For example, if you are interested in a head-on crash in the state of North Carolina, the following equation for the state of Georgia can be a starting point to improve the safety issue.

P(Y = Head On) = EXP (-0.53 Curve Radius + 0.61 ADT) / M

where

M =1 + EXP (1.77 Speed Limit + 0.46 Vehicle Maneuver + 0.10 ADT) + EXP (-0.53 Curve Radius + 0.61 ADT) + EXP (-0.46 Driver Circumstances + 0.53 Vehicle Maneuver + 0.49 ADT - 0.34 Ambient Light -1.16 Weather Condition) + EXP (2.26 Speed Lmit + 0.70 Vehicle Maneuver + 1.14 ADT) + EXP (2.42 Speed Limit)

The second step is to locate the significant factors that contribute to the issue of interest. For the example, the left hand side of the equation includes two significant factors, curve radius and ADT, that can help the highway safety engineer reduce head-on crashes. Table 6.11 Elasticity of Crash Type Model for Georgia includes the information on the magnitude of the impact of these two factors. Table 7.1 is a subset of Table 6.11 with the information related to head-on crashes only. There are more variables than what was included in the equations because only the variables with a p-value less than 0.15 or t statistic greater than 1.42 were considered causal factors and were included in the equations.

The first column in Table 7.1 includes the elasticity of factors. The elasticity for curve radius is -0.98 and the elasticity for ADT is 1.36. The sign of the elasticity indicates the direction of the movement. The negative sign of the curve radius indicates that an increase in the value of curve radius, i.e. improve the sharp curve to mild/gentle curve, decreases the probability of head-on crashes. The positive sign of ADT indicates that an increase in ADT increases the probability of head-on crashes. The absolute value of the elasticity helps identify the most effective factors since it indicates the magnitude of the impact of the factors. In the case of multiple significant factors, the factor with the largest absolute value of elasticity has the biggest impact on the probability with one unit change in the factor.

Table 7.1 Elasticity of Significant Factors in Head-on Crash Model for Georgia

	Head-on		
	Elasticity	t statistic	p value
Contributing Circumstances, Driver	0.91	1.22	0.22
Vehicle Authorized Speed Limit	-0.38	-0.32	0.75
Vehicle Maneuver	0.19	0.70	0.48
Curve Radius	-0.98	-2.04	0.04
ADT	1.36	2.94	0.00
Ambient Light	-0.21	-0.85	0.40
Weather Condition	-0.22	-0.83	0.41

7.3. Applications and Recommendations

The findings from this dissertation provide us the opportunity to improve the safety condition of the rural two lane highways in the Southeastern region. Based on the results of this study, the following countermeasures are recommended for the southeastern states.

7.3.1. Seat Belt Awareness Campaign and Law Enforcement

Increasing seat belt usage is the most effective action that can be taken to save lives and reduce injuries on our roadways. Increased motor vehicle travel and too few people correctly utilizing safety restraints, particularly on residential roads, are factors that lead to tragedy.

Every state but New Hampshire requires its citizens to wear seat belts. Unfortunately, over half of US states have secondary enforcement laws. Secondary enforcement laws require a law enforcement officer to first pull someone over for a different violation and only then can the officer write an additional citation for a seat belt violation.

Primary seat belt laws have proven to be the most effective means of increasing seat belt usage and saving lives. Under the primary law, a law enforcement officer has the authority to stop a driver if the officer has a clear and unobstructed view of a driver or occupant of a motor vehicle not wearing a safety belt or not secured in a child restraint system.

According to the National Occupant Protection Use Survey, seat belt use rates averaged 84 percent in the states where primary law was enacted compared to 73 percent in the states where secondary enforcement law was enacted. Enactment of the primary seat belt law increases average seat belt usage by nine to 14 percentage points. This, in turn, decreasing the severity of injuries in crashes resulting in a decline of approximately 7 to 8 percent in fatality rates as the seat belt law is enforced (NHTSA, 2004).

There are still 27 states that do not have a primary enforcement seat belt law. These states include two Southeastern states, Florida and Kentucky. Many other Southeastern states have only recently passed the primary enforcement of seat belt law. For example, Mississippi passed the Primary enforcement of seat belt laws in Jan 2006. South Carolina changed its law in December 2005.

Examples of awareness campaign activities include the distribution of seatbelt safety literature and materials, and seatbelt safety awareness presentations to the student body.

7.3.2. Geometric Design

Geometric design is the key to the safety of many rural two lane highways. The following countermeasures are proposed based on the results of the crash severity and crash type models.

1. Current levels of enforcement of legislation relating to speed must be maintained or increased.
2. The horizontal alignment of the road, the condition of the road surface, and the provision of shoulders and edge lines are subject to timely review.
3. Widen the lane width and shoulder width to provide extra space to vehicles in danger and reduce the both the severity and the frequency of head-on and angle crashes
4. Improve the geometric features of the dangerous segments of the roadway, particularly the vertical curves. Greater vertical sight distance helps reduce head-on crashes.

7.3.3. Enhancement of the Visibility of Roadway in the Evening

Statistics have shown that traffic crashes occurring in the evening and at night are considerably over-represented as 51% to 66% single vehicle fatal crashes occur in the evening on roads where there is no lighting. Considering most driving occurs during daylight hours, the over-representation of single vehicle fatal crashes poses the serious issue on nighttime driving.

When the driver encounters a hazard on the road, the driver actually executes the following steps before stopping the vehicle:

- Perception and Identification of the hazard, under poor visibility conditions;
- Reaction time used to consider the alternatives available, and deciding what action to take; and
- Braking

A driver's reaction depends rely on vision, and vision is severely limited at night. Vision and visual perception problems lead to dangerous situations for nighttime driving. Serious crashes may be caused by the driver not having enough information about the road ahead or enough time to take appropriate action. As it takes longer and more difficult to complete these steps in the evening than during the day, the risk of death in the case of a crash is greater for night driving than for clear visibility conditions. As shown in this dissertation, the risk of death in the case of a crash is higher for night driving than for clear visibility conditions.

To help drivers handle the poor visibility problem and react more quickly when driving at night, the highway engineers should make the darker environment surrounding the vehicle more visible. This can be accomplished by using raised pavement markings and delineators to help the drivers improve the visibility of the surrounding environment.

7.3.4. Improvement of Road Side Features

For all four southeastern states studied in the dissertation, most of the crash sites had a roadside hazard rating of 4 to 6. In Alabama, 67 percent of the sites had a roadside hazard rating of 4 or 5. In Mississippi, 67 percent had a roadside hazard rating of 5 or 6.

In South Carolina, 70 percent sites had a rating of five. In Georgia, 82 percent of the sites had a roadside hazard rating between 3 and 5. As shown in the appendix, a RHR of 4 has the following features.

- Clear zone 5 to 10 feet from pavement edgeline;
- Sideslope about 1:3 or 1:4;
- Guardrail possible 5 to 6.5 feet from pavement edgeline;
- Exposed trees, poles, or other objects possible about 10 feet from the pavement edgeline; and
- Marginally forgiving terrain, but increased chance of a reportable roadside collision

The following countermeasures are proposed to improve the roadside safety. The improved roadside hazard rating should be no more than 3.

- A clear zone should be maintained for a distance of at least 10 feet from the edge of the road (hazard rating 3) or more wherever practicable.
- Rectify the dangers posed by trees, which have been planted within 30 feet of rural roads. Review the roadside tree planting policies taking into account current best road safety practice to prevent new planting in hazardous locations.

Reliance on attempts to remove the roadside hazards alone will not be an adequate response to the dangers presented by poor driver behavior. Countermeasures aimed at reducing traveling speed, impaired driving, and driver fatigue are likely to decrease the frequency of roadside hazard crashes. Current levels of enforcement of legislation relating to speed and impaired driving should be enforced.

7.4. Future Research

All the impacts reported in this dissertation are the effects of a certain factor controlling for many other factors such as roadway and traffic features. It would be more meaningful to consider cross-section factors together with alignment and roadside factors, rather than trying to determine the safety effects of individual cross-section elements. However, to fully eliminate the effects of all other safety affecting variables is rather difficult.

The sample size in this dissertation is relatively small due to the efforts that are required to collect the detailed site variables. Considering the estimation requirement of logit models, some severity models are estimated as binary logit models, that is, fatal injury and non-fatal injury. It would be helpful to have a larger sample set so that the results are comparable across states for every group of people involved in the crash.

It would also be desirable to perform similar analysis on a variety of crashes rather than the focus on fatal crashes only as included in this dissertation.

APPENDIX A DATA DICTIONARY

Table A.1 Crash Data Elements

Variable #	Data Element Name	Definition	Code (Data Items)
C1	Crash State	The FIPS code identifying the state in which the crash occurred.	{2 digit FIPS code} 01 Alabama 12 Florida 13 Georgia 21 Kentucky 28 Mississippi 37 North Carolina 45 South Carolina 47 Tennessee
C2	Crash Case Number	State specific unique identifier within a given year that identifies a given crash.	-
C3	Crash Date and Time	The date (year, month, and day) and time (hour and minute) at which a crash occurred.	YYYYMMDDHHMM
C4	Crash County	The FIPS code identifying the county in which a crash occurred.	{3 digit FIPS code} 888 N/A 999 Unknown
C5	Crash City/Place	The FIPS code identifying the city/place in which a crash occurred.	{5 digit FIPS code} 88888 N/A 99999 Unknown
C6	Number of Vehicles Involved in Crash	The total number of vehicles involved in the crash - do not include non-motorized vehicles.	Actual vehicle count (0-99)
C7	Number of Driver/Occupants	The total number of vehicle occupants from all vehicles including the drivers who are in the vehicle(s) at the time of the crash.	Actual person count (0-99)
C8	Number of Non-motorists	The total number of non-motorists involved in the crash.	Actual person count (0-99)
C9	Crash Roadway Location	The exact location on the roadway indicating where the crash occurred. The optimum definition uses GPS/GIS location giving latitude/longitude information. States without GPS/GIS should indicate location using current system.	• Latitude / Longitude • Road Name / Route Number / Route Signing • Mile Marker / Milepost / Mile-point • At Intersection of Road Name / Route Number • Miles, Feet (N, S, E, W) of Road Name / Route Number

