

Effect of Speed Limit Increase on Crash Rate on Rural Two-Lane Highways in Louisiana

Technical Assistance Report Number 07-1TA

by

Chester G. Wilmot
Athira S. Jayadevan

Department of Civil & Environmental Engineering and
Louisiana Transportation Research Center
Louisiana State University
Baton Rouge, Louisiana 70803

LTRC Project No. 96-1PLAN
State Project No. 736-99-0285

Conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

The contents of this report reflect the views of the author/principal investigator who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Louisiana Department of Transportation and Development or the Louisiana Transportation Research Center. This report does not constitute a standard, specification, or regulation.

August 2006

ABSTRACT

This study investigated the impact of a speed limit increase on the crash rate on rural two-lane roads in Louisiana. The Louisiana crash database for 1999-2004 was used to compare rates of different crash severities and types before and after a speed limit change on rural roads during the observation period. The comparison was made among homogeneous data groups established using a classification procedure that sought to control as many of the other factors contributing to the high crash rate on rural two-lane roads as possible. The natural trend in crash rates was observed by first dividing the road sections in the data into both those that had experienced a speed limit change in the last five years and those that had not, and then observing the crash trend among those that had not had any speed limit change. The speed limit change group was divided into before and after speed change sections, and the after speed change crash rate values were adjusted for any significant trend in the corresponding no speed limit change cases. These final before and after crash rate values adjusted for the trend were compared statistically to test the null hypothesis that crash rate does not increase with speed limit increase. Based on the results, the null hypothesis that an increase in speed limit had no impact on crash rate was rejected for 6 out of the 39 cases at the 5 percent level of significance. The cases that were found to be significantly affected by an increase in speed limit included run off road, rear-end, and single-vehicle crashes involving no impact with another object or impact with a fixed object, animal, cyclist, or pedestrian.

ACKNOWLEDGMENTS

The assistance of Dr. Helmut Schneider of the Department of Information Services and Decision Sciences in the Ourso College of Business at Louisiana State University, and Dr. Xiaoduan Sun of the Department of Civil Engineering at the University of Louisiana at Lafayette in obtaining the data used in this study is gratefully acknowledged.

IMPLEMENTATION STATEMENT

The results of this study will aid decision-makers in Louisiana in deciding if increasing the speed limits on the state's rural two-lane highways from the existing 55 miles per hour to a higher unspecified speed limit is advisable.

TABLE OF CONTENTS

| | |
|--|------|
| ABSTRACT..... | iii |
| ACKNOWLEDGMENTS | v |
| IMPLEMENTATION STATEMENT | vii |
| TABLE OF CONTENTS..... | ix |
| LIST OF TABLES | xi |
| LIST OF FIGURES | xiii |
| INTRODUCTION | 1 |
| Background..... | 1 |
| Problem Statement..... | 2 |
| OBJECTIVE | 3 |
| SCOPE | 5 |
| LITERATURE REVIEW | 7 |
| Federal and State Speed Limit Law Changes | 7 |
| Speed Limit Setting Practices | 8 |
| Speed Limit Statutes in Louisiana | 10 |
| Practice in Other States..... | 11 |
| Speed and Speed Limits..... | 13 |
| Review of Studies on Speed Limits and Safety | 15 |
| Influences of Speed Limits on Safety | 26 |
| Cost and Benefit of Speed Limit Increase | 28 |
| METHODOLOGY | 31 |
| Research Hypothesis..... | 32 |
| Data | 32 |
| Categorization of Crash Types Using Cross-Classification | 34 |
| Cross-Classification Analysis | 36 |
| Dependent and Independent Variables | 39 |
| Classification Procedure Using Answer Tree 1.0..... | 40 |
| Division into “No Speed Change” and “Speed Change” Group | 50 |
| Plotting of Trends | 51 |
| Adjustment for Trends in Crash Rate | 51 |
| Paired T-test Comparison | 54 |
| ANALYSIS AND DISCUSSION OF RESULTS | 55 |
| Answer Tree Analysis..... | 55 |
| Results of Trend Analysis on No Speed Change Group..... | 64 |
| Results of Adjustment of “After” Group for Trend over Time | 67 |
| Results of Paired T-Test Comparison..... | 69 |
| CONCLUSIONS..... | 73 |
| Study Summary..... | 73 |
| Conclusions..... | 74 |
| RECOMMENDATIONS | 79 |
| REFERENCES | 81 |

LIST OF TABLES

| | |
|--|----|
| Table 1: Speed limit practice in other states | 11 |
| Table 2: Increased driver speeds resulting from 10 mph increase in speed limit..... | 27 |
| Table 3: Summary of studies on effect of speed limit decreases | 27 |
| Table 4: Summary of studies on effect of speed limit decreases | 28 |
| Table 5: Annual economic costs of speed-related crashes | 29 |
| Table 6: Description of manner of collision in field categories | 35 |
| Table 7: Description of type of accident field categories | 35 |
| Table 8: Results of cross-classification analysis on fatality group..... | 37 |
| Table 9: Results of cross-classification analysis on injury group..... | 38 |
| Table 10: Results of cross-classification analysis on PDO group | 39 |
| Table 11: Gain summary of classification analysis on run-off road fatal crashes | 56 |
| Table 12: Risk summary | 57 |
| Table 13: Summary of model performances..... | 64 |
| Table 14: Results of trend analysis | 65 |
| Table 15: Crash rate for rear end injury of homogeneous group 5..... | 67 |
| Table 16: Crash rate for non-motor vehicle injuries of homogeneous groups 2 and 3..... | 68 |
| Table 17: Crash rate for rear end PDO crashes of homogeneous group 3..... | 68 |
| Table 18: Statistical comparison of homogeneous group crash rates | 70 |
| Table 19: Estimated annual cost of an increase in speed limit | 77 |

LIST OF FIGURES

| | |
|---|----|
| Figure 1: Results of Solomon’s Study (Solomon, 1964) | 18 |
| Figure 2: Crash Rates As a Function of Deviation from Average Traffic Speed | 20 |
| Figure 3: Crash Involvement Rates Including and Excluding Turning Vehicles | 21 |
| Figure 4: Tree Map | 49 |
| Figure 5: Classification Tree Showing the Nodes | 50 |
| Figure 6: Crash Rate Before and After Speed Limit Change in 2001 | 53 |
| Figure 7: Crash Rate Change Showing Original and Adjusted Crash Rates | 53 |
| Figure 8: Classification Analysis Model for Run-off Road Fatal Crashes | 58 |

INTRODUCTION

Background

Safety is the primary reason for setting speed limits. Often, while setting appropriate speed limits, attempts are made to strike an appropriate societal balance between travel time and risk for a road class or specific highway section. The posted speed limits thus inform motorists of the maximum legal driving speeds considered reasonable and safe for a road class under favorable conditions of good weather, free-flowing traffic, and good visibility. Drivers are expected to reduce speeds as these conditions deteriorate. However, motorists often exceed the legal posted speed limits. This problem is prevalent on the nation's less traveled rural two-lane highways. Rural roads make up approximately 77 percent of the roadway in the United States, or, about 3.1 million miles out of more than 3.9 million miles. While more than half of the nation's traffic fatalities from 1990 to 2003 occurred on rural, non-Interstate routes, only 28 percent of the nation's total vehicle travel occurred on these routes during this period.

In 1995, the United States Congress repealed the National Maximum Speed Limit of 55 mph, which had been in effect since 1974 when it was started as a fuel-saving measure. Congress returned authority to the states to set their own speed limits on major highways. Following this action, Louisiana set the maximum speed limit on rural and urban limited access interstates to 70 mph and on other roads to 55-60 mph, effective from August 15, 1997 (IIHS, 2005). However, the speed limit on the rural highways remained at 55 mph.

The Louisiana Senate raised the possibility of increasing the speed limit on the two-lane rural highways. In response, Louisiana State University was requested to conduct a

study to estimate the impact of increasing the maximum speed limit on the rural two-lane highways in Louisiana. The study involved conducting a literature review of national and international speed limit practices, an inventory of current practices in Louisiana, and a review of other studies on this issue. The study also involved analyzing crash records on two-lane highways in Louisiana that had experienced speed limit increases in the past.

Problem Statement

Highway safety is a critical issue in Louisiana. Approximately 160,000 crashes occur in the state each year, over 90,000 of which are on the state-maintained highway system. On an average, more than 900 people are killed and about 80,000 injured in automobile crashes in Louisiana each year. As of 2003, Louisiana controlled 60,937 miles of public road serving about 102,585 vehicle miles a day, consisting of 46,987 miles of rural roads and 13,950 miles of urban roads. This includes 904 miles of freeway, 1,345 miles of divided multilane highway and over 59,000 miles of undivided, predominantly two-lane roads (FHWA, 2003). Only about 15 percent of the fatal crashes occur on the interstates and other limited access highways, while 48 percent of fatal crashes and 35 percent of injury crashes occur on the remaining state-controlled highways (LHSC, 2003). As the majority of these crashes occur on two-lane rural roads, increasing the speed limit on these roads could potentially pose a threat to overall highway safety.

OBJECTIVE

The objective of this study was to determine the potential impact of increasing the speed limit on rural two-lane highways in Louisiana from the current 55 mph speed limit to an unspecified higher speed limit. This was achieved by analyzing the safety record of two-lane road sections in Louisiana before and after they experienced an increase in speed limits. Since road safety is affected by multiple factors, the analysis was constructed to reduce the impact of extraneous factors as much as possible, leaving the impact of speed limit increase to be measured in the analysis.

SCOPE

The scope of this study was limited to the rural two-lane undivided roadways in the state of Louisiana with speed limits of 55 mph. The data were obtained from the police crash reports on all crashes that occurred on the rural two-lane roadways in the state from 1999 to 2004.

LITERATURE REVIEW

Presented below are an overview of the current speed limit laws; the various speed limit setting practices in Louisiana, other states, and internationally; trends in rural road conditions and crashes; the relationship between speed and speed limits; and a review of the various studies on speed limit increase and its impact on safety.

Federal and State Speed Limit Law Changes

In 1974, the United States set a National Maximum Speed Limit (NMSL) of 55 miles per hour (mph) as a fuel-saving measure. Previously, states were given the authority to set their own speed limits, and limits of 65 mph and 70 mph were posted on most of the United States' highways. Due to the newly adopted 55 mph speed limit, traffic slowed on all major highways, and the total amount of travel declined. These changes in speed and travel were accompanied by a decrease in the total number of traffic fatalities.

The NMSL was started as an effort to conserve oil following the Arab oil embargo of 1973, but even after that crisis had passed, the NMSL was retained in effect for 13 years, primarily on safety grounds. However, by the mid 1980s, the average highway travel speeds were increasing, and the 55 mph speed limit was increasingly being ignored by drivers. After police agencies and public officials urged for higher speed limits to decrease the long distance travel time, Congress voted in 1987 to allow speed limits to be increased to 65 mph on rural interstate highways in specified experimental states (NHTSA, 1998).

On November 28, 1995, the National Highway System (NHS) Designation Act was signed into law eliminating the Federal mandate for the NMSL, thus giving states complete discretion over setting their speed limits. Within a year of the repeal, 23 states had raised

their rural interstate speed limits to 70 or 75 mph. Montana removed daytime speed limits on its rural interstates altogether and Texas allowed speeds up to 70 mph on almost half of its two-lane “farm-to-market” highways. In response to the repeal of NMSL, Louisiana’s posted maximum limits were raised to 70 mph on rural and urban limited access interstates. However, the speed limit on 2-lane rural highways was retained at 55 mph and 65 mph on divided multilane highways effective August 15, 1997 (IIHS, 2005).

Speed Limit Setting Practices

The relationship between speed limit, driver speed choice, and safety on a given road is complex. Setting appropriate speed limits and related enforcement strategies is the first step in a chain of events that may affect crash probability and crash severity. While setting speed limits, the decision makers attempt to strike an appropriate societal balance between travel time and risk for a road class or specific highway section. Thus, the posted legal limit informs motorists of maximum driving speeds considered reasonable and safe for a road class under favorable conditions.

A study performed by the Transportation Research Board (TRB) in 1998 under the request and funding of the National Highway Traffic Safety Administration (NHTSA), the Federal Highway Administration (FHWA), and the Centers for Disease Control and Prevention, reviewed the current practices for setting and enforcing speed limits on all types of road as described below (TRB, 1998). According to the study, speed limits are one of the oldest strategies for controlling driving speeds. With two exceptions - during World War II and the enactment of the NMSL of 55 mph (89 km/h) in 1974 - setting speed limits in the United States has been the responsibility of state and local governments (TRB, 1998).

The review found that the current framework for speed regulation was developed in the 1920s and 1930s and that each state has a basic statute requiring drivers to operate vehicles at a speed reasonable and prudent for existing conditions. Speed limits are legislated by road class and geographic area and generally, statutory limits apply to all roads of a particular class throughout a political jurisdiction. However, state and most local governments have the authority to change the limits by establishing speed zones for highway sections where statutory limits do not fit specific road or traffic conditions, and to determine alternative maximum speed limits in these zones.

Speed limits are established by state legislatures, city councils, or Congress on the basis of judgment about appropriate trade-offs between public safety, community concerns, and travel efficiency. They are established for favorable conditions like good weather, free-flowing traffic, and good visibility. Drivers are expected to reduce speeds as these conditions deteriorate.

Speed limits in speed zones are determined administratively based on an engineering study, considering factors such as operating speeds of free-flowing vehicles, crash experience, roadside development, roadway geometry, and parking and pedestrian levels. In many speed zones, speed limits are set to coincide with the 85th percentile speed, the speed at or below which 85 percent of drivers travel in free-flow conditions at representative locations on the highway or roadway section. This approach assumes that most drivers are capable of judging the speed at which they can travel safely. Drivers are expected to reduce speeds under deteriorated conditions such as poor visibility, adverse weather, congestion, warning signs, or presence of cyclists and pedestrians, and most state statutes reflect this

requirement. Speed control regulations—both legislated and administratively established maximum speed limits—provide the legal basis for adjudication and sanctions for violations of the law. State and local officials also post advisory speed signs, which do not have the force of law but warn motorists of suggested safe speeds for specific conditions at a particular location (ITE, 1992).

Speed Limit Statutes in Louisiana

The Louisiana State statutes related to speed are summarized here (NHTSA, 2001).

The Basic Speed Rule states that:

No person shall drive a vehicle at a speed greater than is reasonable and prudent under the conditions and potential hazards then existing, having due regard for the traffic on, and the surface and width of, the highway, and the condition of the weather. Louisiana Revised Statute (RS) 32:64(A)

Statutory maximum speed limit:

- I. 70 MPH on interstate or controlled access highways (RS 32:61(B) & 32:62(A)),
- II. 65 MPH on other multi-lane divided highways which have partial or no control of access (RS 32:61(B) & 32:62(A)), and
- III. 55 MPH on other highways (RS 32:61(A) & 32:62(A)).

Posted (Maximum) Speed Limit:

- I. Based on engineering and traffic investigations, the State may increase or decrease the above speed limits (RS 32:63(A)).
- II. The State can promulgate regulations regulating speed on Louisiana expressways (RS 48:1272).

III. Local governments are authorized to establish speed limits or speed zones.

However, no speed limit shall be established in excess of the above maximum limits

(RS 32:41(A)(9), 32:42 & 40:403).

Minimum Speed Limit:

I. No person shall operate a motor vehicle at such slow a speed as to impede the normal and reasonable movement of traffic (RS 32:64(B)).

Practice in Other States

The current speed limits for each state and the date of implementing the most recent rural freeway limit change are given in Table 1 below:

**Table 1
Speed limit practice in other states**

| State | Date | New Speed Limit (mph) | | | |
|-------------|-----------|-----------------------|-------------------|-------------------|-------------------|
| | | Rural Freeway | Divided Highway | Undivided Highway | Urban Freeway |
| Alabama | 9 May 96 | 70 | 65 | 55 | 65 |
| Alaska | 15 Jan 88 | 65 | 55 | 55 | 55 |
| Arizona | 8 Dec 95 | 75 | 55 | 55 | 55 |
| Arkansas | 19 Aug 96 | 70 65 (trucks) | 55 | 55 | 55 |
| California | 7 Jan 96 | 70 55 (trucks) | 65 55 (trucks) | 65 55 (trucks) | 65 55 (trucks) |
| Colorado | 24 Jun 96 | 75 | 65 | 65 | 55 |
| Connecticut | 1 Oct 98 | 65 | 55 | 50 | 55 |
| Delaware | Jan 96 | 65 | 55 | 50 | 55 |
| Florida | 8 Apr 96 | 70 | 65 | 55 | 55 |
| Georgia | 1 Jul 96 | 70 | 65 | 55 | 65 |
| Hawaii | N/A | 55 | 55 | 45 | 55 |
| Idaho | 1 May 96 | 75 65 (trucks) | 65 | 65 | 55 |
| Illinois | 27 Apr 87 | 65 55 (trucks) | 65 55 (trucks) | 55 | 65 55 (trucks) |
| Indiana | 1 Jun 87 | 65 60 (trucks) | 55 | 55 | 55 |

| | | | | | |
|------------------|------------------|--|--|---------------------------------------|--------------------------|
| Iowa | 12 May 87 | 65 | 55 | 55 | 65 |
| Kansas | 7 Mar 96 | 70 | 70 | 65 | 55 |
| Kentucky | 8 Jun 87 | 65 | 55 | 55 | 55 |
| Louisiana | 15 Aug 97 | 70 | 65 | 55 | 60 |
| Maine | 12 Jun 87 | 65 | 55 | 55 | 55 |
| Maryland | 1 Jul 95 | 65 | 55 | 55 | 60 |
| Massachusetts | 5 Jan 92 | 65 | 65 | 55 | 65 |
| Michigan | 1 Aug 96 | 70 55 (trucks) | 55 | 55 | 65 55 (trucks) |
| Minnesota | 1 Jul 97 | 70 | 65 | 55 | 65 |
| Mississippi | 29 Feb 96 | 70 | 55 | 55 | 60 |
| Missouri | 13 Mar 96 | 70 | 70 | 60 | 60 |
| Montana | 28 May 99 | 75 65 (trucks) | 55 | 55 | 55 |
| Nebraska | 1 Jun 96 | 75 | 65 | 60 | 55 |
| Nevada | 8 Dec 95 | 75 | 70 | 70 | 65 |
| New Hampshire | 16 Apr 87 | 65 | 55 | 55 | 55 |
| New Jersey | 19 Jan 98 | 65 | 55 | 50 | 55 |
| New Mexico | 15 May 96 | 75 | 70 | 65 | 55 |
| New York | 1 Aug 95 | 65 | 55 | 55 | 65 |
| N. Carolina | 5 Aug 96 | 70 | 55 | 55 | 65 |
| North Dakota | 10 Jun 96 | 70 | 65 55 (trucks) | 65 55 (trucks) | 55 |
| Ohio | 15 Jul 87 | 65 55 (trucks) | 65 55 (trucks) | 55 | 65 55 (trucks) |
| Oklahoma | 29 Aug 96 | 75 60 (trucks) 55 (night, trucks) 65 (school bus) | 70 (day) 65 (night) 60 (trucks) 55 (night, trucks) 50 (school bus) | 65 (day) 55 (night) 55 (trucks) | 60 55 (night, trucks) |
| Oregon | 27 Jun 87 | 65 55 (trucks) | 55 | 55 | 55 |
| Pennsylvania | 13 Jul 95 | 65 | 55 | 55 | 55 |
| Rhode Island | 12 May 96 | 65 | 55 | 50 | 55 |
| S. Carolina | 30 Apr 99 | 70 | 55 | 55 | 55 |
| South Dakota | 1 Apr 96 | 75 65 (trucks) | 65 55 (trucks) | 65 55 (trucks) | 55 |
| Tennessee | 25 Mar 98 | 70 | 65 | 55 | 65 |
| Texas | 8 Dec 95 | 70 (day) | 70 (day) | 70 (day) | 70 (day) |

| | | | | | |
|---------------|-----------|--|--|--|--|
| | | 65 (night) 60 (trucks) 55 (night, trucks) 50 (school bus) | 65 (night) 60 (trucks) 55 (night, trucks) 50 (school bus) | 65 (night) 60 (trucks) 55 (night, trucks) 50 (school bus) | 55 (night) 55 (trucks) 55 (night, trucks) 50 (school bus) |
| Utah | 1 May 96 | 75 | 65 | 55 | 65 |
| Vermont | 21 Apr 87 | 65 | 55 | 50 | 55 |
| Virginia | 1 Jul 88 | 65 | 55 | 55 | 55 |
| Washington | 15 Mar 96 | 70 60 (trucks) | 70 60 (trucks) | 65 60 (trucks) | 60 |
| West Virginia | 25 Aug 97 | 70 | 65 | 55 | 60 |
| Wisconsin | 17 Jun 87 | 65 | 55 | 55 | 55 |
| Wyoming | Dec 95 | 75 | 65 | 65 | 60 |

Speed and Speed Limits

Relationship between Design Speed, Operating Speed, and Maximum Speed

Posting appropriate speed limits are necessary to ensure a reasonable level of safe and efficient travel on highways and streets. An unrealistic posted speed limit generally reduces driver compliance rates, and in turn increases the number of accidents, related injuries, and fatality rates (Najjar et al., 2000). The practice of speed control was founded on the assumption that controlling speeds reduces the number and the severity of crashes. However, a compromise is reached between the desires to maximize efficiency of travel and to exercise control over travel speeds. Thus, a proper distinction between the various kinds of speed, such as design speed, operating speed, and the 85th percentile speed, and the importance of each in setting speed limit was defined.

Design consistency on two-lane rural highways has been assumed to be provided through the selection and application of a design speed (FHWA, 2000). AASHTO defines the design speed as “the maximum safe speed that can be maintained over a specified section

of highway when conditions are so favorable that the design features of the highway govern.”

One weakness of the design-speed concept is that it uses the design speed of the most restrictive geometric element within the section, usually a horizontal or vertical curve, as the design speed of the road and does not explicitly consider the speeds that motorists travel on tangents or less restrictive curves (FHWA, 2000).

The AASHTO definition for operating speed is “the highest overall speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section basis.”

A maximum speed limit is posted or set by statute on a highway to inform motorists of the highest speed considered to be safe and reasonable under favorable road, traffic, and weather conditions. The maximum limit should seem high to the majority of drivers, or it is not a maximum limit. When less than ideal conditions exist, the driver must adjust their vehicle speed. The posted speed limit usually sets the maximum speed limit for a roadway such that the operating speed may be above the design speed for a particular location of the roadway.

Setting of Speed Limit with Respect to 85th Percentile Speeds

The 85th percentile speed is commonly used by highway agencies for describing actual operating speeds and establishing speed limits. This is the speed at or below which 85 percent of the traffic is traveling and which according to traffic engineers, reflects the safe speed for given road conditions. The 85th percentile speed is in the speed range with the lowest accident involvement rate, since a study revealed that vehicles traveling one standard

deviation above the average speed under free-flow conditions have the lowest involvement rate; average speed plus one standard deviation is approximately the 85th percentile speed (Agent, Pigman, and Weber, 1998). Vehicles traveling two standard deviations above the average speed have been found to have significantly higher crash rates. The 85th percentile speed is found to accommodate the safe and prudent driver and lowering or increasing the posted speed limit has little effect on the 85th percentile speed. In addition, raising the speed limit to the 85th percentile speed causes no increase in crashes. Speed limits determined by the 85th percentile are favored as they are the most realistic and in turn decrease compliance problems and speed variation and lead to better traffic flow (Thornton and Lyles, 1999).

Review of Studies on Speed Limits and Safety

Speed and the Probability of Crash Involvement

The literature review here attempts to examine the evidence that speeding is linked to the probability of being involved in a crash.

Theoretical Approach: Three theoretical approaches link speed with crash involvement:

(a) The *information processing approach*, which views the driver as an information processor with limited capacity to process information. At higher speeds there is less time for the driver to process information, decide, and act between the time the information is presented to the driver and the time when action must be taken to avoid a crash. A crash is likely to occur when the information processing demands exceed the information processing capabilities of the driver (Shinar, 1978). Unexpected events dramatically increase information processing requirements and hence the probability of a crash. This approach leads to the conclusion that “speed kills”; as more drivers increase their speed, the

probability of information overload increases along with the potential for crashes.

(b) The *traffic conflict approach* assumes that the probability of an individual driver being involved in a multiple-vehicle crash increases as a function of the deviation of that individual driver's speed from the speeds of other drivers. Drivers with speeds much higher or much lower than the median traffic speed are likely to encounter more conflicts (Hauer, 1971). This relationship leads to the conclusion that "speed deviation kills" and the prediction that on roads with equivalent average traffic speeds, crash rates will be higher on roads with wider ranges of speed. The theory relates only to two-lane rural roads.

(c) The *risk-homeostasis motivational approach* looks at speed and crash involvement from the perspective of driver perception of risk. From this point of view, drivers adjust their speed according to the risks they perceive, and they strive to maintain a subjectively acceptable level of risk. The issue is not the link between speed and crash probability but between actual and perceived risk. Thus, driving at high speeds per se is not dangerous, but the danger comes from driving at a speed inappropriate for conditions, stemming from a misperception of the situational demands or the vehicle's handling capabilities or the driver's skills.

Correlational Studies: Several studies attempted to determine if a link exists between speed and crash probability. In the benchmark study conducted by Solomon (1964), travel speeds of crash-involved vehicles obtained from police reports were compared with the average speed of free-flowing traffic on 600 miles of main rural highway, of which three quarters were two-lane highways, with the remainder being four-lane divided highways. Solomon found that crash-involved vehicles were overrepresented in the high- and low-speed

areas of the traffic speed distribution (Solomon, 1964). He found that the daytime involvement rates took the form of a U-shaped curve, which was greatest for vehicles with speeds of 22 mph or less (43,238 per 100 million vehicle miles (mvm), decreasing to a low at about 65 mph (84 per 100 mvm), then increasing somewhat for speeds of at least 73 mph (reaching 139 per 100 mvm). The night-time rates took the same form especially for speeds in excess of 60 mph but they were higher for the lowest speed category (Kloeden, Ponte, and McLean, 2001).

Solomon's well-known U-shaped curve showed that crash involvement rates are lowest at speeds slightly above average traffic speeds. The greater the deviation between a motorist's speed and the average speed of traffic—both above and below the average speed—the greater the chance of involvement in a crash. The correlation between crash involvement rates and deviations from average traffic speed gave rise to the often-cited hypothesis that it is speed deviation, not speed itself, that increases the probability of driver involvement in a crash. Hauer (1971), in his subsequent theory of traffic conflict provided a theoretical basis for Solomon's findings. Solomon's results are reproduced in Figure 1 below.