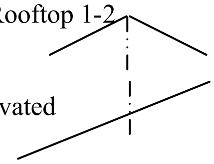
C10, C11, C12	Source of Information	Identity of the source providing the information on the crash report.	Subfield 1: Source of Info. 1 Police agency 2 Motorist 3 Other Subfield 2: Police Reporting Agency Identifier. Subfield 3: Type of Police Agency 1 State police/hwy patrol 2 City police 3 Sheriff department 4 Other
C13	Date and Time Crash Reported to Police Agency	The date and time at which the call was placed notifying the police agency about the crash.	YYYYMMDDHHMM
C14	School Bus Related	Indicates if a school bus is related to the crash. The "school bus", with or without a pupil on board, must be directly involved as a contact vehicle or indirectly involved as a noncontact vehicle. A "school bus" is a yellow vehicle, with the name "school bus" on the front and rear and lettering on both sides identifying the school, school district served, or the company operating the bus.	1 No 2 Yes, school bus directly involved 3 Yes, school bus indirectly involved 4 Not reported 5 Unknown
C15, C16, C17, C18	Work Zone Related	A crash which occurs in or near a construction, maintenance or utility work zone as designated by the state, whether active or inactive.	**Subfield 1:** Was crash located in or near a construction, maintenance or utility work zone. 1 No 2 Unknown 3 Yes (complete subfields 2-4) **Subfield 2:** Location of Crash. 1 Advance warning area 2 Transition area 3 Adjacent to activity area 4 Activity area 5 Termination area **Subfield 3:** Type of work zone. 1 Lane closure 2 Lane shift/crossover 3 Work on shoulder or median 4 Intermittent/moving work 5 Other **Subfield 4:** Workers present 1 Yes 2 No 3 Unknown

C19	Total Fatal Injuries	The total number of fatalities (motorists and non-motorists) which resulted from injuries sustained as the result of a specific road vehicle crash. In reporting fatality statistics, a 30-day counting rule is generally used for highway safety statistics. These rules provide that only those deaths which occur within 30 days of a crash will be counted for statistical purposes.	Actual Count (0-99)
C20	Total Non-fatal Injuries	The total number of persons injured in a specific traffic crash.	Actual Count (0-99)
C21	Alcohol/Drug Involvement	Investigating police officer's assessment of whether alcohol or drug use was suspected or demonstrated to be present by test for any vehicle driver or non-motorist in the crash.	1 Neither alcohol nor other drugs 2 Yes (alcohol) 3 Yes (drugs other than alcohol) 4 Yes (alcohol and drugs) 5 Not reported 6 Unknown
C22	Hit and Run	Indicate whether or not the crash involved a hit and run.	1 No Hit and Run 2 Hit motor vehicle in transport 3 Hit pedestrian or non-motorist 4 Hit parked vehicle
C23	Day of Week	The day of the week on which a crash occurred.	1 Monday 2 Tuesday 3 Wednesday 4 Thursday 5 Friday 6 Saturday 7 Sunday
C24	Date Incident Reported	Date the call is first received by a public safety answering point (PSAP) or other designated entity.	YYYYMMDD
C25	Time Incident Reported	Time call is first received by Public Safety Answering Point (PSAP) or other designated entity.	HHMM
C26	Time Dispatch Notified	Time of first connection with EMS dispatch	HHMM
C27	Date Unit Notified	Date response unit is notified by EMS dispatch	YYYYMMDD
C28	Time Unit Notified	Time response unit is notified by EMS dispatch	HHMM
C29	Time Unit Responding	Time that the response unit begins physical motion.	HHMM

C30	Time arrival at scene	Time EMS unit stops physical motion at scene (last place that the unit or vehicle stops prior to assessing the patient).	HHMM
C31	Time of arrival at patient	Time response personnel establish direct contact with patient.	HHMM
C32	Time Unit Left Scene	Time when the response unit begins physical motion from scene.	HHMM
C33	Time Arrival at Destination	Time when patient arrives at destination or transfer point.	HHMM
C34	Incident Number	Unique number for each incident reported to dispatch.	-
C35	Agency / Unit Number	Number that identifies the agency and unit responding to an incident.	-

Table A.2 Site Data Elements

Variable #	Data Element Name	Definition	Code (Data Items)
S1	Site Reviewer	Name of person who completed the site review.	-
S2	Date of Site Review	Date on which the site review was completed.	-
S3	Time of Site Review	Time of day that the site review was conducted	-
S4	Crash State	The FIPS code identifying the state in which the crash occurred.	{2 digit FIPS code} 01 Alabama 12 Florida 13 Georgia 21 Kentucky 28 Mississippi 37 North Carolina 45 South Carolina 47 Tennessee
S5	Crash Case Number	State specific unique identifier within a given year that identifies a given crash. This number should be available on police reports or reports maintained by the state DOT.	-
S6	Sequential Case Number	Sequential case number assigned by the university for purposes of the pooled fund study.	2 Letter State Code followed by sequential case number (1-150) Georgia Format: GA001 - GA150
S7, S8, S9, S10	Horizontal Alignment	The change in general horizontal alignment of a roadway.	Subfield 1:General Alignment 1 Straight 2 Curved Subfield 2:Direction of Curve NA Not Applicable 01 Right 02 Left Subfield 3:Estimated Curve Radius NA Not Applicable 01 Sharp curve (requires driver speed adjustment) 02 Mild/gentle curve Subfield 4: Crash Curve Location NA Not Applicable 01 Inside of curve 02 Outside of curve

S11, S12, S13, S14	Grade	The inclination of a roadway, expressed as a percent of grade.	Subfield 1: Direction of Slope 1 Up 2 Down 3 Flat Subfield 2: Estimate of the Percent of Slope NA Not Applicable 01 Level (1 ±) 02 Mild Slope (2-6 ±) 03 Steep Slope (>6 ±) Subfield 3: Crest Vertical Curve NA Not Applicable 01 Yes 02 No Subfield 4: Sag Vertical Curve NA Not Applicable 01 Yes 02 No
S15, S16	Cross-Section	Cross-section type of two-lane rural road.	Subfield 1: type 1 Typical Rooftop 1-2 2 Superelevated  Subfield 2: Other, (If so, indicate other type in column S13 <other.cs>)
S17, S18	National Highway System	Designation as part of the national highway system.	Subfield 1: Designation 1 Yes 2 No 3 Unknown Subfield 2: Other
S19	Functional Classification of Rural Roadway	The character of service or function of streets or highways.	1 Principal arterial 2 Minor arterial 3 Major Collector 4 Minor Collector 5 Local 6 Unknown
S20, S21	Guardrail/ Bridge Railing	Was a guardrail or bridge rail involved in crash, if so, indicates type.	Subfield 1: 1 None 2 Steel Breakaway Guardrail 3 Concrete Barrier (Jersey) 4 Wood Guardrail 5 Concrete Bridge Rail 6 Steel Bridge Rail 7 Wood Bridge Rail Subfield 2 Indication of other type of guardrail/bridge railing.

S22, S23, S24	Lanes	Number of lanes in addition to the two main traffic-way lanes, by function , at the particular cross section of the roadway where the crash occurred.	Subfield 1: Number of turning lanes in addition to the two main lanes Subfield 2: Number of passing lanes in addition to the two main lanes Subfield 3: Number of emergency lanes in addition to the two main lanes
S25, S26, S27, S28, S29, S30	Average Daily Traffic	The average number of vehicles passing a point on a trafficway per day, for some specified time period (ADT), or during a specified calendar year (AADT).	Subfield 1: ADT or AADT 1 Average Daily Traffic (ADT) – average daily traffic averaged over a period less than one year 2 Annual Average Daily Traffic (AADT) –average daily traffic averaged over a continuous count period of one year Subfield 2: Daily Traffic Count Subfield 3: Length of Count Subfield 4: Time Increment of Count 1 Hours 2 Days 3 Months 4 Years Subfield 5: Date Collection Began MMDDYYYY Subfield 6: Counts obtained from 1 Actual Roadway 2 Similar Roadway
S31	Lane Width	Width of lane where crash occurred.	Width (feet) (NA = Not Applicable)
S32, S33, S34	Shoulder Type/Width	Type of shoulder adjacent to lane in which crash occurred.	Subfield 1: Shoulder Type 1 Paved 2 Graded 3 Combination Paved and Graded 1 Raised Curb, Traversable 2 Raised Curb, Barrier 3 No Shoulder Subfield 2: Paved Shoulder Width (NA = Not Applicable) Subfield 3: Graded Shoulder Width (NA = Not Applicable)
S35, S36	Nature of Adjacent Influences	The type of visual content of abutting land, air, or view in connection with a roadway (within 500 ft. laterally of crash site).	Subfield 1: Type 1 Billboards 2 Driveways, residential 3 Driveways, commercial 4 Driveways, industrial Subfield2: Other, (If so, indicate other type in column S30 <other.ai>)

S37, S38	Driveways/ Intersections	Number of driveways and intersections surrounding crash site which provide sources of vehicular conflict.	Subfield 1 – Indicate number of driveways within 250 ft upstream and 250 ft downstream of the crash site. Circular drives that have two access points are counted as two. Driveways directly across the street from each other count as two driveways. Subfield 2 – Indicate the number of intersection with 250 ft upstream and 250 ft downstream of the crash site. A four-way intersection will count as two intersections to determine conflict patterns.
S39	Bridge or Railroad Involvement	Indication of whether or not a bridge or railroad was involved in the crash.	Not Applicable 0 Bridge 1 Railroad 2 Bridge and Railroad
S40	Bridge/Structure Identification	A unique code assigned to a bridge, underpass, overpass ,or tunnel.	- (NA = Not Applicable)
S41	Railroad Crossing ID	A unique number assigned to a railroad crossing by a state highway agency in cooperation with the American Association of Railroads for identification purposes	- (NA = Not Applicable)
S42	Roadside Illumination	The type of roadway illumination within 250 ft longitudinally of crash site.	1 No illumination fixtures 2 Spot illumination 3 Continuous illumination
S43	Pavement Markings, Longitudinal	The longitudinal markings (paint, plastic, or other) used on the roadway surface to guide or control the path followed by drivers at crash site.	Function and Color 01 Centerline, skip-dash, yellow 02 Centerline, solid, yellow 03 Centerline, solid double, yellow 04 No passing barrier, right or left, yellow 05 Lane line, skip-dash, white 06 Lane line, solid, white 07 Edge line, left, yellow 08 Edge line, right, white 09 Left turn lane lines, combination of solid and skip-dash, yellow 10 Turn arrow symbols, right, through, left, or combination of two 11 Unknown
S44	Bikeway	Any road, path, or way which in some manner is specifically designated as being open to bicycle travel, regardless of whether such facilities are designated for the exclusive use of bicycles or are to be shared with other transportation modes. Select only one value – closest to actual configuration.	1 No Bikeway 2 Bicycle Route (signed only) 3 Bicycle Lane (striped)-right only 4 Bicycle Lane (striped)-both sides 5 Bicycle Lane (striped)-left only 6 Separate Bicycle Path/Trail 7 Unknown