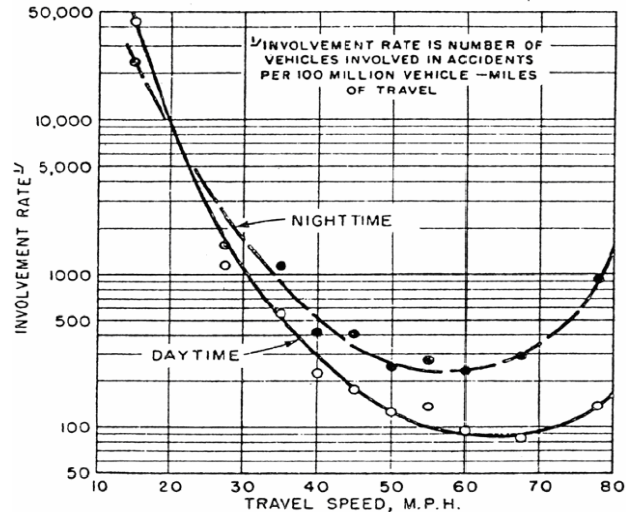


Figure 1
Results of Solomon's Study (Solomon, 1964)

Solomon's U-shaped relationship was replicated by Munden (1967) using a different analytic method on main rural roads in the United Kingdom, by Cirillo (1968) on U.S. Interstate highways, and more recently by Harkey et al. (1990) on rural and urban roads posted at speeds ranging from 25 to 55 mph (40 to 89 km/h) in two U.S. states. All of the U.S. studies, but most particularly Solomon's, have been criticized for their dependence on crash reports for the pre-crash speeds of the crash-involved vehicles, which could bias the results (White and Nelson, 1970)]. Solomon's study has also been criticized for unrepresentative comparative traffic speed data, lack of consistency between the crash and speed data, and combining crash rates of free-flowing and slowing vehicles, which could explain high crash involvement rates at low speeds. When Solomon's data are disaggregated by crash type, the U-shaped relationship is only fully replicated for one crash type—night-time head-on collisions (Cowley 1987).

The Research Triangle Institute (RTI) together with Indiana University addressed several of these issues by using speed data based, in part, on traffic speeds recorded at the time of the crash. They examined crashes on highways and county roads with speed limits of 40 mph (64 km/h) and above and found a similar, but less pronounced, U-shaped relationship between crash involvement and speed. Thus, the RTI study appears to confirm the critical role of deviation from average traffic speeds for crash-involved vehicles.

Several studies have provided alternative explanations for the high crash involvement rates found by Solomon at the low end of the speed distribution, whereas others have simply not found the association. West and Dunn (1971) investigated the relationship between speed and crash involvement, replicating Solomon's U-shaped relationship. However, when crashes involving turning vehicles were removed from the sample, the U-shaped relationship was considerably weakened—the curve became flatter—and the elevated crash involvement rates that Solomon had found at the low end of the speed distribution disappeared; crash involvement rates were more symmetric above and below mean traffic speeds (figure 3). West and Dunn's analysis supports the conclusion that the characteristics of the road are as responsible for creating the potential for vehicle conflicts and crashes as the motorist's driving too slowly for conditions.

A recent Australian study, which examined crash involvement rates as a function of speed on urban arterials as well as on two-lane rural roads, found no evidence of the U-shaped relationship. Crash involvement rates rose linearly as a function of speed. Crash involvements were lowest at speeds below average traffic speeds and highest at speeds above the average with no advantage at the average (Fildes et al., 1991) (figure 2). Furthermore,

the researchers did not find evidence of very low-speed driving that had been apparent in both the Solomon and Cirillo data. The results are based on small sample sizes and self-reported crash involvement. The findings point to a linear and positive association between crash probability and the speed of crash involved vehicles.

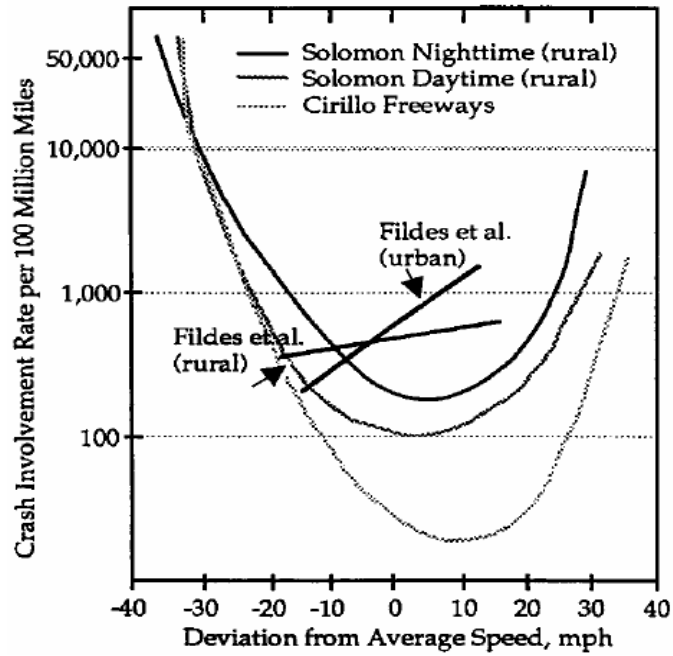


Figure 2
Crash rates as a function of deviation from average traffic speed

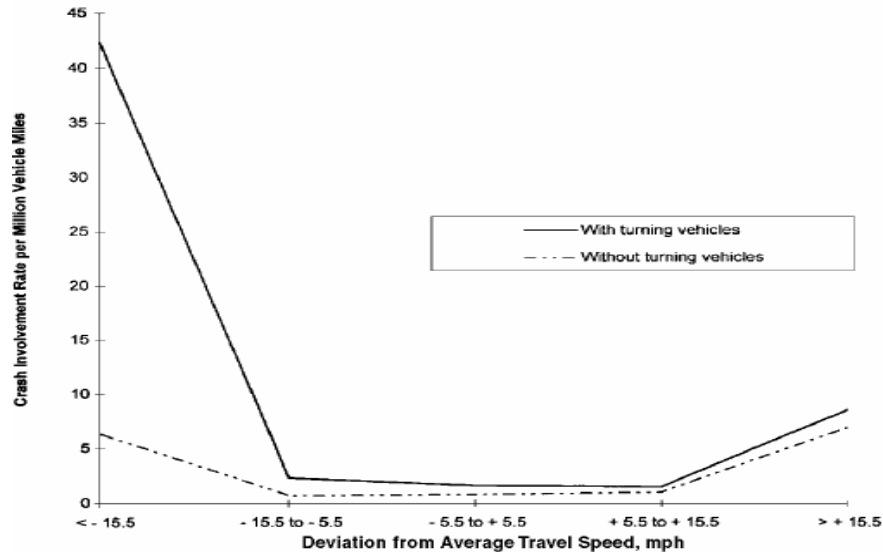


Figure 3
Crash involvement rates including and excluding turning vehicles

A more recent Australian study (Kloeden et al., 1997) that examined the relationship between speed and the probability of involvement in a casualty crash supports some of the results reported earlier by Fildes et al. (1991), at least for speeds above the average speed of traffic. Using a case control approach, the speeds of cars involved in casualty crashes (the case vehicles) were compared with the free-flowing speeds of cars not involved in crashes but traveling in the same direction at the same location, time of day, day of week, and time of year (the control vehicles). Data collection was focused on weekday, daylight crashes—to exclude most alcohol-related crashes—in speed zones with a 37-mph (60-km/h) speed limit. Pre-crash speeds were determined using crash reconstruction techniques. The data showed a steady and statistically significant increase in the probability of involvement of the case vehicles in a casualty crash with increasing speed above, but not below, the 37-mph speed limit, which roughly approximated the average traffic speed. The risk approximately doubled with each 3-mph (5-km/h) increase in speed above the limit. The probability of

casualty crash involvement at speeds below 37 mph was not statistically different from the probability at the speed limit. The absence of a significant association between speed and crash involvement at speeds below the average traffic speed may be the result of the study design.

Several studies have attempted to analyze the relationship between crash involvement and measures of the distribution of speeds in a traffic stream, thereby avoiding the problem of estimating the pre-crash speeds of individual vehicles. On the basis of data from 48 states, Lave (1985) developed models for a range of road classes (e.g., Interstates, arterials, collectors) to investigate the relationship between average traffic speed, speed dispersion, and fatality rates, attempting to hold constant some of the other factors that affect highway fatality rates using standard statistical techniques. He found that speed dispersion was significantly related to fatality rates for rural Interstates and rural and urban arterials. After controlling for speed dispersion, average traffic speed was not found to be significantly related to fatality rates for any road type.

A related study by Garber and Gadiraju (1988) found, as Lave had, that average traffic speeds are not significantly related to fatality rates. They examined the relationship between crash rates, speed dispersion, average traffic speed, and other measures that influence speed—design speed and posted speed limits—on several different classes of roads in Virginia. They found that crash rates declined with an increase in average traffic speeds when data for all road classes were combined (Garber and Gadiraju, 1988). The correlation disappeared when the data were disaggregated by road class, suggesting that the aggregated analysis simply reflected the effects of the different design characteristics of the roads being

studied (e.g., lower crash rates on high-speed Interstates). When crash rates were modeled as a function of speed dispersion for each road class, however, crash rates increased with increasing speed dispersion. The minimum speed dispersion occurred when the difference between the design speed of the highway, which reflects its function and geometric characteristics, and the posted speed limit was small.

The studies just reviewed suggest that the type of road may play an important role in determining driver travel speeds and crash probability. Thus, speed and crash probability on rural non-limited access highways was also examined.

Studies on Non-limited-access Rural Highways

The potential for vehicle conflicts is considerably greater on undivided highways, particularly high-speed, non-limited-access highways. Vehicles entering and exiting the highway at intersections and driveways and performing passing maneuvers on two-lane undivided highways increase the occurrence of conflicts between vehicles with large speed differences and hence increase crash probability. Solomon's study (1964) provides strong evidence for these effects on two- and four-lane rural non-limited-access highways. High crash involvement rates are associated with vehicles traveling well above or below the average traffic speed; at low speeds, the most common crash types are rear-end and angle collisions, typical of conflicts at intersections and driveways.

West and Dunn's analysis (1971) pinpointed the important contribution of turning vehicles to crash probability on these highways. When turning vehicles were excluded from the analysis, crash involvement rates at low speeds were not as high as those found by Solomon (Figure 2); they were more symmetric with crash involvement rates at high speeds

(Figure 3). The study by Fildes et al. (1991) showed a gradual increase in crash probability for vehicles traveling above, but not below, average traffic speeds on two-lane rural roads (Figure 2). The previously cited studies by Garber and Gadiraju (1988) and Lave (1985) provide additional support for the contribution of speed dispersion to traffic conflicts and crash involvements on rural non-limited-access highways. Garber and Gadiraju (1988) found a high correlation between increasing speed dispersion and crash rates on rural arterial roads, but the model included only these two variables. Lave's rural arterial model, which attempted to control for more variables, found a weak but statistically significant relationship between traffic speed dispersion and fatality rates for only one year of data (Lave 1985). Neither study found any significant relationships between average traffic speeds and crash or fatality rates for this road class. Solomon's study provides some support for the role of speed in crash involvement on high-speed, non-limited-access rural highways. He found that the percentage of single-vehicle crashes, which are more common on high-speed roads generally, increased sharply as a function of the speed of the crash involved vehicles (Solomon 1964). Together, these studies suggest that speed dispersion, created in part by the characteristics of rural non-limited-access highways, contributes significantly to increased crash probability for this road class. The level of speed also appears to affect crash probability for certain crash types, such as single-vehicle crashes.

Speed as a Contributing Factor to Crashes

According to a study conducted by the GAO on rural highway safety, one or more of the four following factors have been identified to contribute to rural road fatalities—human behavior, roadway environment, vehicles, and the degree of care for victims after a crash

(GAO, 2004). Victim care includes the quality of the emergency response and the hospitals that provide medical treatment for those involved in a crash.

Excessive speed is reported to be an important factor contributing to many crashes. Analyses of a number of large databases in the United States indicated that speeding contributed to around 12 percent of all crashes reported to the police and to about one-third of fatal crashes (Kloeden, Ponte, and McLean, 2001). As rural roads have fewer intersections than urban roads and are more likely to provide travel between urban areas, they often have higher speed limits than many urban routes. From 2000 through 2002, about 62 percent of the nation's speeding related fatalities were on rural roads, amounting to about 24,000 of the 39,000 fatalities in which speed was a contributing factor, according to NHTSA data. According to Insurance Institute for Highway Safety officials, speed influences crashes by increasing the distance traveled from the time when a driver detects an emergency until he/she reacts, thus increasing the distance needed to stop and ultimately increasing the severity of an accident and reducing the ability of the vehicles, restraint systems, and roadside hardware, such as guardrails and barriers, to protect occupants (GAO, 2004).

Rural roads are more likely than urban roads to have poor roadway design, including narrow lanes, limited shoulders, sharp curves, exposed hazards, pavement drop-offs, steep slopes and limited clear zones along roadsides. Many rural routes have been constructed over a period of years and as a result often have inconsistent design features for such things as lane widths, curves, shoulders, and clearance zones along roadsides. Because rural traffic accidents often occur in more remote locations than urban accidents, emergency medical care

following a serious accident is often slower, contributing to a higher traffic fatality rate on rural roads. In about 30 percent of fatal rural traffic accidents in 2002, victims who died did not reach a hospital within an hour of the crash, whereas only eight percent of people injured in fatal, urban traffic accidents did not reach a hospital within an hour (TRIP, 2005)].