S45, S46	Delineator Presence	The presence or absence of a series of reflecting devices mounted at regular intervals along the side, center, or lane lines of the road to assist in directing drivers along the alignment of the roadway.	Subfield 1: Delineator Presence 1 None 2 Delineators, right 3 Delineators, left 4 Delineators, both sides 5 Unknown Subfield 2: Type of Delineator 1 Directional chevron signs 2 Mounted reflectors NA Not Applicable
S47, S48, S49, S50, S51, S52, S53	Traffic Control Device	Traffic control devices present at the crash site at the time of the crash.	Subfield 1: Highway Traffic Signals 1 Traffic control signal (operating green, yellow, red) without pedestrian signal 2 Traffic control signal (operating green, yellow, red) with pedestrian signal 3 Traffic control signal (operating green, yellow, red) pedestrian signal not known 4 Flashing traffic control signal 5 Flashing beacon 6 Flashing highway traffic signal, type unknown, or other 7 Lane use control signal 8 Unknown highway traffic signal NA Not Applicable Subfield 2: Other Traffic Signals Subfield 3: Regulatory Signs 1 Stop Sign 2 Yield Sign 3 Unknown type regulatory sign NA Not Applicable Subfield 4: Other type regulatory sign Subfield 5: School Zone Signs 1 School speed limit sign 2 School advance or crossing sign 3 Unknown type school zone sign NA Not Applicable Subfield 6: Other school related sign Subfield 7: Warning Signs – Indicate type (NA Not Applicable)
S54, S55	Speed Limit	Posted speed limit at the location of the crash.	Subfield 1: Speed Limit Type 1 Regulatory 2 Warning Subfield 2: Posted Speed Limit
S56	Roadside Parking	Presence of adjacent roadside parking.	1 No Roadside Parking 2 Parallel parking 3 Head-in parking 4 Unknown

S57	Roadside Hazard Rating	A subjective measure of the hazard associated with the roadside environment. The rating values indicate the crash damage likely to be sustained by errant vehicles on a scale from one (low likelihood of an off-roadway collision or overturn) to seven (high likelihood of an accident resulting in a fatality or severe injury). For more clarification see Zegeer, FHWA-RD-87-008.	(1-7) Ratings are determined from a 7-point rural pictorial scale as shown in Appendix S1.
S58, S59	Surface Type	Roadway surface material at the crash site.	Subfield 1: Type 1 Concrete 2 Blacktop 3 Brick or block 4 Slag, gravel or stone 5 Dirt 6 Unknown Subfield 2: Other
S60, S61	Roadside Barrier	A roadside barrier is a longitudinal barrier used to shield motorists from natural or man-made obstacles located along either side of a traveled way.	Subfield 1: Type 1 None 2 3-Strand Cable 3 W-Beam (weak post) 4 Thrie-Beam (weak post) 5 Box Beam (weak post) 6 Blocked-out W-Beam (strong post) 7 Blocked-out Thrie-Beam (strong post) 8 Modified Thrie-Beam 9 Self-Restoring Barrier 10 Steel-Backed Wood Rail 11 Concrete Safety Shape 12 Stone Masonry Wall Subfield 2: Other See appendix S2 for more details on Barrier types.
S62	Raised Pavement Reflectors	Are raised pavement reflectors used to accent or replace painted pavement markings?	1 Yes 2 No
S63	Terrain	Indicate the general terrain surrounding the crash site.	1 Flat 2 Rolling 3 Mountainous

Table A.3 Environmental Data Elements

Variable #	Data Element Name	Definition	Code (Data Items)
E1	Crash State	The FIPS code identifying the state in which the crash occurred.	{2 digit FIPS code} 01 Alabama 12 Florida 13 Georgia 21 Kentucky 28 Mississippi 37 North Carolina 45 South Carolina 47 Tennessee
E2	Crash Case Number	State specific unique identifier within a given year that identifies a given crash.	-
E3	Sequential Case Number	Sequential case number assigned by the university for purposes of the pooled fund study.	2 Letter State Code followed by sequential case number (1-150) Georgia Format: GA001 - GA150
E4	Crash Date and Time	The date (year, month, and day) and time (hour and minute) at which a crash occurred.	YYYYMMDDHHMM
E5	Crash County	The FIPS code identifying the county in which a crash occurred.	{3 digit FIPS code} 888 N/A 999 Unknown
E6	First Harmful Event	The injury or damage producing event which characterizes the crash type and identifies the nature of the first harmful event, such as an explosion in the vehicle.	01 Overturn 02 Jackknife 03 Other Non-collision 04 Collision w/ pedestrian 05 Collision w/pedalcycle 06 Collision w/ railway vehicle 07 Collision w/ animal 08 Collision w/ motor vehicle in transport 09 Collision w/ parked vehicle 10 Collision w/ work zone equipment 11 Collision w/ other non-fixed object 12 Collision w/ bridge/culvert 13 Collision w/ guardrail/median barrier 14 Collision w/ utility pole/light support 15 Collision w/ embankment/ditch/curb 16 Collision w/ tree 17 Collision w/ other fixed object 18 Collision w/ unknown fixed object 19 Not reported 20 Unknown

E7	Relation to Roadway	The location of the First Harmful Event as it relates to its position within or outside the traffic-way.	01 Roadway 02 Shoulder 03 Median 04 Roadside 05 Not Reported 06 Unknown 07 Ramp 08 Gore 09 Off-Roadway – Location Unknown 10 In Parking Lane
E8	Manner of Impact	The identification in a crash of the manner in which two vehicles in transport initially came together without regard to the direction of force.	1 Not collision between two vehicles in transport. 2 Rear-end 3 Head-on 4 Rear-to rear 5 Angle 6 Sideswipe, same direction 7 Sideswipe, opposite direction 8 Not reported 9 Unknown
E13	Force of collision	The direction of the force in a crash which caused the two vehicles to come together.	1 Not collision between two vehicles in transport. 2 Rear-end 3 Head-on 4 Rear-to rear 5 Angle 6 Sideswipe, same direction 7 Sideswipe, opposite direction 8 Not reported 9 Unknown
E18	Weather Condition	The prevailing atmospheric conditions that existed at the time of the crash.	01 Clear 02 Cloudy 03 Fog, smog, smoke 04 Rain 05 Sleet, hail (freezing rain/drizzle) 06 Snow 07 Severe crosswinds 08 Blowing sand, soil, dirt, snow 09 Other 10 Not reported 11 Unknown
E19	Ambient Light	The type of light that exists at the time of a motor vehicle crash.	1 Daylight 2 Dawn 3 Dusk 4 Dark – lighted roadway 5 Dark - roadway not lighted 6 Dark – unknown roadway lighting 7 Other 8 Not reported 9 Unknown

E20	Road Surface Condition	The roadway surface condition at the time and place of a crash.	01 Dry 02 Wet 03 Snow 04 Ice 05 Sand, mud, dirt, oil, gravel 06 Water (standing, moving) 07 Slush 08 Other 09 Not reported 10 Unknown
E21	Contributing Circumstances, Environment	Apparent environmental conditions which contributed to the crash.	1 None 2 Weather conditions 3 Physical obstruction 4 Glare 5 Animal in roadway 6 Other 7 Not reported 8 Unknown
E22	Contributing Circumstances, Road	Apparent condition of the road which contributed to the crash.	01 None 02 Road surface condition (wet, icy, slush, etc.) 03 Debris 04 Rut, holes, bumps 05 Work zone(construction/ maintenance/utility) 06 Worn, travel-polished surface 07 Obstruction in Roadway 08 Traffic control device inoperative or missing 09 Shoulders (none, low, soft, high) 10 Non-highway work 11 Other 12 Not reported 13 Unknown
E23	Type of Roadway Junction	A junction is either an intersection or the connection between a driveway access and a roadway other than a driveway access.	1 Not a junction 2 Four-way intersection 3 T-intersection 4 Y-intersection 5 Traffic circle/roundabout 6 Five-point, or more 7 On ramp 8 Off ramp 9 Crossover 10 Driveway 11 Railway grade crossing 12 Shared-use paths or trails 13 Not reported 14 Unknown

Table A.4 Person Data Elements

Variable #	Data Element Name	Definition	Code (Data Items)
P1	Crash State	The FIPS code identifying the state in which the crash occurred.	{2 digit FIPS code} 01 Alabama 12 Florida 13 Georgia 21 Kentucky 28 Mississippi 37 North Carolina 45 South Carolina 47 Tennessee
P2	Crash Case Number	State specific unique identifier within a given year that identifies a given crash.	-
P3	Date of Birth	The year, month, and day of birth of person involved in a crash.	YYYYMMDD
P4	Sex	The sex of person involved in a crash.	1 Male 2 Female 3 Not reported 4 Unknown
P5	Person Type	Type of person involved in a crash.	1 Driver 2 Passenger 3 Nonmotorist 4 Not reported 5 Unknown
P6	Injury Status	The most severe injury to the person involved in a crash.	1 Fatal Injury (K) 2 Nonfatal Injury, Incapacitating (A) 3 Nonfatal Injury, Nonincapacitating (B) 4 Nonfatal Injury, Possible (C) 5 No injury (O) 6 Not reported 7 Unknown
P7	Occupant's Vehicle Unit Number	The number assigned to the vehicle in which this person was an occupant.	(01-99)