Drivers' speed choices impose risks that affect both the probability and severity of crashes. Speed is directly related to injury severity in a crash. The probability of severe injury increases sharply with the impact speed of a vehicle in a collision, reflecting the laws of physics. Although injury to vehicle occupants in a crash can be mitigated by safety belt use and airbags, the strength of the relationship between speed and crash severity alone is very evident.

Crash involvement on Interstate highways and non-limited-access rural roads has been associated with the deviation of the speed of crash-involved vehicles from the average speed of traffic. Crash involvement has also been associated with the speed of travel, at least on certain road types. For example, single-vehicle crash involvement rates on non-limited-access rural roads have been shown to rise with travel speed. Speed limits enhance safety in mainly two ways. By establishing an upper bound on speed, they have a limiting function to reduce both the probability and the severity of crashes. Speed limits also have a coordinating function of reducing speed dispersion and thus reducing the potential for vehicle conflicts. A related function of speed limits is to provide the basis for enforcement and sanctions for those who drive at speeds excessive for conditions and endanger others.

Influences of Speed Limits on Safety

A summary of several speed-related studies and their contribution to highway safety

are given below. Table 2 presents the increase in speed recorded by a number of researchers when speed limits on U.S. highways were increased from 55 mph to 65 mph. Tables 3 and 4 list a number of studies that focused on the relationship between speed limit changes and highway safety. Taken together, these studies show that speeds do increase with an increase in speed limit and that crash rates generally decrease when speed limits are decreased, and increase when speed limit are increase. However, there is no evidence that a change in speed limits consistently leads to a change in safety.

Table 2
Increased driver speeds resulting from 10 mph increase in speed limit

| Authors | Speed Increase (55 → 65 mph) |
|--------------------------------------|---------------------------------|
| Brown, Maghsoodloo, and Ardle (1990) | 2.4 mph |
| Freedman and Esterlitz (1990) | 2.8 mph |
| Mace and Heckard (1991) | 3.5 mph |
| Pfefer, Stenzel, and Lee (1991) | 4–5 mph |
| Parker (1997) | 0.2–2.3 mph |

Table 3
Summary of studies on effect of speed limit decreases
(Dougherty, 2000)

| Authors | Country | Speed Limit Decreases | Results |
|----------------------------|----------------|--------------------------------|--|
| Peltola (1991) | United Kingdom | 62–50 mph | Speeds declined by 4 km/h. |
| Sliogeris (1992) | Australia | 68–62 mph | Injury crashes declined by 19 percent. |
| Authors | Country | Amount of Speed Limit Decrease | Results |
| Newstead and Mullan (1996) | Australia | 3–12 mph | No significant change. (4 percent increase relative to sites not changed.) |
| Parker (1997) | United States | 5–20 mph | No significant changes. |

Table 4
Summary of studies on effect of speed limit increases
(Dougherty, 2000)

| Authors | Country | Speed Limit Increases | Results |
|----------------------------|---------------------------|------------------------------|--|
| McKnight and Klein (1990) | United States | 55–65 mph | Fatal crashes increased by 22 percent. Speeding increased by 48 percent. |
| Garber and Graham (1990) | United States (40 States) | 55–65 mph | Fatalities increased by 15 percent. Decrease or no effect in 12 states. |
| Lave and Elias (1994) | United States (40 states) | 55–65 mph | Statewide fatality rates decreased by 3-5 percent. (Significant in 14 of 40 states.) |
| Newstead and Mullan (1996) | Australia (Victoria) | 3–12 mph | Crashes increased overall by 8 percent, but 35 percent declined in zones raised from 60–80 mph. |
| Rock (1995) | United States (Illinois) | 55–65 mph | Crashes increased by 33 percent. Fatalities increased by 40 percent. Injuries increased by 19 percent. |
| Parker (1997) | United States (22 states) | 5–15 mph | No significant changes. |

Cost and Benefit of Speed Limit Increase

In 2003, speeding was a contributing factor in 31 percent of all fatal crashes, and 13,380 lives were lost in speeding-related crashes compared to 12,480 lives in 1994. In 1994, the economic cost to society of speed-related crashes, estimated by NHTSA, was more than \$23 billion per year, while the 2000 costs of speeding-related crashes were estimated to be \$40.4 billion per year. Table 5 below shows the estimated annual economic costs of speed-related crashes for the year 1994 (1990 Dollars per Year).

Table 5
Annual economic costs of speed-related crashes
(1990 Dollars)

| Crash Type | Cost |
|----------------------|-----------------------|
| Fatal | \$9.8 billion |
| Injury (Non-Fatal) | \$9.1 billion |
| Property-Damage-Only | \$4.3 billion |
| Total | \$23.2 billion |

According to the National Safety Council, the economic cost of motor-vehicle crashes in the year 2004 has been estimated as (NSC, 2005):

- \$1,130,000 per Fatality crash,
- \$49,700 per Injury crash and
- \$7,400 per PDO crash

Several studies have attempted to quantify the benefits and costs of speed limit changes on highways. The results of these studies uniformly conclude that raising speed limits has higher costs than benefits (Reed, 2001). In a study of potential benefits and costs of speed changes on rural roads, Professor Max Cameron of the Monash University Accident Research Centre (MUARC) looked at the economic costs and benefits of increasing the speed limit to 130 km/h on rural roads. Impacts were examined for rural freeways, rural divided roads and rural two-way undivided roads. The costs tested were vehicle operating costs, time costs, crash costs and air pollution costs, the aggregate of these impacts representing the total social cost. Two different methodologies were used: “human capital” and “willingness to pay.”

With regard to rural undivided roads, the report found that there was no economic justification for increasing the speed limit on two-lane undivided rural roads, even on those safer roads with sealed shoulders. On undivided roads through terrain requiring slowing for sharp bends and occasional stops in towns, the increased fuel consumption and air pollution emissions associated with deceleration from and acceleration to high cruise speeds added substantially to the total social costs. Using “human capital” costs to value road trauma, the optimum speed for cars was about the current speed limit (100 km/h) on straight sections of these roads, but 10–15 km/h less on the curvy roads with intersections and towns. The optimum speed for trucks was substantially below the current speed limit, and even lower on the curvy roads. The optimum speeds would have been even lower if “willingness to pay” valuations of crash costs were used.

METHODOLOGY

The main objective of this study was to determine how an indeterminate speed limit increase would impact safety on rural two-lane highways. The term safety was defined in terms of the crash rate, defined in this study as the number of persons killed or injured per hundred million vehicle miles of travel. Though some studies showed that the crash rate increased with increase in speed limit, some other studies argued that the crash rate did not change or sometimes decreased with an increase in speed limit. Most of the studies revealed a definite relation between speed limit and crash rate with the exception of a few cases shown in tables 3 and 4. The major part of this study involved the development of a methodology to study the effect of a speed limit change on the crash rate on two-lane rural roads in Louisiana.

The study involved observation of crash rate trends at different speed limits on rural roads in Louisiana over the period 1999-2004, and the observation of the crash rates on rural road segments before and after a speed limit change on those segments. The analysis was directed through the use of hypotheses formulated in advance of the analysis. External factors influencing the analysis were controlled, using classification procedures, so that their influences did not compromise the results of the analysis. This classification was done using Answer Tree 1.0 software, which is available as an add-in to the statistical package SPSS. Statistical tests were conducted to identify the relative significance of crash involvement with speed limit change in Louisiana.

Research Hypothesis

The crash rate, defined as the number of crashes per 100 million vehicle miles of travel has increased with a speed limit increase on the rural two-lane highways in Louisiana.

Data

The database used for the analysis consisted of crash and roadway data for Louisiana for the years 1999 to 2004 obtained from the Louisiana Department of Transportation and Development.

Crash Database

Crash data was obtained from police crash reports on all motor vehicle crashes that occurred in Louisiana from 1999 to 2004, regardless of the jurisdiction in which it occurred or the ownership of the road. The crash data contains details such as crash year, crash date, crash hour, crash severity, location of crash, control section number, time and day of crash, manner of collision, crash type; vehicle details such as vehicle type, and vehicle condition; roadway characteristics at the crash site such as posted speed limit, road alignment, surface type and condition, lighting and weather conditions, pavement and median width; and driver characteristics such as driver age, sex, driver conditions and other details. Crashes on two-lane rural highways were extracted from the crash data for analysis in this study.

Sections that experienced a speed limit change during the period 1999-2004 were identified so that the crash rate before and after the speed limit change could be observed. To identify these sections, the posted speed limit on all two-lane rural road sections was observed over the years 1999 to 2004 to determine any recorded speed limit change. The sections which had a speed limit increase were identified using the field "Before/After", and

thus determined if a particular crash occurred before or after a speed limit change and the year in which the speed limit was increased. The sections with no speed limit change were also identified. Thus each crash was identified as a before speed limit increase crash or after speed limit increase crash according to the year of speed limit increase, or as a no speed limit increase crash.

Division into Crash Severity Types

The speed at which a vehicle travels affects the severity of a crash. Consequently, the crash data was divided according to severity level so that the effect of speed limit change on each severity level could be studied individually. The three severity levels into which the crashes were divided were:

- Fatality Crash
- Injury Crash
- Property Damage Only (PDO) Crash

Crash Rate Calculation

Though the fatality, injury, and the PDO crash cases contained all the required details on crash, roadway, and vehicle characteristics, the crash rate on each section was not known.

Thus crash rate was calculated separately for the fatality, injury, and the PDO crashes.

Since the rural two-lane roads are less traveled, low-volume roads, the crash rate was calculated in terms of the number of crashes per hundred million vehicle miles traveled (VMT) rather than the total number of crashes. VMT, the total vehicle miles traveled on a road section during a year, was estimated from the Average Daily Traffic (ADT) and length (L) of the section (in miles) as follows:

$$VMT = ADT * 365 * L$$

To express VMT in units of 100 million vehicle miles traveled, VMT must be divided by 10^8 in the expression above. Thus, the crash rate (*CR*) for PDO crashes, for example, on section *i* in year *t* is:

$$CR_{PDO,i,t} = (\text{Number of PDO crashes on section } i \text{ in year } t) / [(ADT_{i,t} * 365 * L_i) / 10^8]$$

where,

$ADT_{i,t}$ = Average Daily Traffic on section *i* in year *t*, and,

L_i = Length of section *i* (in miles)

For fatalities and injuries, crash rates are expressed in terms of the number of people affected rather than the number of crashes. That is, the crash rate is determined from the total number of drivers, occupants, and pedestrians killed or injured per 100 million vehicle miles of travel in that section during a particular year. Thus, the crash rate for fatalities, for example, on section *i* in year *t* is:

$$CR_{fatalities,i,t} = (\text{Number of people killed on section } i \text{ in year } t) / [(ADT_{i,t} * 365 * L_i) / 10^8]$$

Similarly, the crash rate for injuries on section *i* in year *t* is:

$$CR_{injuries,i,t} = (\text{Number of people injured on section } i \text{ in year } t) / [(ADT_{i,t} * 365 * L_i) / 10^8]$$

Categorization of Crash Types Using Cross-Classification

Crash type is expected to be dependent, to an extent, on the speed of the vehicles involved in a crash. Since an increase in speed limit will lead to an increase in speed, it is expected that crash types will be affected differently by an increase in speed limit. To account for this in the analysis, each of the severity types was subdivided into different crash types. Some of the common crash types such as run-off road, head-on collisions, rear- end

collisions, sideswipe, collision with pedestrian, collision with parked vehicle, collision with animal, collision with a fixed object and many other types of crashes fall under the category of two fields in the crash table, namely, manner of collision field and type of accident field.

The “manner of collision” field contains the sub-categories shown in Table 6.

Table 6
Description of manner of collision field categories

| COLUMN | CODE | DESCRIPTION |
|-------------|------|----------------------------------|
| man_coll_cd | A | non collision with motor vehicle |
| man_coll_cd | B | rear end |
| man_coll_cd | C | head on |
| man_coll_cd | D | right angle |
| man_coll_cd | E | left turn angle |
| man_coll_cd | F | left turn opposite direction |
| man_coll_cd | G | left turn same direction |
| man_coll_cd | H | right turn angle |
| man_coll_cd | I | right turn opposite direction |
| man_coll_cd | J | Side swipe same direction |
| man_coll_cd | K | Side swipe opposite direction |
| man_coll_cd | L | other |

The “type of accident” field consists of the following sub-categories:

Table 7
Description of type of accident field categories

| COLUMN | CODE | DESCRIPTION |
|----------|------|---|
| type_acc | A | Running off roadway |
| type_acc | B | Overturning on roadway |
| type_acc | C | Collision with pedestrian |
| type_acc | D | Collision with other motor vehicle in traffic |
| type_acc | E | Collision with parked vehicle |
| type_acc | F | Collision with train |
| type_acc | G | Collision with bicyclist |
| type_acc | H | Collision with animal |
| type_acc | I | Collision with fixed object |
| type_acc | J | Collision with other object |
| type_acc | K | Other non-collision on road |

A cross-classification analysis was performed on these two fields for fatality, injury and PDO crashes. The details of the cross-classification conducted on each severity group are reported below.

Cross-Classification Analysis

As the crash types were described in the data by the fields “manner of collision” (table 6) and “type of accident” (table 7), a cross classification analysis was conducted on both these fields for all the three severity types to establish a common set of crash types. The results of the classification are shown below for each severity type. Color coding was used to show the different crash types ultimately established.