P8	Seating Position	The location for this occupant in, on, or outside of the motor vehicle prior to the impact of a crash.	01 Front seat – left side (or motorcycle driver) 02 Front seat – middle 03 Front seat – right side 04 Second seat – left side (or motorcycle passenger) 05 Second seat – middle 06 Second seat – right side 07 Third row – left side (or motorcycle passenger) 08 Third row – middle 09 Third row – right side 10 Sleeper section of cab (truck) 11 Passenger in other enclosed passenger or cargo area (non-trailing unit such as a bus) 12 Passenger in unenclosed passenger or cargo area (non-trailing unit such as a pickup) 13 Trailing unit 14 Riding on vehicle exterior (non-trailing unit) 15 Not reported 16 Unknown
P9	Occupant Protection System Use	The restraint equipment in use by occupant at the time of the crash, or the helmet use by a motorcyclist.	1 None used – vehicle occupant 2 Shoulder belt only used 3 Lap belt only used 4 Shoulder and lap belt used 5 Child safety seat used 6 Helmet used 7 Not reported 8 Restraint use unknown
P10, P11	Air Bag Deployed	Deployment status of an air bag relative to position of the occupant.	**Subfield 1:** Deployment Deployed-front Deployed-side Deployed-both front/side Not-deployed Not applicable Not reported Deployment unknown **Subfield 2:** Switch Status • Switch in ON position • Switch in OFF position • ON-OFF switch not present • Unknown if ON-OFF switch present • Not reported • Unknown position

P12	Ejection	The location of each occupant's body as being completely or partially thrown from the vehicle as a result of a crash.	- Not ejected - Totally ejected - Partially ejected - Not applicable - Not reported - Unknown
P13	Trapped	Persons who are mechanically restrained in the vehicle by damaged vehicle components as a result of a crash, and are freed from the vehicle.	- Not trapped - Extricated by mechanical means (Jaws of Life, etc.) - Freed by non mechanical means - Not reported - Unknown
P14	Driver License State/Province	A code identifying the state or province issuing a driver license to an individual. Includes the states of the United States (including the District of Columbia and outlying areas), Indian Nation, U.S. Government, Canadian provinces, and Mexican Sates (including the District Federal), as well as other jurisdictions.	- Not Licensed - State code (FIPS) - Indian Nation - U.S. Government - Canadian Province - Mexican State - International License (other than Mexico, Canada) - Not reported - Unknown
P15	Driver License Number	A unique number assigned by the authorizing agent issuing a driver license to the individual.	Alphanumeric identifier assigned by the state, foreign country, U.S. government, Indian Nation, etc.
P16	Driver Name	The full name of the individual driver.	Provided in appendix
P17	Contributing Circumstances, Driver	The actions of the driver which may have contributed to the crash.	- No Improper driving - Failed to yield right of way - Disregarded traffic signs, signals, road markings - Exceeded authorized speed limit - Driving too fast for conditions - Made an improper turn - Wrong side or Wrong way - Followed too closely - Improper action - Failure to keep in proper lane or running off road - Operation vehicle in erratic, reckless, careless, negligent or aggressive manner - Swerving or avoiding due to wind, slippery surface, vehicle, object, nonmotorist in roadway, etc. - Overcorrecting/oversteering - Visibility obstructed - Inattention - Distracted - Fatigued/asleep - Operation defective equipment - Other - Not reported - Unknown

P18	Driver Condition	The condition of the driver which may have contributed to the crash.	- Apparently normal - Physical impairment - Emotional (e.g., depressed, angry, disturbed) - Illness - Fell asleep, fainted, fatigued, etc. - Under the influence of medications/drugs/alcohol - Other - Not reported - Unknown
P19	Cited	Driver cited for actions which contributed to the crash.	- Yes - No - Pending - Unknown
P20, P21, P22, P23	Violation Codes	All violation codes that apply to indicate the type of violations.	**Subfield 1:** Violation Code #1 No violation (Violation Code) Not reported Unknown **Subfield 2:** Violation Code #2 No violation (Violation Code) Not reported Unknown **Subfield 3:** Violation Code #3 No violation (Violation Code) Not reported Unknown **Subfield 4:** Violation Code #4 No violation (Violation Code) Not reported Unknown
P24	Driver License Class	The type of commercial or non-commercial vehicle that a licensed driver has been examined on and approved to operate.	1 Class A 2 Class B 3 Class C 4 Class M 5 Unknown
P25	Driver License Status, CDL	The current status of an individual's federally-approved commercial drivers license (CDL).	1 Eligible 2 Licensed 3 Not Eligible 4 Reported Deceased
P26	Driver License Status, Non-CDL	The current status of an individual's drivers license other than a federally approved commercial driver license.	1 Eligible 2 Licensed 3 Not Eligible 4 Reported Deceased

P27	Driver License Restrictions	Restrictions assigned to an individual's driver license by the license examiner.	01 None 02 Corrective Lenses 03 Mechanical devices (special brakes, hand controls, or other adaptive devices) 04 Prosthetic aid 05 Automatic transmission 06 Outside mirror 07 Limit to daytime only 08 Limit to employment 09 Limited - other 10 Other 11 CDL Intrastate only 12 Vehicles without air-brakes 13 Except Class A Bus 14 Except Class A and Class B bus 15 Except tractor-trailer 16 Farm waiver
P28	License Endorsements	Compliance with license endorsements.	1 No Endorsements required for this vehicle 2 Endorsements required, complied with 3 Endorsements required, not complied with 4 Endorsements required, compliance unknown 5 Unknown, if required
P29	License Compliance	Drivers license type compliance	1 Not Licensed 2 No License required for this class vehicle 3 No valid license for this class vehicle 4 Valid License for this class vehicle 5 Unknown if CDL Endorsement required for this vehicle 6 Unknown
P30	Driver Presence	Indicate whether or not there was a driver present in the vehicle at the time of the crash as well as afterwards.	1 Driver Operated Vehicle 2 Driverless (No Driver) 3 Driver Left Scene 4 Unknown
P31	Previous Recorded Accidents	Number of events occurring within three years of the crash.	00 None 01-97 Actual Value 98 CDL Disqualified 99 Unknown
P32	Previous Recorded Suspensions	Number of events occurring within three years of the crash.	00 None 01-97 Actual Value 98 CDL Disqualified 99 Unknown
P33	Previous DWI Convictions	Number of events occurring within three years of the crash.	00 None 01-97 Actual Value 98 CDL Disqualified 99 Unknown

P34	Previous Speeding Convictions	Number of events occurring within three years of the crash. Speeding violations count going too slow, as well as, going too fast.	00 None 01-97 Actual Value 98 CDL Disqualified 99 Unknown
P35	Previous Other Motor Vehicle Convictions	Number of events occurring within three years of the crash.	00 None 01-97 Actual Value 98 CDL Disqualified 99 Unknown
P36	Month/Year of Last Accident		MMYYYY
P37	Month/Year of First Accident		MMYYYY
P38	Driver Street Address		Provided in appendix
P39	Driver Address City	The FIPS code identifying the city/place in which the driver resides.	{5 digit FIPS code} 88888 N/A 99999 Unknown
P40	Driver Address State	The FIPS code identifying the state in which the driver resides.	{2 digit FIPS code} Provided in appendix
P41	Driver Zip Code		
P42	Alcohol/Drug Suspected	Investigating police officer's assessment of whether alcohol or drugs are used by the vehicle driver or nonmotorist.	- Neither alcohol nor drugs suspected - Yes – alcohol suspected - Yes – drugs suspected - Yes – alcohol and drugs suspected - Not reported - Unknown
P43, P44, P45	Alcohol	The percent of Blood Alcohol Content (BAC).	**Subfield 1:** Test Status None given Test refused Test given, results unknown Test given, contaminated sample/unusable Unknown **Subfield 2:** Type of Test Blood Breath Urine **Subfield 3:** Test Result (x.xx)

P46, P47, P48	Drugs	Indication of the presence of drugs through drug testing.	**Subfield 1:** Test Status Test not given Test given, no drugs reported Test given, drugs reported Test given, contaminated sample/unusable Not reported Unknown **Subfield 2:** Type of Test Blood Urine Serum **Subfield 3:** Test Result (Drugs regulated for commercial motor vehicle drivers and others) Marijuana Cocaine Opiates Amphetamines PCP
P49	Nonmotorist Number	The unique number assigned to the non motorist involved in a crash.	Sequential number uniquely identifying the nonmotorist involved in a crash.
P50	Nonmotorist Type	A code indicating the type of nonmotorist involved in a crash.	- Pedestrian - Pedacyclist (bicycle, tricycle, unicycle, pedalcar) (2.2.39) - Skater - Other - Not reported - Unknown
P51	Nonmotorist Action	The actions of the nonmotorist prior to the crash.	- Entering or crossing specified location - Improper crossing - Walking, playing, running/jogging - Working - Darting - Is lying and/or illegally in roadway - Failure to yield right of way - Not visible - Bicycle violation - Inattentive (talking, eating, etc.) - Failure to obey traffic signs, signals, or officer - Pushing vehicle - Approaching or leaving vehicle - Playing or working on vehicle - Standing - Other - Not reported - Unknown

P52	Nonmotorist Condition	A code which specifies the condition of the nonmotorist immediately prior to a crash.	- Apparently normal - Physical impairment - Emotional (e.g., depression, angry, disturbed) - Illness - Fell asleep, fainted, fatigue, etc. - Under the influence of medications / drugs / alcohol - Other - Not reported - Unknown
P53	Nonmotorist Location Prior to Impact	The nonmotorist's location with respect to the roadway prior to impact.	- Marked crosswalk at intersection - At intersection but no crosswalk - Nonintersection crosswalk - Driveway access crosswalk - In roadway - Not in roadway - Median (but not on shoulder) - Island - Shoulder - Sidewalk - Within 10 feet of roadway (but not shoulder, median, sidewalk, or island) - Beyond 10 feet of roadway (within trafficway) - Outside trafficway - Shared-use path or trails - Not reported - Unknown
P54, P55	Nonmotorist Safety Equipment	The safety equipment(s) used by the nonmotorist.	**Subfield 1:** Safety Equipment used by nonmotorist - None used - Helmet used - Protective pads used (elbows, knees, shins, etc.) - Reflective clothing - Lighting - Not applicable - Other - Not reported - Unknown **Subfield 2:** Safety Equipment used by nonmotorist - See Subfield 1
P56	Number of Vehicle Striking Nonmotorist	Number assigned to identify the vehicle that struck the nonmotorist in the crash.	