Cross-Classification Analysis on Fatality Group





Table 8 shows the distribution of crashes in each category and the four crash types established for the fatality group by cross-classification. The four crash types most common in the fatality group were:

- Run-off road crashes
- Head-on and right angle crashes
- Turning angle and sideswipe crashes
- Non-motor vehicle crashes

Structured Query Language queries were built to extract each crash type from the main fatality group.

Table 8
Results of cross-classification analysis on fatality group

| Count of CRASH_NUM | MAN_COLL_CD | | | | | | | | | | | | | | |
|-----------------------|-------------|------------|-----------|------------|------------|-----------|-----------|----------|----------|----------|-----------|-----------|------------|----------------|--|
| TYPE_ACC | | A | B | C | D | E | F | G | H | I | J | K | L | Grand Total | |
| A | 8 | 8 | 8 | 6 | 4 | | | | | | 1 | 1 | | 918 | |
| B | 1 | 12 | | 2 | | | | | | | | 1 | 2 | 18 | |
| C | 2 | | | | 1 | | | | | | | | | 100 | |
| D | 5 | 20 | 53 | | | | | | | | | | 66 | 761 | |
| E | 2 | 1 | 3 | | | | | | | | | | 1 | 8 | |
| F | | | | | 6 | | | | | | | | | 7 | |
| G | | | 3 | | | | | 1 | | | 1 | 1 | | 7 | |
| H | | | | 3 | | | | | | | | | | 7 | |
| I | 4 | | | 7 | 4 | | 1 | | | | | | | 87 | |
| J | 1 | | 1 | 2 | | 1 | | | | | | | | 8 | |
| K | | 9 | | 5 | 4 | 1 | | | | | 2 | | 4 | 25 | |
| Grand Total | 23 | 951 | 68 | 340 | 185 | 25 | 42 | 2 | 2 | 4 | 15 | 58 | 231 | 1946 | |

-  - Run-off road (890 cases)
-  - Head-on and Right angle (481 cases)
-  - Turning angle and Sideswipe (137 cases)
-  - Non-motor vehicle collisions (190 cases)

Cross-Classification Analysis on Injury Group

Table 9 shows the distribution of crashes in each category and the five crash types arrived at for the injury group by cross-classification. The five crash types obtained were:

- Run-off road and Overturning
- Rear-end crashes
- Head-on and Right angle crashes
- Turning angle and side swipe crashes
- Non-motor vehicle crashes

Table 9
Results of cross classification analysis on injury group

| Count of CRASH_NUM | MAN_COLL_CD | | | | | | | | | | | | | |
|--------------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|------------|------------|------------|------------|-------------|-------------|--------------|
| TYPE_ACC | | A | B | C | D | E | F | G | H | I | J | K | L | Grand Total |
| A | 226 | 11368 | 75 | 81 | 67 | 9 | 4 | 2 | 5 | 4 | 49 | 30 | 1892 | 13812 |
| B | 12 | 387 | 9 | 1 | 5 | 2 | | | 2 | | | 1 | 119 | 538 |
| C | 8 | 125 | 1 | | 9 | | | | | | 2 | 2 | 75 | 222 |
| D | 364 | 940 | 8144 | 1086 | 4383 | 1324 | 1437 | 380 | 172 | 115 | 526 | 979 | 2255 | 22105 |
| E | 4 | 3 | 68 | 4 | 5 | 1 | 1 | | | | 6 | 3 | 15 | 110 |
| F | 1 | 8 | 1 | 2 | 23 | 1 | | | | | | 1 | 8 | 45 |
| G | 6 | 12 | 17 | | 14 | 4 | 3 | 2 | 1 | 1 | 14 | 3 | 15 | 92 |
| H | 13 | 459 | 2 | 3 | 9 | | | | 1 | 1 | 3 | 2 | 110 | 603 |
| I | 104 | 2175 | 351 | 65 | 139 | 45 | 41 | 21 | 15 | 10 | 41 | 41 | 973 | 4021 |
| J | 41 | 94 | 105 | 13 | 36 | 9 | 22 | 5 | 5 | 1 | 9 | 6 | 139 | 485 |
| K | 46 | 337 | 28 | 18 | 16 | 4 | 7 | 1 | | 1 | 7 | 13 | 163 | 641 |
| Total | 825 | 15908 | 8801 | 1273 | 4706 | 1399 | 1515 | 411 | 201 | 133 | 657 | 1081 | 5764 | 42674 |

- Run-off road and Overturning (13958 cases)
- Rearend crashes (8212 cases)
- Head-on and Right angle (5632 cases)
- Turning angle and Sideswipe (4944 cases)
- Non-motor vehicle collisions (5846 cases)


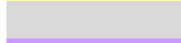


Cross-Classification Analysis on PDO Group

Table 10 shows the distribution of crashes in each category and the four crash types established for the injury group by cross-classification. The four crash types obtained were:

- Run-off road and overturning
- Rear end crashes
- Right angle and sideswipe
- Non-motor vehicle collisions

Table 10
Results of cross classification analysis on PDO group

| Count of CRASH_NUM | MAIN_COLL_CD | | | | | | | | | | | | | | |
|--------------------|--------------|-------|-------|-----|------|------|------|------|-----|-----|------|------|------|-------------|--|
| TYPE_ACC | | A | B | C | D | E | F | G | H | I | J | K | L | Grand Total | |
| A | 300 | 10692 | 74 | 53 | 60 | 9 | 3 | 1 | 16 | 12 | 109 | 38 | 1752 | 13119 | |
| B | 28 | 325 | 2 | 2 | 1 | 3 | | | | 2 | 2 | | 96 | 461 | |
| C | 11 | 122 | 4 | 1 | 3 | | | | | | 2 | | 59 | 202 | |
| D | 1059 | 1954 | 12450 | 303 | 4287 | 1868 | 1261 | 957 | 451 | 329 | 1899 | 1428 | 4140 | 32386 | |
| E | 11 | 13 | 91 | 3 | 18 | 3 | | 2 | 1 | | 38 | 16 | 134 | 330 | |
| F | 3 | 36 | 1 | 1 | 18 | | 1 | | | | | | 19 | 79 | |
| G | 10 | 37 | 55 | | 11 | 6 | 4 | 5 | 5 | 4 | 13 | 6 | 54 | 210 | |
| H | 128 | 2751 | 3 | 25 | 71 | | | 1 | 1 | 1 | 3 | 6 | 780 | 3770 | |
| I | 276 | 3637 | 601 | 56 | 160 | 90 | 58 | 66 | 36 | 24 | 106 | 87 | 1695 | 6892 | |
| J | 167 | 341 | 205 | 10 | 55 | 19 | 14 | 19 | 6 | 7 | 29 | 31 | 327 | 1230 | |
| K | 96 | 863 | 74 | 5 | 26 | 8 | 8 | 11 | 3 | 3 | 14 | 19 | 369 | 1499 | |
| Grand Total | 2089 | 20771 | 13560 | 459 | 4710 | 2006 | 1349 | 1062 | 519 | 382 | 2215 | 1631 | 9425 | 60178 | |

-  - Run-off road & Overturning (13252 cases)
-  - Rear end Crashes (12541 cases)
-  - Right angle and Sideswipe (7686 cases)
-  - Non-motor vehicle collisions (12915 cases)

Dependent and Independent Variables

Dependent Variables

In this study the dependent variable was the crash rate classified by severity level and crash type resulting from the cross-classification.

Independent Variables

Independent variables are those that are expected to influence the value of the dependent variables. Many variables have individual as well as combined influences on crash occurrence, but this study is interested in the influence of increased speed limits on

safety. To reduce the impact that other variables have on observed crash occurrence, the data was subdivided into groups in which the observed crash rates were as homogeneous as possible regarding these other variables. That is, we effectively controlled the influence of these other variables by creating groups in which they were homogenous, leaving speed limit change as the only variable within each group.

Classification Procedure Using Answer Tree 1.0

Many factors contribute to the incidence and severity of crashes, and speed is suspected to be only one of these. Speeding alone is estimated to contribute to about one-third of all fatal crashes, but speeding is often combined with other factors, such as road conditions or environmental conditions, to cause a much higher number of crashes.

To isolate the effect of speed from the effect of other factors, the other factors needed to be identified and controlled. Identification was achieved by observing the variables most influential in changing the crash rate of each crash type within each severity type. A classification procedure was employed that seeks out the division of data so that the resulting groups were as homogeneous with respect to crash rate as possible. This classification procedure was repeated on each of the crash type obtained for each severity type, resulting in 13 runs of the Classification and Regression Tree (CART) process in Answer Tree, one for each of the groups. The variables describing each of the groups were then the variables most influential in describing crash rates.

Answer Tree 1.0

Answer Tree is a computer learning system that creates classification systems displayed in decision trees. It is used to generate the classification rules from existing data.

Answer Tree exhaustively examines all the fields of the database with respect to the criterion variable by building a tree from the entire database that splits and subdivides the data into homogeneous groups until the tree growth is stopped. It seeks out the prime factors by sequentially considering all possible subdivisions of the data and choosing the subdivision that maximizes the between-group variance and minimizes the within-group variances.

It provides four algorithms for performing classification and segmentation analysis (Answer Tree 1.0 User's Guide, 1998). They are:

- **CHAID** - Chi-squared Automatic Interaction Detector, a method that uses chi-squared statistics to identify optimal splits.
- **Exhaustive CHAID** - A modification of CHAID that does a more thorough job of examining all possible splits for each predictor but takes longer to compute.
- **C&RT (or CART)** - Classification and Regression Trees, methods that are based on minimization of impurity measures.
- **QUEST** - Quick, Unbiased, Efficient Statistical Tree, a method that is quick to compute and avoids other methods' biases in favor of predictors with many categories

The CART algorithm was used to perform the classification in this analysis because it is capable of handling the categorical variables that are present in this analysis.

CART is an exploratory data analysis method that is used to study the relationships between a dependent measure and a number of possible predictor variables, which may interact between themselves. The CART tree is constructed by splitting subsets of the data set using all predictor variables to create two child nodes repeatedly, beginning with the

entire data set. The best predictor is chosen using a variety of measures to reduce impurity or diversity. The performance of the classifier is measured using risk estimate values. Thus each end node of a fully grown tree can be traced back to the parent node to indicate a homogeneous group of variables affecting the crash rate. The classification procedure in this research was required to identify those variables that can effectively distinguish the homogeneous set of factors affecting the crash rate for each severity and crash type group.

Data Items Used in CART Classification Procedure

The CART classification is performed on each crash type group for each of the severity types, (Fatality, Injury and PDO crashes) and the data items used for each of the group may vary. Some of the more important data items that featured in all the groups are described below.

Each data item or variable can be characterized by the kind of values it can take and what those values measure. This general characteristic is referred to as the measurement level of the variable. A variable has one of three measurement levels:

Nominal - This measurement level includes categorical variables with discrete values, where there is no particular ordering of values.

Ordinal - This measurement level includes variables with discrete values, where there is a meaningful ordering of values. Ordinal variables generally don't have equal intervals, however, so the difference between the first category and the second may not be the same as the difference between the fourth and fifth categories for example, for example.

Continuous - This measurement level includes variables that are not restricted to a list of values but can essentially take any value (although the values may be bounded above or

below or both).

Thus the variables or data items described below may be nominal, ordinal or continuous as described below.

Crash Hour - It is the hour in the day at which the crash occurred. The value of this data item varies from 0 to 23 where 0 represents midnight to just before 1:00 am and 23 represents 11 pm to just before midnight. Thus crash hour is a continuous variable.

Alcohol - This data item shows if alcohol was a factor in the crash. This field takes the value 0 or 1 representing alcohol involvement or no alcohol involvement, respectively. It is a categorical variable measured on a nominal scale.

Alignment Condition - This field describes the vertical and horizontal alignment of the roadway at which the crash occurred. It may be straight-level, straight-level-elevated, curve-level, curve-level-elevated, on grade straight, on grade curve, hillcrest straight, hillcrest curve, dip/hump straight, dip/hump curve, unknown and other. This is a categorical variable measured on a nominal scale.

Day of Week - This describes the day of the week of the crash. It can take a value ranging from 1 to 7, where 1 represents a Monday and 7 represents a Sunday. This is a categorical variable measured on a nominal scale.

Lighting Condition - This field describes the illumination at the time of the crash. It maybe daylight, dark-no street light, dark-continuous street lights, dark-street lights-intersect only, dusk, dawn, and unknown. This is a categorical variable measured on a nominal scale.

Location Type - This field describes the surrounding environment of the crash described as manufacturing or industrial, business continuous, business, mixed residential,

residential district, residential scattered, school or playground, open country, and other. This is a categorical variable measured on a nominal scale.

Road Condition - This field describes the condition of the roadway at the time of the crash. It may be one of the following: no defects, defective shoulders, holes, deep ruts, bumps, loose surface material, construction, repair, overhead clearance limited, construction – no warning, previous crash, flooding, animal in the roadway, object in the roadway, and other defects. This is a categorical variable measured on a nominal scale.

Surface Condition - This data item describes the moisture condition on the road surface and can be dry, wet, snow or slush, ice, contaminant, unknown, and other. This is a categorical variable measured on a nominal scale.

Driver Age - This field describes the age of the driver at the time of crash and can take any value ranging from 0 to 99. Drivers aged 99 or above are represented as 99. This is a continuous variable.

Driver Sex - This field describes the sex of the driver and is coded as either M or F, representing male and female, respectively. This is a categorical variable measured on a nominal scale.