Table A.5 Vehicle Data Elements

Variable #	Data Element Name	Definition	Code (Data Items)
V1	Crash State	The FIPS code identifying the state in which the crash occurred.	{2 digit FIPS code} 01 Alabama 12 Florida 13 Georgia 21 Kentucky 28 Mississippi 37 North Carolina 45 South Carolina 47 Tennessee
V2	Crash Case Number	State specific unique identifier within a given year that identifies a given crash.	-
V3	Vehicle Unit Number	Number assigned to uniquely identify within the crash each vehicle involved in the crash.	Sequential number (1, 2, 3, 4…)
V4	Vehicle Registration State and Year	The state, commonwealth, territory, Indian nation, U.S. Government, foreign country, etc. issuing the registration plate and the year of registration as indicated on the registration plate displayed on the vehicle. For foreign countries, MUCC requires only the name of the country. Border states may want to collect the name of individual Canadian Provinces or Mexican States.	2 digit FIPS code for state and YYYY for the year.
V5	Vehicle License Plate Number	The alphanumeric identifier or other characters, exactly as displayed, on the registration plate or tag affixed to the vehicle. For combination trucks, vehicle plate number is obtained from the power unit or tractor.	Alphanumeric identifier assigned by the state, foreign country, U.S. government, Indian Nation.
V6	Vehicle Make	The distinctive (coded) name applied to a group of vehicles by a manufacturer.	Provide in appendix
V7	Trailer Registration State and Year	The state, commonwealth, territory, Indian nation, U.S. Government, foreign country, etc. issuing the registration plate and the year of registration as indicated on the registration plate displayed on trailer. For foreign countries, MUCC requires only the name of the country. Border states may want to collect the name of individual Canadian provinces or Mexican States.	2 digit FIPS code for state and YYYY for the year.
V8	Trailer License Plate Number	The alphanumeric identifier exactly as displayed, on the registration plate or tag affixed to the trailer.	Alphanumeric identifier assigned by the state, foreign country, U.S. government, Indian Nation.

V9	Vehicle Configuration	Indicates the general configuration of vehicle.	1 Passenger car 2 Light truck(van, mini-van, panel, pickup, sport utility) with only four tires 3 Single-unit truck (2-axle, 6-tire) 4 Single-unit truck (3-or-more axles) 5 Truck/trailer 6 Truck tractor (bobtail) 7 Tractor/doubles 8 Tractor/triples 9 Unknown heavy truck, cannot classify 10 Motor home/recreational vehicle 11 Motorcycle 12 Bus (seats for more than 15 people, including driver) 13 Bus (seats for 7-15 people, including driver) 14 Other 15 Not reported 16 Unknown vehicle configuration
V10	Cargo Body Type	Coded for buses and trucks over 10,000 pounds GVWR.	01 Not applicable 02 Bus (seats for more than 15 people, including driver) 03 Bus (seats for 7-15 people, including driver) 04 Van/enclosed box 05 Grain/chips/gravel truck 06 Pole truck 07 Cargo tank 08 Flatbed 09 Dump 10 Concrete mixer 11 Auto transporter 12 Garbage/refuse 13 Other 14 Not reported 15 Unknown
V11	Weight Rating of Power Unit	A gross vehicle weight ration is a value specified by the manufacturer for a single-unit truck, truck tractor or trailer, or the sum of such values for the units which make up a truck combination. (2.2.23)	1 less than or equal to 10,000 lbs. 2 10,001-26,000 3 more than 26,000

V12	Vehicle Adaptive Equipment or Modifications	The presence of adaptive equipment, other than that supplied by the OEM, which accommodates the vehicle functions to the capabilities of a person with disabilities. This may be for either a driver or passenger. Examples include: steering control device mounted on the steering wheel, hand controls, wheelchair lift or ramp, wheelchair tie down, additional or relocated switches for secondary controls (lights, wipers, etc.).	1 No—adaptive equipment/ modifications not observed 2 Yes—adaptive equipment/ modifications observed 3 Not reported 4 Unknown if adaptive equipment/ modifications present
V13	Total Occupants In Vehicle	The total number of occupants in this vehicle involved in the crash, including persons in or on the vehicle at the time of the crash.	(1-99) Total number of occupants including the driver 00 Unknown
V14	Vehicle Role	Indicates vehicle role in single and multi-vehicle crashes. Role does not imply fault.	1 Noncontact 2 Noncollision 3 Striking 4 Struck 5 Both striking and struck 6 Not reported 7 Unknown
V15	Emergency Use	Indicates vehicles, such as military, police, ambulance, fire, etc., which are on an emergency response. Emergency refers to a vehicle that is traveling with physical emergency signals in use; typically red light blinking, siren sounding, etc. Code yes only if the vehicle was on an emergency response.	1 No 2 Yes 3 Not reported 4 Unknown
V16, V17, V18	Hazardous Materials Involvement (Cargo Only)	Indication that a motor vehicle had a hazardous material placard as required by federal regulations.	**Subfield 1:** Did this vehicle have a hazardous materials placard? 1 Yes 2 No 3 Not reported 4 Unknown **Subfield 2:** If yes, record from the hazardous materials placard: 1) 4-digit placard number from the middle of the diamond or from the rectangular box; and 2) 1-digit placard number from bottom of diamond **Subfield 3:** Hazardous Materials, Cargo Released from the Cargo Compartment? 1 Yes – haz mat released 2 No – haz mat not released 3 Not reported 4 Unknown

V19, V20	Vehicle Authorized Speed Limit	Authorized speed limit for the vehicle at the time of the crash. The authorization may be indicated by the posted speed limit, blinking sign at construction zones, etc.	**Subfield 1:** Authorized Value **Subfield 2:** Unit of Measure 1 Miles per hour 2 Kilometers per hour 3 Not applicable 4 Unknown
V21	Direction of Travel Before Crash	The direction to a vehicle's normal, general travel on the roadway before the crash. Notice that this is not a compass direction but a direction consistent with the designated direction of the road. For example, the direction of a state designated north-south highway must be either northbound or southbound even though a vehicle may have been traveling due east as a result of a short segment of the highway having an east-west orientation.	1 Northbound 2 Southbound 3 Eastbound 4 Westbound 5 Not on roadway 6 Not reported 7 Unknown
V22	Traffic Control Device Type	The type of traffic control, if any at a crash location. This element needs to be collected at the scene because the presence of specific devices is better verified at the time of the crash.	01 No controls 02 Traffic control signal 03 Flashing traffic control signal 04 School zone signs 05 Stop signs 06 Yield signs 07 Warning signs 08 Railway crossing device 09 Not reported 10 Unknown
V23	Vehicle Maneuver/ Action	What the vehicle was doing prior to the crash.	01 Movements essentially straight ahead 02 Backing 03 Changing lanes 04 Overtaking/passing 05 Turning right 06 Turning left 07 Making u-turn 08 Entering traffic lane 09 Leaving traffic lane 10 Parked 11 Slowing or stopped in traffic 12 Other 13 Not reported 14 Unknown
V24	Point of Impact	The portion of the vehicle that impacted first in a crash.	Provided in appendix

V25, V26, V27, V28	Sequence of Events	The events in sequence for this vehicle.	**Subfield 1:** First Event Provided in Appendix **Subfield 2:** Second Event See codes in Subfield 1 **Subfield 3:** Third Event See codes in Subfield 1 **Subfield 4:** Fourth Event See codes in Subfield 1
V29	Most Harmful Event for this Vehicle	Event which produced the greatest property damage or most severe injury caused by this vehicle.	Provided in appendix
V30, V31	Underride/Overide	An underride refers to a vehicle sliding under another vehicle during a crash. An override refers to a vehicle riding up over another vehicle. Both can occur with a parked vehicle.	**Subfield 1:** 1 Underride 2 Override 3 No underride or override 4 Unknown if underride or override **Subfield 2:** 1 Compartment intrusion 2 No compartment intrusion 3 Compartment intrusion unknown
V32	Most Damaged Area	The location of most damage on vehicle and extent of total damage to vehicle from crash.	Provided in appendix
V33	Extent of Damage	Estimation of total damage to vehicle from crash.	1 None 2 Functional damage 3 Disabling damage 4 Severe/vehicle totaled 5 Not reported 6 Unknown
V34	Vehicle Model Year	The year which is assigned to a vehicle by the manufacturer.	YYYY
V35	Vehicle Model	The manufacture assigned code denoting a family of vehicles (within a make) which has a degree of similarity in construction, such as body, chassis, etc.	
V36	Vehicle Body Type	Code derived from the VIN to indicate the general configuration or shape of a vehicle distinguished by characteristics such as number of doors, seats, windows, roof line, hard top or convertible.	Provided in appendix
V37	Total Trailers Attached to Truck	Total number of trailers attached to a large truck.	Actual number of trailers (0-4)
V38	Vehicle Identification Number	A unique combination of alphanumeric characters assigned to a specific vehicle and formulated by the manufacturer.	VIN found on vehicle

V39	Registered Vehicle Owner Type	Indicate whether or not the vehicle was registered and to whom.	1 N/A, Vehicle not registered 2 Driver was registered owner 3 Driver not registered owner (other private owner) 4 Vehicle registered as a business, company, or government vehicle 5 Vehicle registered as a rental vehicle 6 Vehicle was stolen 7 Driverless vehicle 8 Unknown
V40	Travel Speed	An estimate of the travel speed - most likely a judgment rather than a measurement.	00Stopped Vehicle 01-96 Travel Speed in MPH 97 Speed of 97 MPH or higher 99 Unknown
V41	Vehicle Towed?	Manner of leaving scene	1 Driven 2 Towed Away 3 Abandoned/Left Scene 4 Unknown
V42	Fire Occurrence	Indication of fire or explosion as an involvement in the crash.	1 No Fire 2 Fire occurred in vehicle during crash
V43	Crash Avoidance Maneuver	The maneuver that the driver executed to attempt to avoid the crash.	1 No avoidance maneuver reported 2 Braking (skidmarks evident) 3 Braking (no skidmarks, driver stated) 4 Braking (other reported evidence) 5 Steering (evidence or stated) 6 Steering and Braking (evidence or stated) 7 Other avoidance maneuver 8 Not reported (by police)
V44	Number of Deaths	The number of fatalities that occurred in the specific vehicle.	Actual number of fatalities (0-99)

APPENDIX B ROADSIDE HAZARD RATING

Roadside Hazard Rating – A subjective measure of the hazard associated with the roadside environment. The rating values indicate the accident damage likely to be sustained by errant vehicles on a scale from one (low likelihood of an off-roadway collision or overturn) to seven (high likelihood of an accident resulting in a fatality or severe injury).

The ratings are determined from a 7-point rural pictorial scale, as shown in Figures 1 through 7. The data collector should choose the rating value (1 through 7) that most closely matches the roadside hazard level for the roadway section in question. In many cases, the roadside hazard along a section will vary considerably, so the roadside hazard rating should represent a "middle" value (e.g., if ratings generally range from 4 to 6 along a section, a rating of 5 should be used to best represent the roadside hazard rating of the section).

Roadside Hazard Rating = 1

Figure 1. Rural roadside hazard rating of 1.

- Wide clear zones greater than or equal to 30 feet from the pavement edge line
- Sideslope flatter than 1:4
- Recoverable

Roadside Hazard Rating = 2

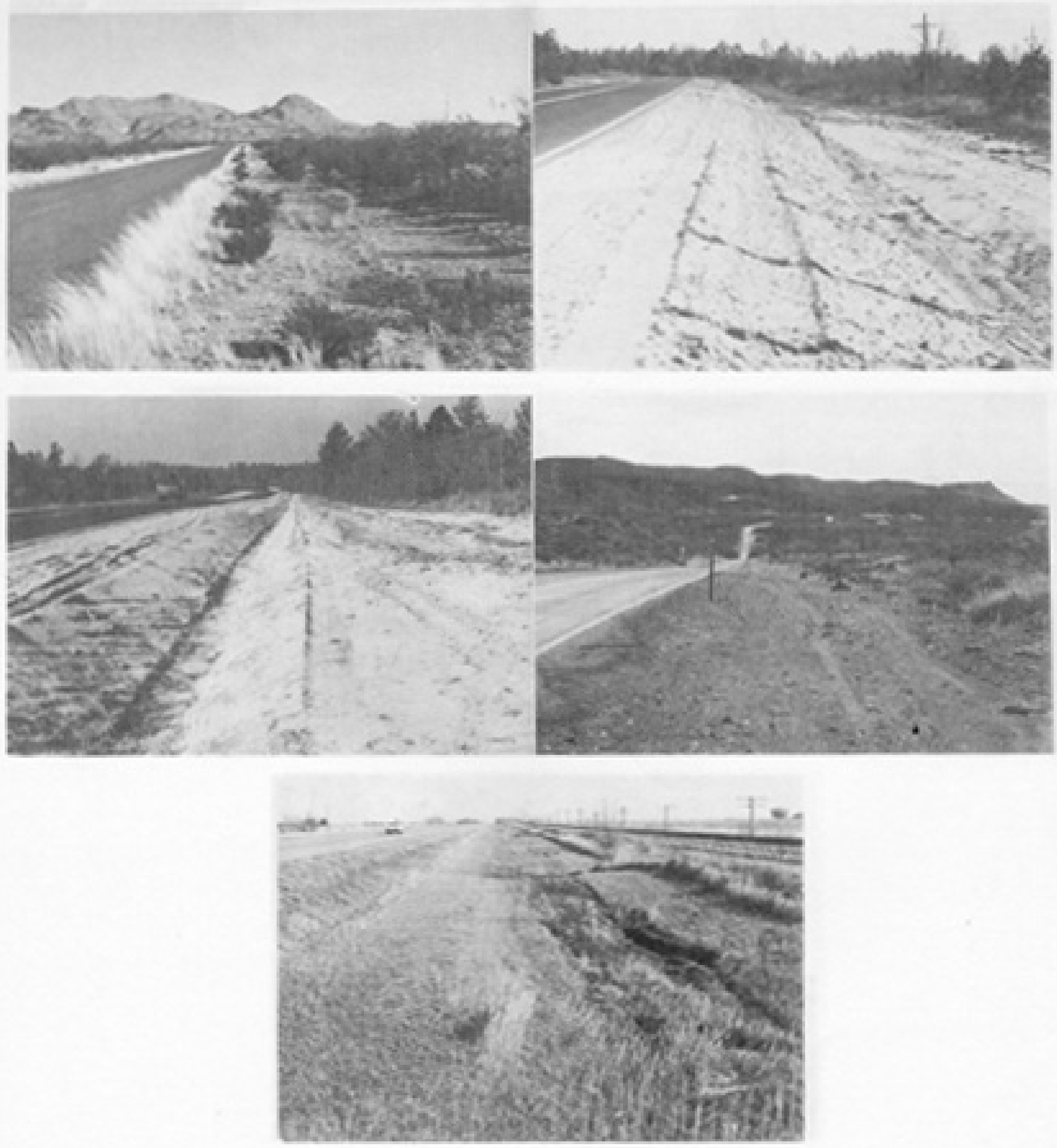


Figure 2. Rural roadside hazard rating of 2.

- Clear zone between 20 and 25 feet from pavement edge line
- Sideslope 1:4
- Recoverable

Roadside Hazard Rating = 3

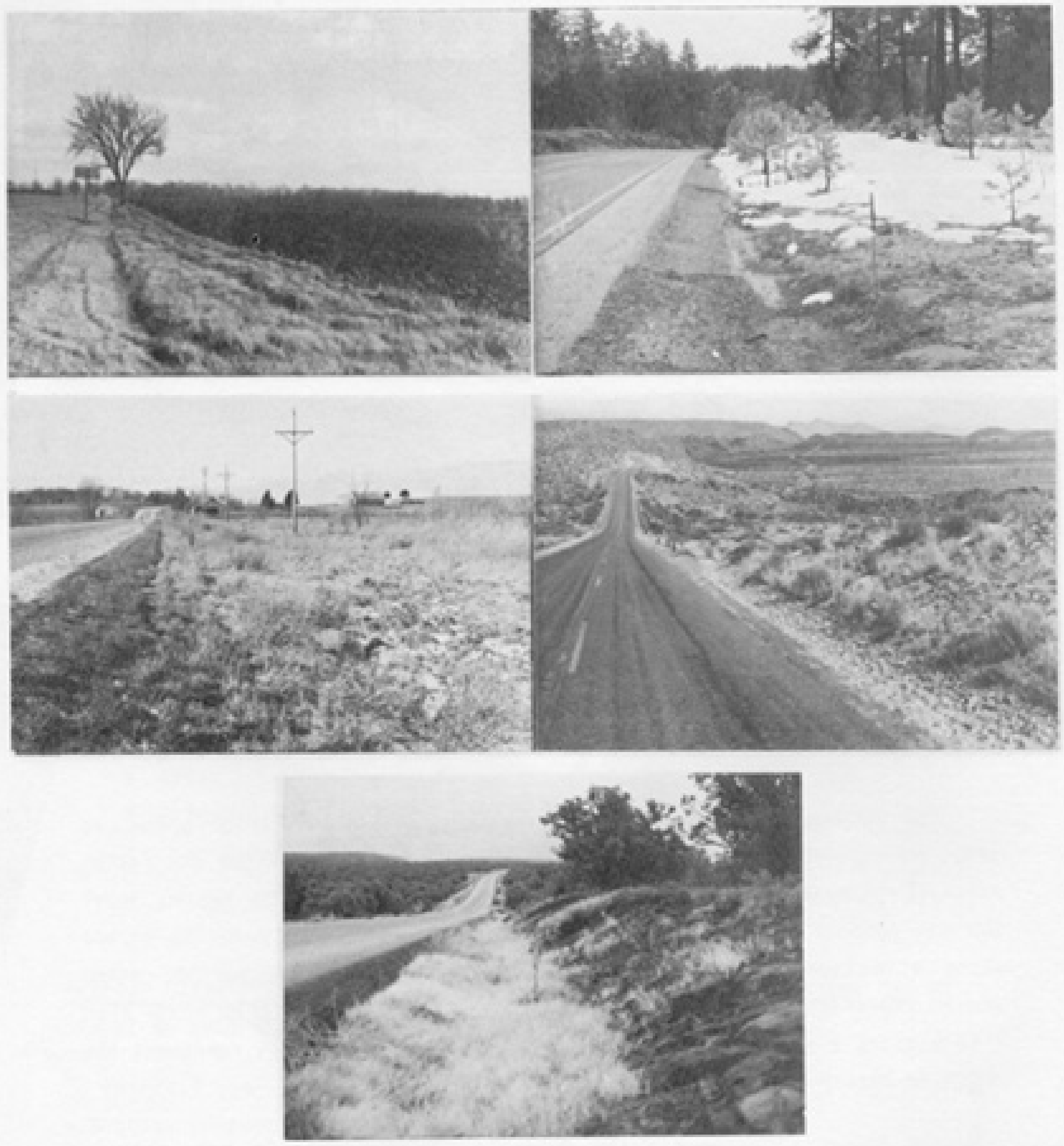


Figure 3. Rural roadside hazard rating of 3.