Traffic Control Condition - This field describes the presence of traffic control at the location of crash and it may be a stop sign, yield sign, red signal on, yellow signal on, green signal on, green turn arrow on, right turn arrow on red, light phase unknown, flashing yellow, flashing red, officer, watchman, RR crossing-sign, RR crossing-signal, RR crossing-no control, warning sign (school, etc), school flashing speed sign, yellow no passing line, white dashed line, yellow dashed line, bike lane, cross walk, no control, unknown, and other.

This is a categorical variable measured on a nominal scale.

Vehicle Type - This field describes the type of the vehicle, which can be a passenger car, light truck or pickup, van, A, B or C with trailer, motor cycle, pedal cycle, off road vehicle, emergency vehicle, school bus, other bus, motor home, single unit truck, truck with trailer, farm equipment and other. This is a categorical variable measured on a nominal scale.

Prior Movement - This field describes the movement of the vehicle prior to the crash and one of the following possible cases: stopped, proceeding straight ahead, traveling wrong way, backing, crossed median into opposing lane, crossed center line into opposing lane, ran off road (not while making turn at intersection), changing lanes on multilane roads, making left turn, making right turn, stopped preparing to or making a U-turn, making turn, direction unknown, stopped, preparing to turn left, stopped, preparing to turn right, slowing to make left turn, slowing to make right turn, slowing to stop, properly parked, parking maneuver, entering traffic from shoulder, entering traffic from median, entering traffic from parking lane, entering traffic from private lane, entering freeway from on-ramp, leaving freeway via off-ramp, and others. This is a categorical variable measured on a nominal scale.

Violations - This field describes the vehicle violations at the time of crash and can include the following. Exceeding stated speed limit, exceeding safe speed limit, failure to yield, driving too closely, driving left of center, cutting in improper passing, failure to signal, made wide right turn, cut corner on left turn, turned from wrong lane, other improper turning, disregarded traffic control, improper starting, improper parking, failed to set out flags or flares, failed to dim headlights, vehicle condition, driver's condition, careless operation,

unknown violation, no violation, and other. This is a categorical variable measured on a nominal scale.

Pavement Width - This field describes the width of the pavement where the crash occurred. It can have values ranging from 12 feet to 70 feet in the case of rural two-lane roads. This is a continuous variable.

Weather Condition - This describes the weather at the time of the crash, which may be clear, cloudy, rain, fog or smoke, sleet or hail, snow, severe cross wind, blowing sand, soil, dirt, snow, unknown, and other. This is a categorical variable measured on a nominal scale.

The rest of the data items included in the CART classification system vary according to the type of crash for which the analysis is being performed. For example, the data items vehicle type 1 and vehicle type 2, driver age 1 and driver age 2, driver sex 1 and driver sex 2, violation 1 and violation 2, prior movement 1 and prior movement 2 may be included in a head on collision crash type, as two vehicles are involved in such a crash. However, these data items may not be included in a run-off road crash, as it usually involves only one vehicle. Similarly, an intersection crash may be included in turning angle and sideswipe crashes but may not be included in a run-off road crash.

By considering all of the above variables - with the exception of change in speed limit - in the classification procedure with crash rate as the criterion variable, the resulting groups were “controlled” for the influence of these variables within each group (depending on the level of homogeneity achieved). That is, since the influential variables are as uniform as possible within each group, their influence on the crash rate, within the group, is limited.

Comparing, the crash rate between road sections that have experienced a change in speed limit with those that have not within each group isolates the influence of change in speed limit on crash rate from the influence of other variables as much as possible.

Growing the Tree

To grow a classification tree in SPSS Answer Tree 1.0, the model must first be defined by selecting the target and predictor variables, and the classification procedure. In this case, the target variable was the Crash Rate for each crash type and severity level (defined as continuous) and the predictor variables were Crash Hour (continuous), Alcohol (nominal), Alignment Condition (nominal), Day of Week (nominal), Lighting Condition (nominal), Location Type (nominal), Road Condition (nominal), Surface Condition (nominal), Driver Age (continuous), Driver Sex (nominal), Traffic Control Condition (nominal), Vehicle Type (nominal), Prior Movement (nominal), Violations (nominal), and Pavement Width (continuous). The classification procedure chosen was the CART method. After defining the model, the *Growing Criteria* for the tree were specified.

The following stopping rules were employed in the application of CART:

Maximum Tree Depth: This setting allowed controlling the depth (number of levels below the root node) of the generated tree.

Minimum Number of Cases: This setting allowed specifying the minimum numbers of cases for nodes. Nodes that do not satisfy these criteria will not be split.

Parent Node Total: The minimum number of cases in a parent node. A parent node is the node in a tree structure that links to one or more child nodes. Thus parent nodes with fewer cases will not be split.

Child Node: The minimum number of cases in child nodes. A child node is a node in the tree structure that is linked to by a parent node, and the child node results from the parent node. If splitting a node would result in a child node with a number of cases less than this value, the node will not be split.

The stopping rule for CART depends on the minimum change in impurity. Impurity is the probability of misclassification in the splitting process. If splitting a node results in a change in impurity less than the minimum, the node is not split. The minimum change in impurity was specified as 0.0001. The CART process was run on all 13 crash type groups, changing the predictor variables for each group according to the crash type, and giving appropriate stopping rules, resulting in 13 fully grown trees with a different number of terminal nodes for each tree.

An overview of the classification tree can be seen in the Tree Map shown in figure 4. The nodes display the mean, standard deviation, and the number of data records it could split and the improvement, i.e., the measure of decrease in impurity for each predictor in each node, with the use of each variable, as shown in figure 5. The risk and gain summaries are also displayed for each fully grown tree. The gain charts give the node statistics relative to the mean of the target variable. The risk estimate is the within-node variance about each node's mean, averaged over all the nodes, and is thus a measure of non-homogeneity of the subdivisions obtained. The automatically grown tree was then analyzed by examining the standard deviation values of the end nodes and finding the proportion of variance captured by the classification procedure. The end nodes were traced back to the parent node and each of these were defined as a homogeneous group. The details of the analysis on the 13 crash type

are given in detail in the next section. After conducting the 13 consecutive runs of the CART process, the variable splits were examined to identify the homogeneous group of variables that consistently played an important role in distinguishing factors affecting crash rate. The groups with very few cases were neglected, and finally 47 homogeneous groups were identified, and the crash types were queried to establish the new homogeneous groups.

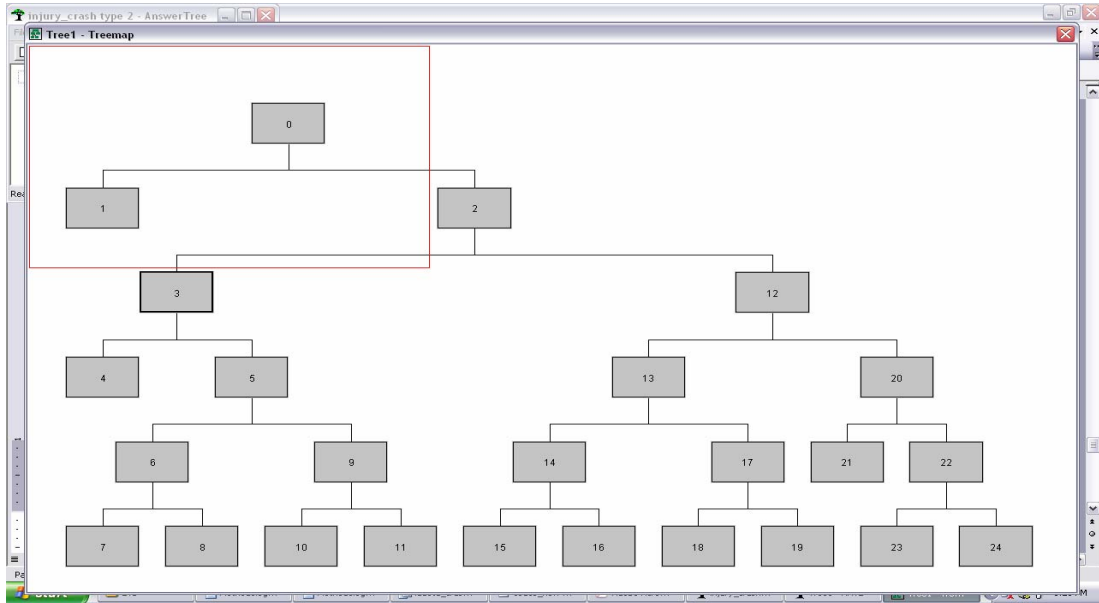


Figure 4
Tree map

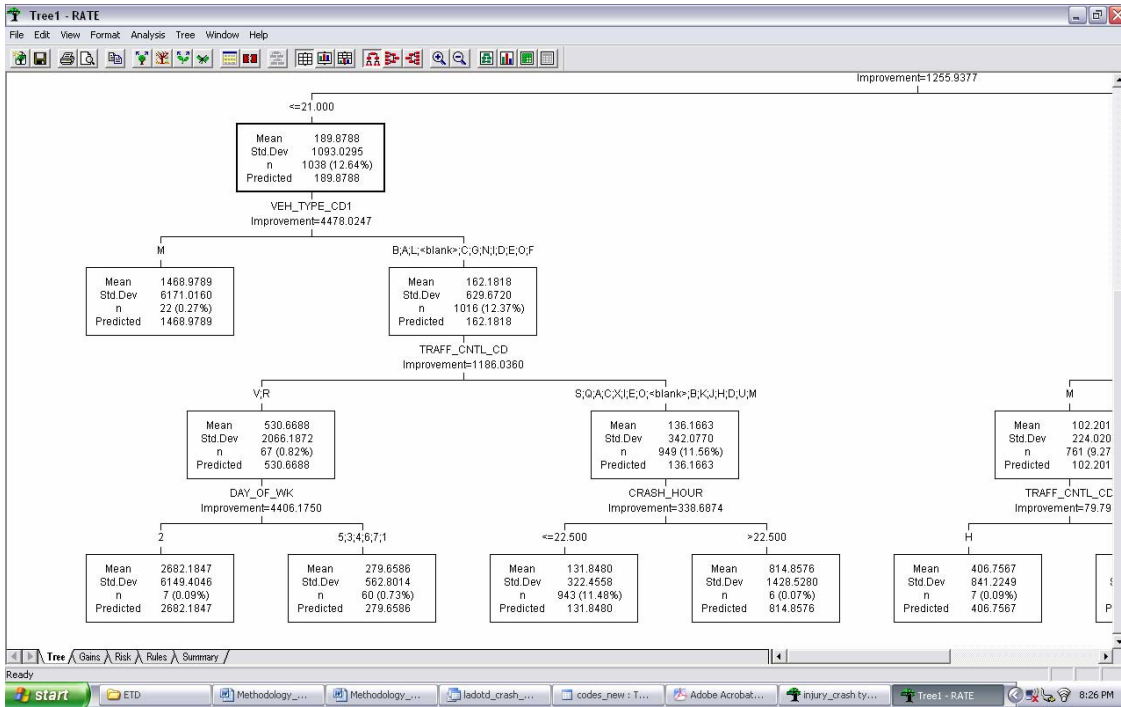


Figure 5
Classification tree showing the nodes

Division into “No Speed Change” and “Speed Change” Group

In each of the 47 homogenous groups, the field “Before/After” identifies each section as a section which underwent a speed limit change or no speed limit change section. As the next step in the analysis, the speed limit change sections were separated from the no speed limit change group.

The no speed change group was identified by the value “S” in the “Before/After” field while the speed change group was distinguished by values such as “99B” or “99A” or “00B” or “00A” and so on in the “Before/After” field, if the year in which the speed limit change was observed was in 1999 or 2000, for example. Any amount of speed limit change was recorded as a speed limit increase regardless of the amount of increase.

Plotting of Trends

The no speed limit change group tables for each of the 47 cases were observed for any trend in crash rate increase so that any crash rate increase in the speed limit change group could be adjusted. The average crash rate was plotted against the years and regression analysis was performed to identify any significant trend. Where the trend line was significantly different from zero at the 95 percent level of significance, a significant trend was assumed to exist.

Adjustment for Trends in Crash Rate

Each of the speed limit change groups were observed, and the average crash rate was calculated according to year of speed limit change and the average year before and after speed limit change. For example, in a case with a speed limit change in 2001, the average year of speed limit change would be 2000 (the average of 1999, 2000 and 2001). The average crash rate for these three years was calculated as well and then plotted at the average before speed limit change year. Similarly, all the after speed limit change years were averaged and the crash rate of all the after years, i.e., 2002, 2003 and 2004, were averaged and plotted against the year 2003. This was done for each of the 47 cases for speed limit change in each year from 1999 to 2004. Figure 6 shows the plot of average crash rate against average year of a case where speed limit change occurred in 2001. In the figure, the years are marked 0 to 5 corresponding to 1999 to 2004.

After plotting the average crash rates before and after a speed limit change, the after speed change crash rate values needed to be adjusted for the cases that had significant crash trends in the no speed limit change group. This adjustment was done so that the effect of

natural trends on the “after” speed change crash rate was eliminated and the new “adjusted” after speed limit change crash rate value could be attributed solely to the speed limit change and no other external influences or natural trends.

This adjustment was done by multiplying the slope of the trend line of the particular case with the difference in years between the average before and after speed limit change years and subtracting this product from the original “after” speed limit change crash rate.