- Clear zone about 10 feet from pavement edge line
- Sideslope about 1:3 or 1:4
- Rough roadside surface
- Marginally recoverable

Roadside Hazard Rating = 4

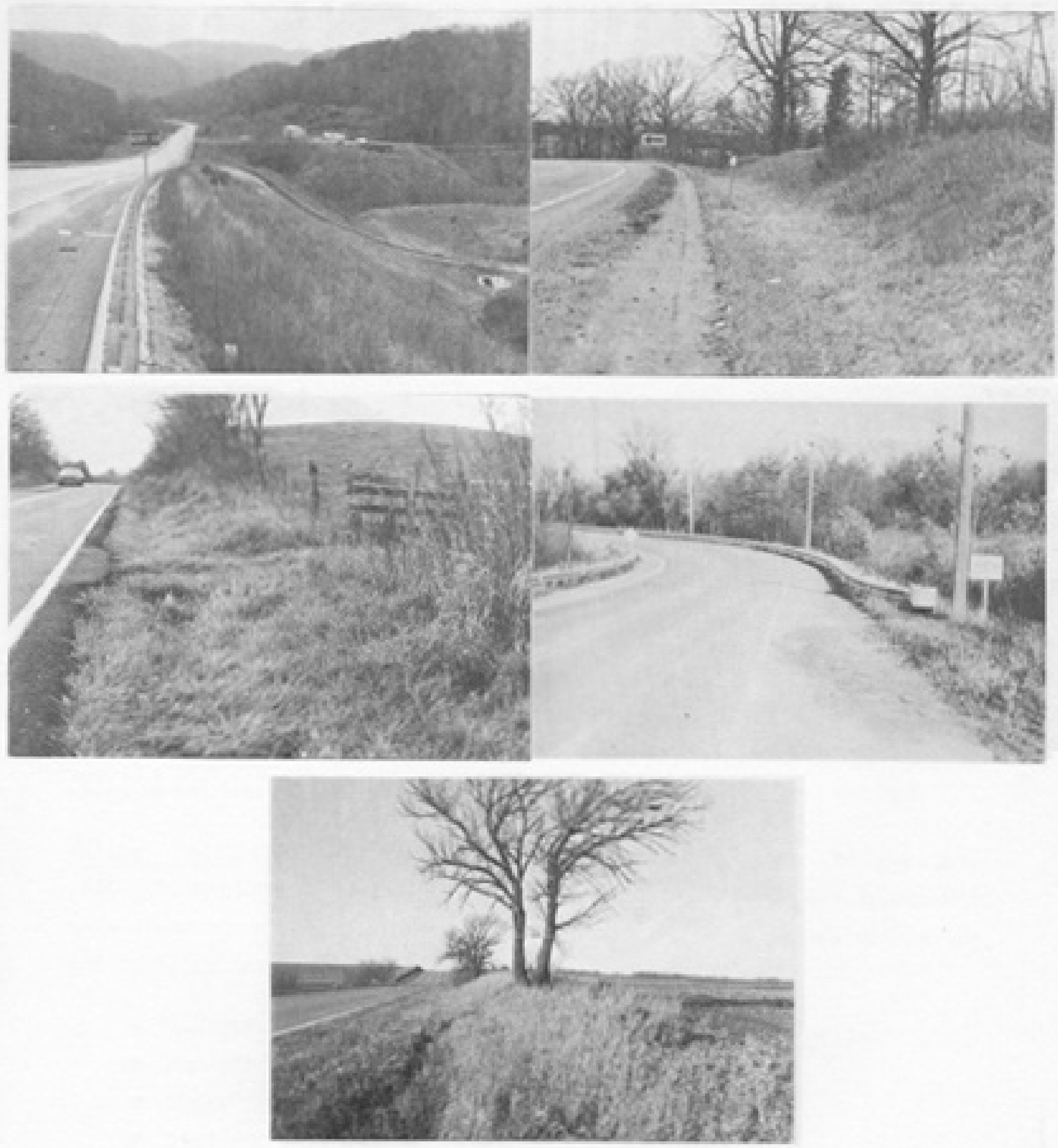


Figure 4. Rural roadside hazard rating of 4.

- Clear zone 5 to 10 feet from pavement edge line
- Side slope about 1:3 or 1:4
- May have guardrail (1.5 to 2 m [5 to 6.5 feet] from pavement edge line)
- May have exposed trees, poles, or other objects (about 10 feet from pavement edge line)
- Marginally forgiving, but increased chance of a reportable roadside collision

Roadside Hazard Rating = 5

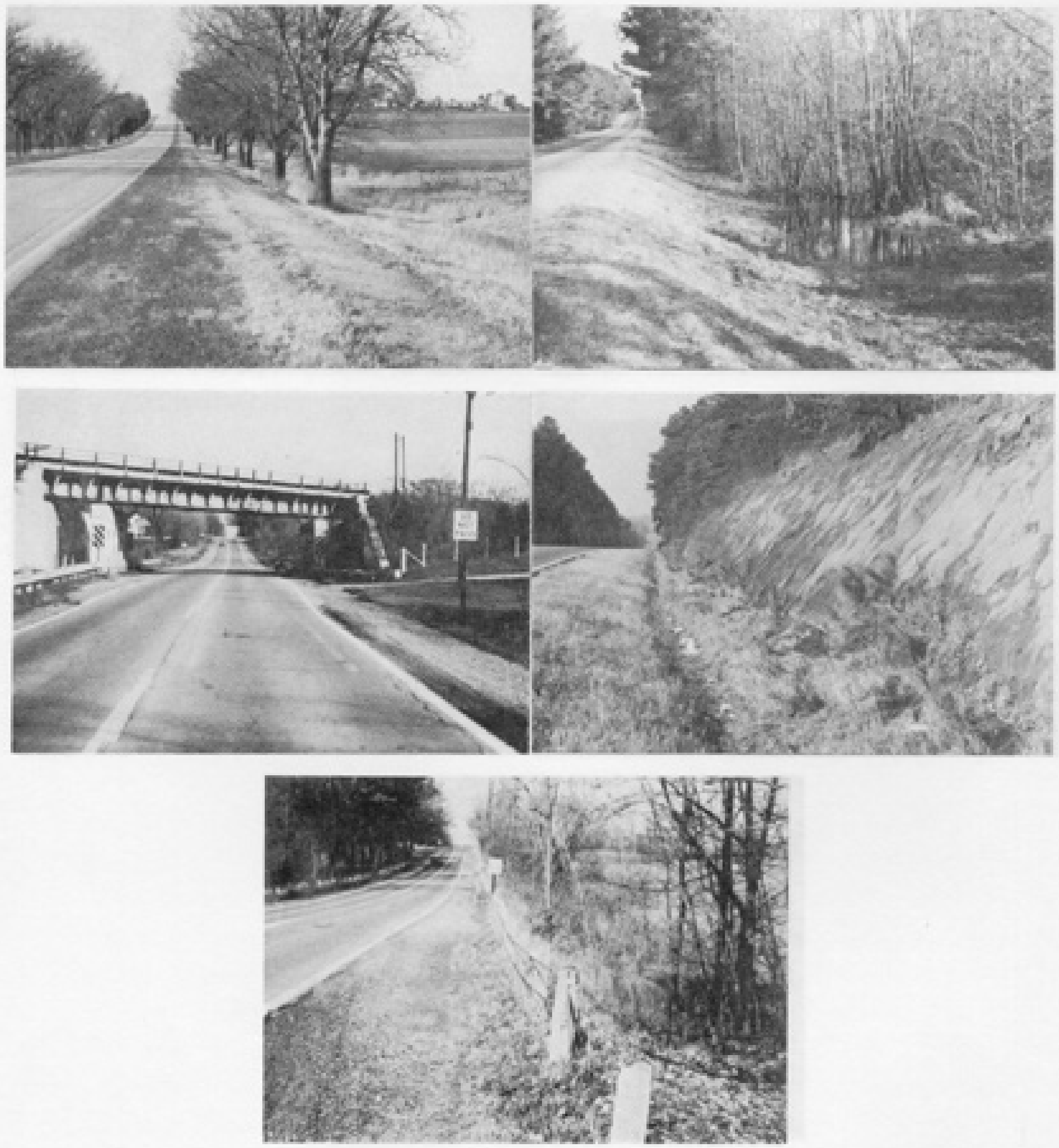


Figure 5. Rural roadside hazard rating of 5.

- Clear zone 5 to 10 feet from pavement edge line
- Side slope about 1:3
- May have guardrail 0 to 5 feet from pavement edge line)
- May have rigid obstacles or embankment within 6.5 to 10 feet of pavement edge line
- Virtually non-recoverable

Roadside Hazard Rating = 6

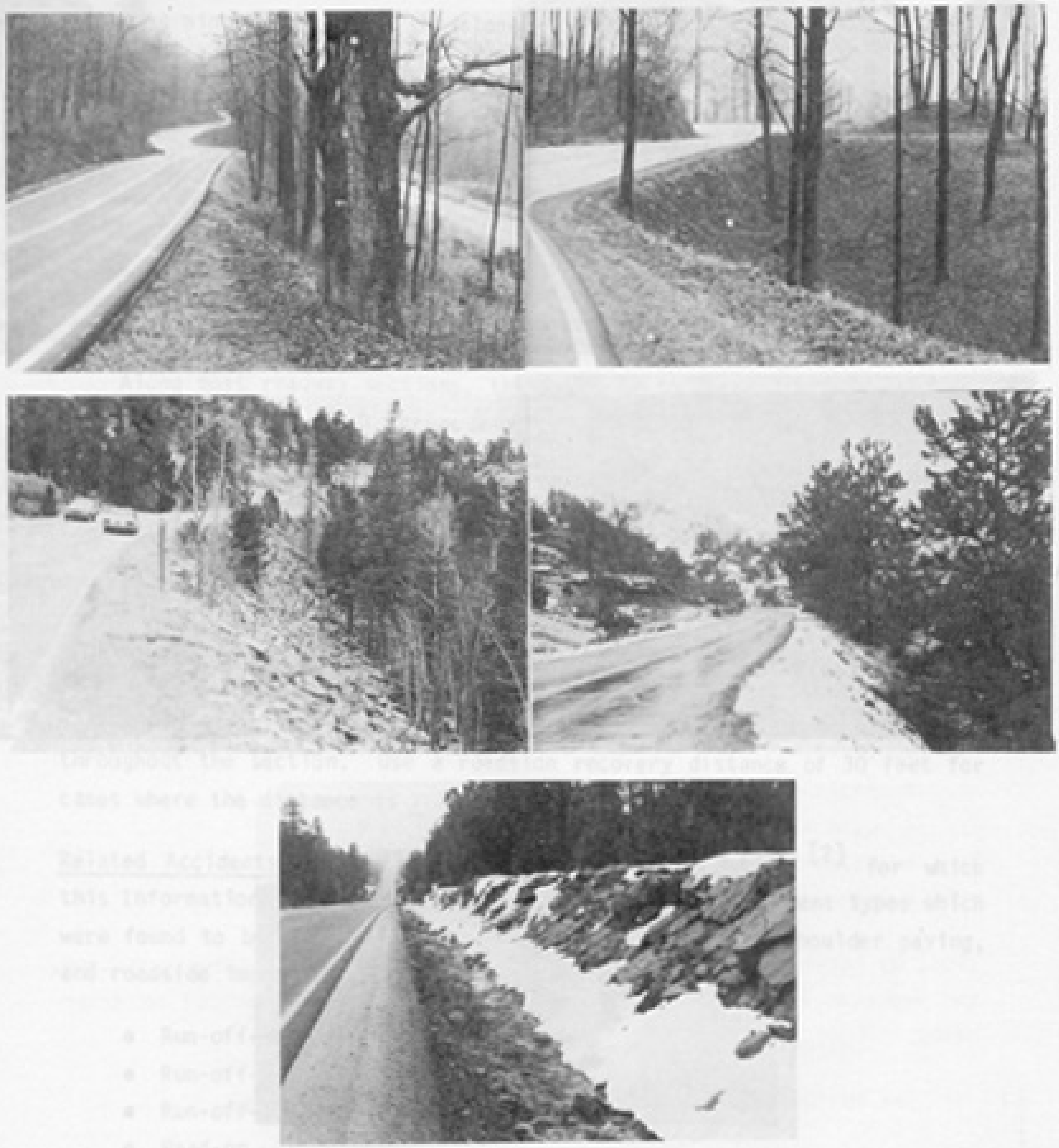


Figure 6. Rural roadside hazard rating of 6.