This can be expressed by the following equation:

$$CR_{(Adj)} = CR_{(Orig)} - S * (Y_{(Avg Aft)} - Y_{(Avg Bfore)})$$

Where,

$CR_{(Adj)}$ = Adjusted Average after speed limit change Crash Rate

$CR_{(Orig)}$ = Original Average after speed limit change Crash Rate

S = Slope of Trend line

$Y_{(Avg Aft)}$ = Average of After speed limit change Years

$Y_{(Avg Bfore)}$ = Average of Before speed limit change Years

Thus, for all the cases in which a significant crash trend was found in the no speed limit change group, the corresponding cases in the speed limit change group were adjusted for the crash rate value “after” speed limit change using the above explained equation to get the adjusted crash rate value. An example of original and adjusted before and after crash rate values is shown in figure 7.

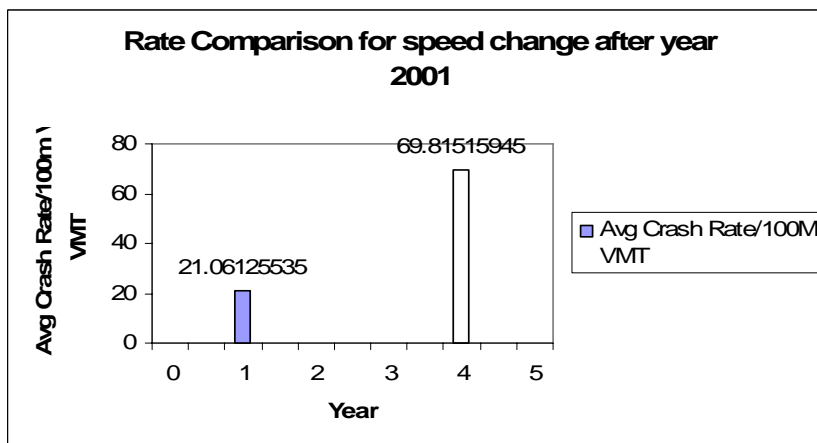


Figure 6
Crash rate before and after speed limit change in 2001

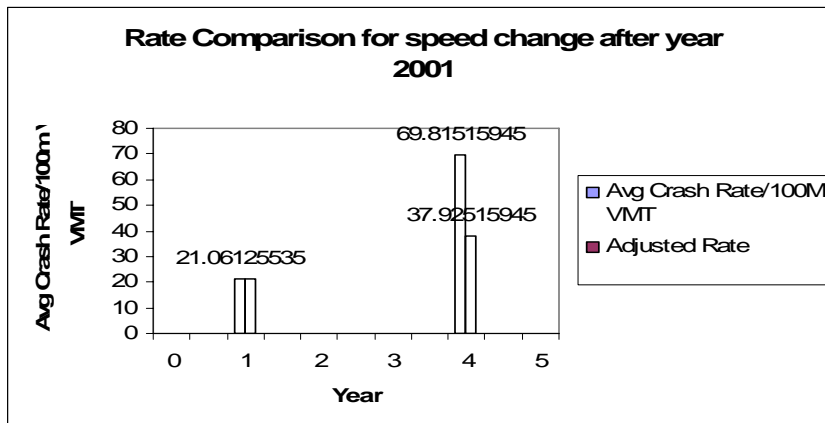


Figure 7
Crash rate change showing original and adjusted crash rates

Thus, for each case, we get pairs of values before and after the speed limit change in which the after value has been adjusted for the trend. These pairs were tested for any statistical similarity to arrive at a statistical conclusion of a change in crash rate.

Paired T-test Comparison

A single tailed paired sample t-test was conducted to test the statistical difference between the before and after speed limit change crash rates. The crash rate of the “after” speed limit change group adjusted for the trend over time was compared with the crash rate of “before” group for each year of speed change to obtain pairs of values in each of the homogeneous groups. Thus, several pairs of values were obtained for each of the classification analyses performed. These pairs were compared and analyzed using the single-tailed paired comparison t–test to prove the null or alternate hypothesis.

A paired sample t-test compares the means of two variables. It computes the difference between the two variables for each case and tests to see if the average difference is significantly different from zero. Here, a single-tailed paired sample t-test was used because researchers are only interested in observing whether crash rates increase with an increase in speed limit or not. The null hypothesis is that the crash rate has not increased with a speed limit increase (i.e., the crash rate after speed limit change is not greater than crash rate before the change), against the alternative hypothesis that the crash rate has increased with an increase in speed limit (i.e., the “after” crash rate value is greater than “before” value).

ANALYSIS AND DISCUSSION OF RESULTS

This section describes the analysis of Louisiana crash data and the results that were obtained from that analysis. The details of the analysis and the results are presented below.

Answer Tree Analysis

Classification procedures were employed to seek out the division of data so that the resulting groups were as homogeneous as possible with respect to crash rate. The classification analysis was carried out using the CART process in Answer Tree software. The detailed analysis on each crash type is given below.

Classification Analysis on Fatality Crashes

Classification Analysis on Run-off Road Crash Type - To grow the classification tree, the crash rate was selected as the target variable and the predictor variables included crash hour, alcohol involvement, alignment, lighting condition, day of the week, location type, road condition, road-related condition, surface condition, driver age 1, driver sex 1, traffic control condition, vehicle type 1, violations and pavement width. Figure 8 shows the classification tree obtained. The maximum tree depth was specified as 5 and the minimum number of cases was specified as 20 for the parent node and 1 for the child node as the total number of cases were 890 in all. This analysis resulted in 16 end nodes with a different number of crash cases. Each end node, when traced back to the parent node, created a homogeneous group. The groups in which the end node had less than 30 cases were neglected, resulting in three final homogeneous groups, 'HG-1', 'HG-2' and 'HG-3', having 225, 281, and 270 cases respectively.

The gain charts displaying the statistics associated with the terminal nodes relative to the mean of the target variable are presented in table 11. The rows of the table represent statistics for individual nodes and the following information is displayed for each node:

- **Node:** identifies the node associated with the row
- **Node: n:** Number of cases in the terminal node
- **Node: %:** The percentage of the total sample cases falling into the particular group
- **Gain:** Gain value of the group computed as the average value for the node for a continuous target variable
- **Index (%):** Ratio of the group's gain score to the gain score for the entire sample

Table 12 displays the risk summary of the classification analysis. Risk is calculated as the within-node variance about the mean of the node. The risk estimate and the standard error of risk indicate how well the classifier is performing.

Table 11
Gain summary of classification analysis on run-off road fatal crashes

| Target Variable: RATE | | | | |
|-----------------------|---------|---------|-------|-----------|
| Statistics | | | | |
| Node | Node: n | Node: % | Gain | Index (%) |
| 5 | 3 | 0.34 | 10.67 | 1467.16 |
| 25 | 2 | 0.22 | 9.56 | 1315.16 |
| 2 | 1 | 0.11 | 6.86 | 943.30 |
| 23 | 1 | 0.11 | 5.97 | 820.79 |
| 22 | 1 | 0.11 | 2.71 | 372.39 |
| 27 | 8 | 0.90 | 2.44 | 335.76 |
| 30 | 5 | 0.56 | 1.83 | 251.05 |
| 10 | 14 | 1.57 | 1.82 | 250.02 |
| 7 | 7 | 0.79 | 1.29 | 177.65 |
| 18 | 21 | 2.36 | 1.28 | 175.76 |
| 13 | 18 | 2.02 | 1.26 | 173.43 |
| 12 | 225 | 25.28 | 0.83 | 113.75 |
| 19 | 281 | 31.57 | 0.58 | 79.11 |
| 8 | 16 | 1.80 | 0.51 | 70.55 |
| 21 | 270 | 30.34 | 0.40 | 54.36 |
| 29 | 17 | 1.91 | 0.30 | 41.36 |

Table12
Risk summary

| | |
|----------------------|----------------|
| | Resubstitution |
| Risk Estimate | 2.0254 |
| SE of Risk Estimate | 0.505277 |

Within node (error) variance = 2.0254

Total variance = 2.72607 (risk estimate for the tree with only one node)

Proportion of variance due to error = $2.0254/2.72697 = 0.74297$

Proportion of variance explained by the model = $1 - 0.74297 = 0.257 = 25.7\%$

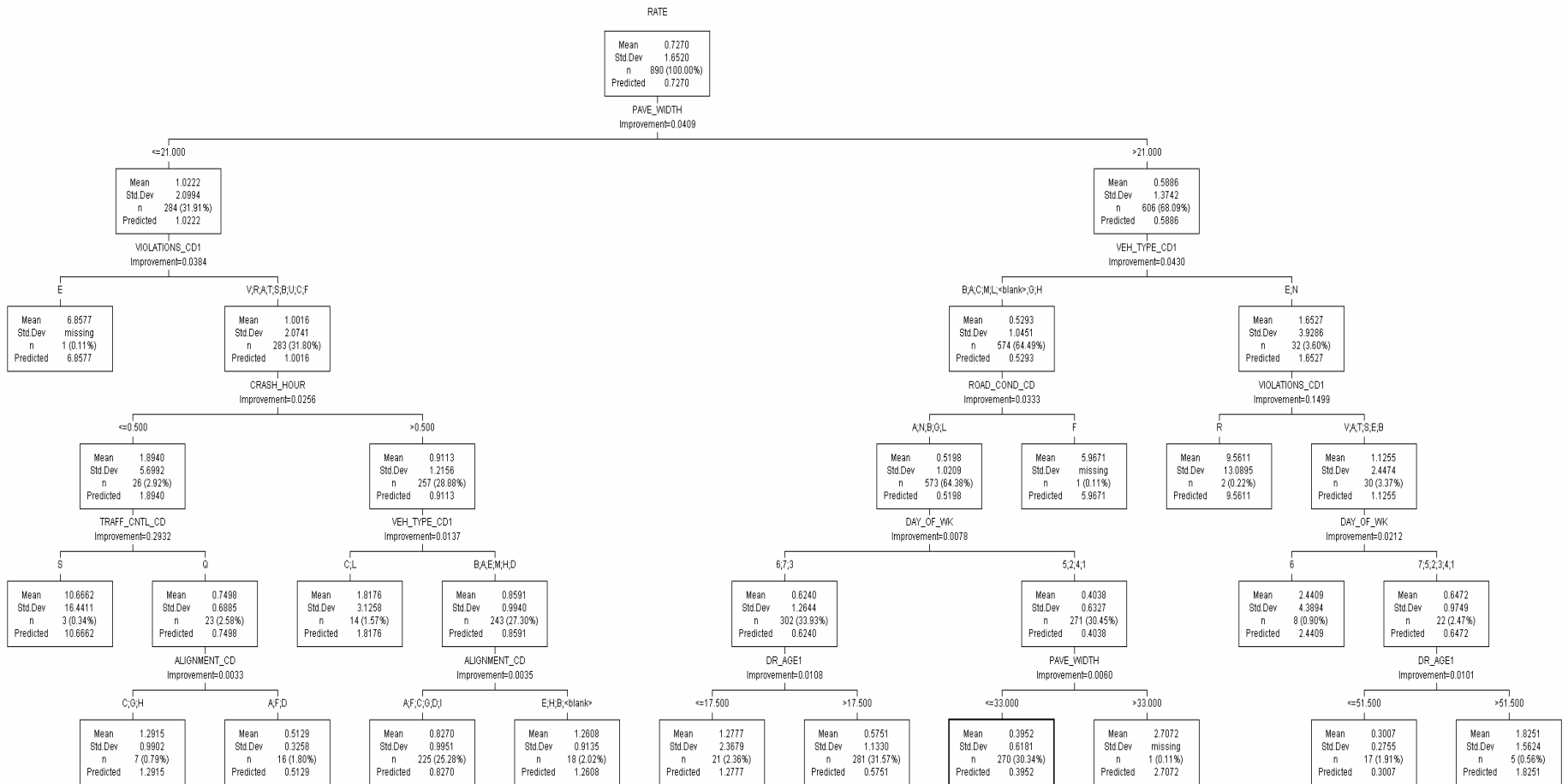


Figure 8
Classification analysis model for run-off road fatal crashes

Classification Analysis on Head-on and Right Angle Crash Type - The tree was grown by selecting the target variable, crash rate, and the predictor variables: alcohol involvement, alignment, lighting condition, day of the week, location type, surface condition, driver age 1, driver age 2, driver sex 1, driver sex 2, traffic control condition, vehicle type 1, vehicle type 2 and pavement width. The maximum tree depth was specified as 5 and the minimum number of cases was specified as 10 for the parent node and 1 for the child node as the total number of cases were 481. The analysis resulted in 15 end nodes, each with a different number of cases, resulting in 15 homogeneous groups. The groups with less than 30 cases in the end nodes were neglected, resulting in four final homogeneous groups.

Classification Analysis on Turning Angle and Sideswipe Crash Type - The classification tree was grown on these 137 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, driver age 1, driver age 2, driver sex 1, driver sex 2, traffic control condition, vehicle type 1, vehicle type 2, and pavement width. The maximum tree depth was specified as 5 and the minimum number of cases was specified as 10 for the parent node and 1 for the child node. The analysis resulted in 12 homogeneous groups, and the groups with less than 20 cases in the end node were neglected, resulting in 3 final homogeneous groups.

Classification Analysis on Non Motor Vehicle Crash Type - The classification tree was grown by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, driver age 1, driver sex 1, traffic control condition, vehicle type 1, pedestrian, and pavement width. The maximum tree depth was specified as four in this case, as the total number of cases was 190 and the minimum number of cases was specified as 10 for the parent node and 1 for the child node. The analysis resulted in 7

homogeneous groups with different numbers of cases. The groups with less than 30 cases in the end node were neglected, resulting in 2 final homogeneous groups.