- Clear zone less than or equal to 5 feet
- Side slope about 1:2
- No guardrail
- Exposed rigid obstacles within 0 to 6.5 feet of the pavement edge line
- Non-recoverable

Roadside Hazard Rating = 7

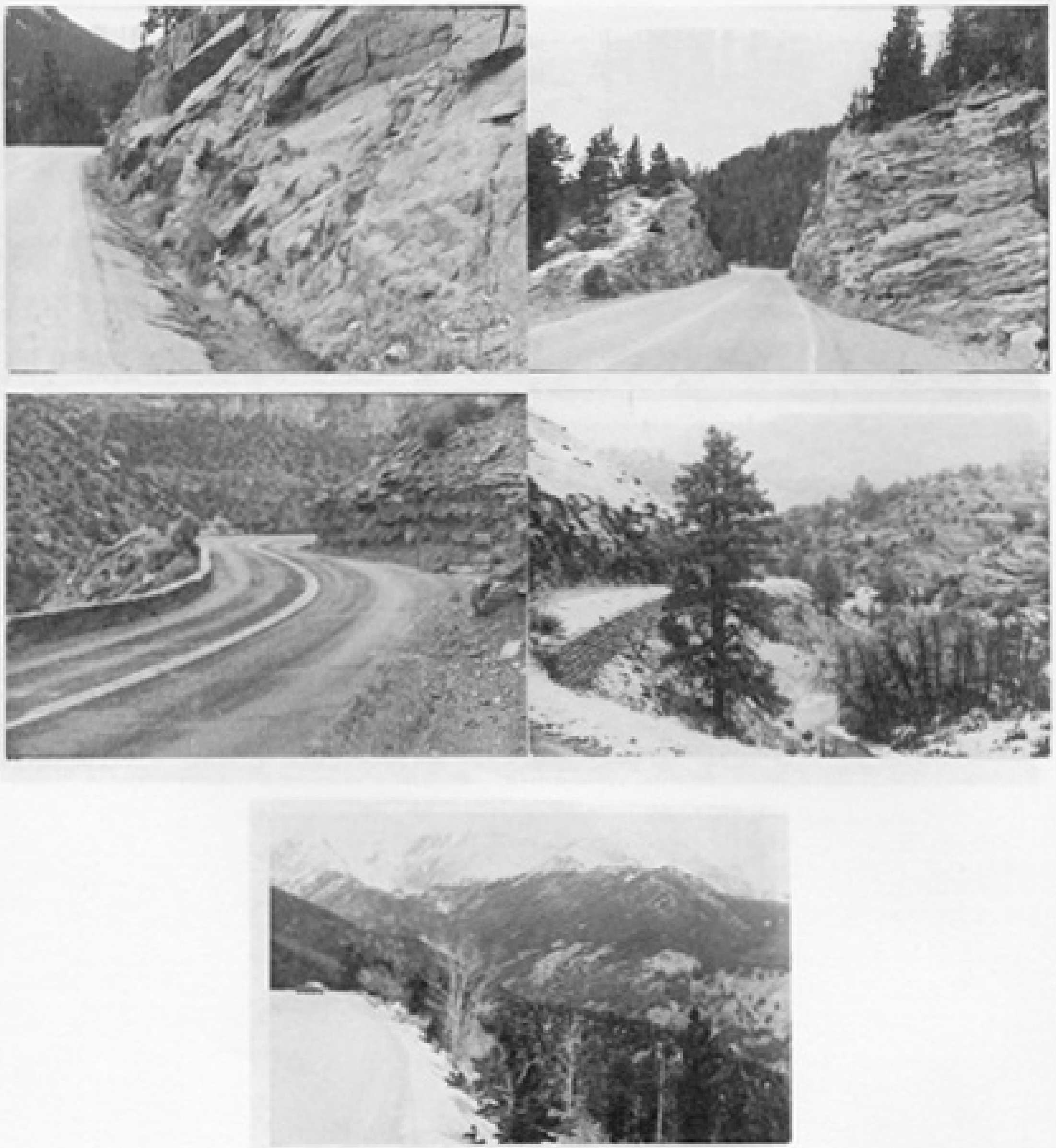


Figure 7. Rural roadside hazard rating of 7.

- Clear zone less than or equal to 5 feet
- Side slope 1:2 or steeper
- Cliff or vertical rock cut
- No guardrail
- Non-recoverable with high likelihood of severe injuries from roadside collision

REFERENCES

Abdel-Aty and Abdelwahab. Development of Artificial Neural Network Models to Predict Driver Injury Severity in Traffic Accidents at Signalized Intersections. Transportation Research Record 1746: 6-1; 2001.

Al-Ghamdi, A. S. Using Logit Regression to Estimate the Influence of Crash Factors on Crash Severity. Crash Analysis and Prevention 34: 729-741; 2002.

Ben-Akiva, M., and Lerman, S. R. Discrete Choice Analysis: Theory and Application to Travel Demand. The MIT Press. 1985.

Carson, J., and Mannering, F. The Effects of Icing Warning Signs on Ice-crash Frequencies and Severities. Crash Analysis and Prevention 33: 99-109; 2001.

Dixon, K., Hausman, J. and Lewis, A. "Analysis of Fatal Crashes at Utility Pole Locations in Georgia for 1999 and 2000." Georgia Institute of Technology, Georgia Transportation Institute, prepared for The Southern Company, 2002.

Evans, L. Double pair comparison – a new method to determine how occupant characteristics affect fatality risk in traffic crashes. Crash Analysis and Prevention 18: 217-228; 1986.

Eugene, R., Hani,M., and Rafel, M. Guidelines for the Removal of Bridge Rail on Low Volume Roads. Proceedings of the 42nd Annual Meeting of the Transportation Research Forum: 7-28; 2000.

Golob, T. F. and Recker, W. Relationships among Urban Freeway Accidents, Traffic Flow, Weather, and Lighting Conditions. Journal of Transportation Engineering 129 (4): 342-353; 2003.

Groeger, J. A., and Rothengatter, J. A. Traffic Psychology and Behaviour. Transportation Research Part F 1: 1-9; 1998.

Harwood, D.W. Council, F.M. Hauer, E. Hughes, W.E. Vogt, A. Prediction of the Expected Safety Performance of Rural Two-lane highways. FHWA-RD-99-207; 2000.

Kim K., Nits, L., Richardson J., and Li, L. Personal and Behavioral Predictors of Automobile Crash and Injury Severity. Crash Analysis and Prevention 27: 469-481; 1995.

Kloeden, CN., McLean, AJ, Baldock, MRJ, and Cockington, AJT. Severe and Fatal Car Crashes Due to Roadside Hazards. NHMRC Road Crash Research Unit. 1999.

Kockelman, K. M., and Kweon, Y. J. Driver Injury Severity: an Application of Ordered Probit Models. Crash Analysis and Prevention 34: 313-321; 2002.

Lee, J. and Mannering, F. Impact of Roadside Features on the Frequency and Severity of Run-Off-Roadway Crashes: An Empirical Analysis. Crash Analysis and Prevention 34: 149-161; 2002.

Long, S. J. Regression Models for Categorical and limited Dependent Variables. Sage Publications. 1997.

McCarthy, P. and Talley, W. K. Safety Investments, Behaviours, and Injury Severity. Applied Economics 33: 701-710; 2001.

McFadden, D. Conditional Logit Analysis of Qualitative Choice Behavior. Frontiers in Economics. Academic Press. 1973.

National Highway Traffic Safety Association (NHTSA). Traffic Facts. 1996.

National Highway Traffic Safety Association (NHTSA). Traffic Facts. 2003.

National Highway Traffic Safety Association (NHTSA). Traffic Facts. 2004.

O'Donnell, C. J., and Connor, D. H. Predicting the Severity of Motor Vehicle Crash Injuries Using Models of Ordered Multiple Choice. Crash Analysis and Prevention 28: 739-753; 1996.

Parker, D. West, R., Stradling, S., Manstead, S. R. Behavioural Characteristics and Involvement in Different Types of Traffic Crash. Crash Analysis and Prevention 27: 571-581; 1995.

Shankar, V., Mannering, F. and Barfield, W. Statistical Analysis of Crash Severity on Rural Freeways. Crash Analysis and Prevention 28: 391-401; 1996.

Stockburger D. W. Multivariate Statistics: Concepts, Models, and Applications. Southwest Missouri State University. 1998.

The Hartford Loss Control Department. Fatigue: Its Impact on Motor Vehicle Crashes. http://mb.thehartford.com/insurance_info/pdfs/331-002.pdf: 2002.

Traynor, L. The Impact of Driver Alcohol Use on Crash Severity: A Crash Specific Analysis. Transportation Research. Part E: Logits & Transportation Review 41 (5): 421-437; 2005.

Ulfarsson, G. F., Mannering, F. Differences in Male and Female Injury Severities in Sport-Utility Vehicle, Minivan, Pickup and Passenger Car Crashes. Crash Analysis and Prevention 36: 135-147; 2004.

Washington, S., Metarko, J., Fomunung, I., Ross, R., Julian, F., Moran, E. An Inter-regional Comparison: Fatal Crashes in the Southeastern and Non-southeastern United States: Preliminary Findings. Crash Analysis and Prevention 31: 135-146; 1999.

Zegeer, C., Council, F. Safety Relationships Associated with Cross Sectional Roadway Elements. Transportation Research Record 1512: 29-36; 1995.

Zegeer, C. V., Reinfurt, D. W. Hummer, J. Herf,L. and Hunter, W. Safety Effects of Cross-Section Design for Two-Lane Roads. Transportation Research Record 1195: 20-32; 1988.