Classification Analysis for Injury Crashes

Classification Analysis on Run-off Road Crash Type - The classification tree was grown on these 13,958 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, lighting condition, day of the week, location type, surface condition, driver age 1, driver sex 1, vehicle type 1, first harmful event, most harmful event, and pavement width. The maximum tree depth was specified as 5 and the minimum number of cases was specified as 100 for the parent node and 1 for the child node. The analysis resulted in 11 homogeneous groups with different numbers of cases. The groups with less than 30 cases in the end node were neglected, resulting in five final homogeneous groups.

Classification Analysis on Rear End Collision Type - The classification tree was grown by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, road condition, surface condition, driver age 1, driver age 2, driver sex 1, driver sex 2, traffic control condition, vehicle type 1, vehicle type 2, and pavement width. The maximum tree depth was specified as 5 and the minimum number of cases was specified as 10 for the parent node and 1 for the child node. The analysis resulted in 13 homogeneous groups with different number of cases. The groups with less than 30 cases in the end node were neglected, resulting in 6 final homogeneous groups.

Classification Analysis on Right Angle and Head on Crash Type - The classification tree was grown on these 5,632 crash cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, surface condition, driver age 1, driver age 2, driver sex 1, driver sex 2, traffic control condition,

vehicle type 1, vehicle type 2, and pavement width. The maximum tree depth was specified as five and the minimum number of cases was specified as 10 for the parent node and 1 for the child node. The analysis resulted in 15 end nodes with different numbers of cases and two final homogeneous groups.

Classification Analysis on Turning Angle and Sideswipe Crash Type - The classification tree was grown on these 4,944 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, road condition, surface condition, driver age 1, driver age 2, driver sex 1, driver sex 2, traffic control condition, vehicle type 1, vehicle type 2, violations 1, violations 2, and pavement width. The maximum tree depth was specified as 5 and the minimum number of cases was specified as 10 for the parent node and 1 for the child node. The analysis resulted in 10 homogeneous groups with different numbers of cases and two final homogeneous groups having 165 and 4,698 cases, respectively, were selected depending on the end node values.

Classification Analysis on Non Motor Vehicle Crash Type - The classification tree was grown on these 5,846 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, road condition, road-related factors, surface condition, surface type, driver age 1, driver sex 1, traffic control condition, vehicle type 1, and pavement width. The predictor variables such as driver age 2, vehicle type 2, etc., were not considered in this case as it deals with a non-motor vehicle crash, i.e., the crash between a motor vehicle and a fixed object, animal or person. The maximum tree depth was specified as five and the minimum number of cases was specified as 300 for the parent node and 30 for the child node. The analysis resulted in 7 end nodes with different numbers of cases. The nodes with a smaller number of cases compared to the original

number of cases were neglected, resulting in 5 homogeneous groups.

Classification Analysis for PDO Crashes

Classification Analysis on Run off Road and Overturning Crash Type - The classification tree was grown on these 13,252 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, lighting condition, day of the week, location type, road condition, road related factors, surface condition, driver age 1, driver sex 1, traffic control condition, vehicle type 1, and pavement width. The analysis resulted in 9 terminal nodes. The groups with relatively few cases were neglected, resulting in 5 final homogeneous groups containing 4,012; 2,704; 672; 960; and 3,821 cases respectively.

Classification Analysis on Rear End Crash Type - The classification tree was grown on these 12,541 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, road condition, road related factors, surface condition, driver age 1, driver age 2, driver sex 1, driver sex 2, traffic control condition, vehicle type 1, vehicle type 2, and pavement width. The analysis resulted in 8 terminal nodes, of which 4 homogeneous groups containing the majority of the observations (2,334; 6,047; 760; and 2,986 cases) were selected.

Classification Analysis on Right Angle and Sideswipe Crash Type - The classification tree was grown on these 7,686 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, intersection, lighting condition, day of the week, location type, road condition, road related factors, surface condition, driver age 1, driver age 2, driver sex 1, driver sex 2, traffic control condition, prior movement 1, prior movement 2, vehicle type 1, vehicle type 2, and pavement width. The maximum tree depth was specified as 5 and the minimum number of cases was specified as 100 for the parent node and 10 for the child node. The analysis

resulted in 7 terminal nodes from which 3 final homogeneous groups were established.

Classification Analysis on Non Motor Vehicle Crash Type - The classification tree was grown on these 12,914 cases by selecting the predictor variables: crash hour, alcohol involvement, alignment, lighting condition, day of the week, location type, road condition, road related factors, surface condition, driver age 1, driver sex 1, traffic control condition, vehicle type 1, and pavement width. The analysis resulted in 7 terminal nodes. The groups with few cases were neglected, resulting in 3 final homogeneous groups.

In total, 47 homogeneous groups were obtained through application of classification analysis to the 13 crash types by severity level. Table 13 explains how well each of the 13 trees has performed in achieving the required classification. It presents the summary of the risk estimates and the proportion of variance explained by each of the classification tree models described above. The risk estimate is the within node variance, and it indicates how well the classifier is performing. Total variance is the sum of the within node (error) variance and the between node (explained) variance. The total variance is the risk estimate for the tree with only one node.

Table 13
Summary of model performances

| Crash Case | Within Node Variance | Total Variance | Proportion of Variance due to Error | Proportion of Variance Explained by Model | Proportion of Explained Variance (%) |
|----------------------------|-----------------------------|-----------------------|--|--|---|
| FATALITY | | | | | |
| Run-off Road | 2.02 | 2.72 | 0.74 | 0.26 | 25.7% |
| Head-on & Right Angle | 6065.18 | 7803.84 | 0.78 | 0.22 | 22.2% |
| Turning Angle & Sideswipe | 719.13 | 4698.23 | 0.15 | 0.85 | 84.7% |
| Non Motor Vehicle | 14397.7 | 40633.7 | 0.35 | 0.65 | 64.6% |
| INJURY | | | | | |
| Run-off Road | 186430 | 192688 | 0.97 | 0.03 | 3.2% |
| Rear End | 241089 | 256503 | 0.94 | 0.06 | 6.0% |
| Right Angle & Head-on | 190484 | 276401 | 0.69 | 0.31 | 31.1% |
| Turning Angle & Sideswipe | 140292 | 322716 | 0.44 | 0.56 | 56.5% |
| Non Motor Vehicle | 141445 | 145875 | 0.97 | 0.03 | 3.0% |
| PDO | | | | | |
| Run-off Road & Overturning | 135903 | 137997 | 0.99 | 0.01 | 1.5% |
| Rear End | 97855.5 | 107196 | 0.91 | 0.08 | 8.7% |
| Right Angle & Sideswipe | 85898.6 | 89072.5 | 0.96 | 0.03 | 3.6% |
| Non Motor Vehicle | 306440 | 316560 | 0.96 | 0.03 | 3.20% |

Results of Trend Analysis on No Speed Change Group

The trend in crash rate was plotted for all the no speed limit change road sections and the statistical significance of the trend tested for each case. For the fatality group, none of the trends in crash rate were found to be significant. However, in the injury crash group, rear end injury crash case of homogeneous group 5, non motor vehicle injury crash of homogeneous group 2, and non motor vehicle injury crash of homogeneous group 3 were found to be significantly different to zero at the 5% level of significance. For the PDO crash group, rear end PDO crash

of homogeneous group 3 was found to have a significant crash rate. Table 14 presents the results of the trend analysis on each homogeneous group of each crash type and each severity level. The standard error value “S”, the R-squared value, the adjusted R-squared value, the F value, and the P value are shown. The cases that had a P value less than 0.05 were considered to have a significant crash trend and those cases have been highlighted in the table. The regression equation of each case is also given in the figure in terms of year and average crash rate as:

$$\text{Average crash rate} = \text{Intercept} + \text{Slope} * \text{Year}$$

Table 14
Results of trend analysis

| CRASH CASE | S | R ² | R ² _(Adj) | F | P | REGRESSION EQUATION |
|---|-------|----------------|---------------------------------|------|-------|---|
| FATALITY GROUP | | | | | | |
| RUN OFF ROAD CRASH TYPE | | | | | | |
| HG1 | 23.44 | 0.21 | 0.02 | 1.12 | 0.35 | Crash Rate _(Avg) = 62.78 + 5.920 Year |
| HG2 | 11.40 | 0.62 | 0.53 | 6.71 | 0.061 | Crash Rate _(Avg) = 76.03 - 7.061 Year |
| HG3 | 8.08 | 0.22 | 0.03 | 1.18 | 0.339 | Crash Rate _(Avg) = 33.58 + 2.095 Year |
| HEAD ON AND RIGHT ANGLE CRASH TYPE | | | | | | |
| HG1 | 15.21 | 0.33 | 0.17 | 2.01 | 0.229 | Crash Rate _(Avg) = 63.21 - 5.159 Year |
| HG2 | 11.98 | 0.32 | 0.15 | 1.91 | 0.239 | Crash Rate _(Avg) = 20.06 + 3.962 Year |
| HG3 | 3.61 | 0.16 | 0.00 | 0.77 | 0.43 | Crash Rate _(Avg) = 12.59 + 0.758 Year |
| HG4 | 17.18 | 0.34 | 0.17 | 2.09 | 0.222 | Crash Rate _(Avg) = 15.78 + 5.941 Year |
| SIDESWIPE AND TURNING ANGLE CRASH TYPE | | | | | | |
| HG1 | 39.83 | 0.07 | 0.00 | 0.24 | 0.656 | Crash Rate _(Avg) = 54.32 - 6.21 Year |
| HG2 | 5.91 | 0.55 | 0.43 | 4.89 | 0.092 | Crash Rate _(Avg) = 29.42 + 3.128 Year |
| HG3 | 4.07 | 0.01 | 0.00 | 0.04 | 0.85 | Crash Rate _(Avg) = 11.67 - 0.1960 Year |
| NON MOTOR VEHICLE CRASH TYPE | | | | | | |
| HG1 | 25.44 | 0.10 | 0.00 | 0.46 | 0.537 | Crash Rate _(Avg) = 94.00 - 4.104 Year |
| HG2 | 11.16 | 0.26 | 0.07 | 1.42 | 0.299 | Crash Rate _(Avg) = 25.59 + 3.181 Year |
| INJURY GROUP | | | | | | |
| RUN OFF ROAD CRASH TYPE | | | | | | |
| HG1 | 70.00 | 0.00 | 0.00 | 0 | 0.996 | Crash Rate _(Avg) = 182.7 - 0.10 Year |
| HG2 | 15.93 | 0.00 | 0.00 | 0 | 0.994 | Crash Rate _(Avg) = 110.8 + 0.028 Year |
| HG3 | 11.78 | 0.05 | 0.00 | 0.21 | 0.669 | Crash Rate _(Avg) = 64.41 + 1.296 Year |
| HG4 | 11.64 | 0.10 | 0.00 | 0.45 | 0.54 | Crash Rate _(Avg) = 68.09 - 1.860 Year |
| HG5 | 6.82 | 0.25 | 0.06 | 1.37 | 0.307 | Crash Rate _(Avg) = 43.85 + 1.908 Year |
| REAR END CRASH TYPE | | | | | | |
| HG1 | 15.08 | 0.46 | 0.33 | 3.52 | 0.134 | Crash Rate _(Avg) = 97.57 + 6.762 Year |
| HG2 | 25.80 | 0.18 | 0.00 | 0.91 | 0.395 | Crash Rate _(Avg) = 76.96 + 5.870 Year |

(Table 14 Continued.)

| CRASH CASE | S | R ² | R ² (Adj) | F | P | REGRESSION EQUATION |
|--|--------------|----------------|----------------------|--------------|--------------|--|
| REAR END CRASH TYPE | | | | | | |
| HG3 | 63.83 | 0.50 | 0.37 | 4.05 | 0.114 | Crash Rate _(Avg) =91.24 + 30.72 Year |
| HG4 | 84.13 | 0.18 | 0.00 | 0.89 | 0.4 | Crash Rate _(Avg) =198.3 - 18.94 Year |
| HG5 | 14.65 | 0.69 | 0.62 | 9.21 | 0.039 | Crash Rate_(Avg)=43.46 + 10.63 Year |
| HG6 | 5.10 | 0.62 | 0.52 | 6.54 | 0.063 | Crash Rate _(Avg) =45.07 + 3.121 Year |
| RIGHT ANGLE AND HEAD ON CRASH TYPE | | | | | | |
| HG1 | 18.38 | 0.40 | 0.25 | 2.7 | 0.17 | Crash Rate _(Avg) =113.9 + 7.223 Year |
| HG2 | 14.27 | 0.17 | 0.00 | 0.82 | 0.41 | Crash Rate _(Avg) =80.17 + 3.095 Year |
| TURNING ANGLE AND SIDESWIPE CRASH TYPE | | | | | | |
| HG1 | 97.80 | 0.01 | 0.00 | 0.06 | 0.82 | Crash Rate _(Avg) =106.4 + 5.67 Year |
| HG2 | 8.09 | 0.62 | 0.52 | 6.61 | 0.06 | Crash Rate _(Avg) =78.90 + 4.974 Year |
| NON MOTOR VEHICLE CRASH TYPE | | | | | | |
| HG1 | 19.3861 | 0.02 | 0.00 | 0.08 | 0.787 | Crash Rate _(Avg) =113.4 + 1.337 Year |
| HG2 | 10.08 | 0.79 | 0.74 | 15.82 | 0.016 | Crash Rate_(Avg)=61.68 + 9.592 Year |
| HG3 | 9.039 | 0.71 | 0.63 | 9.83 | 0.035 | Crash Rate_(Avg)=60.83 + 6.776 Year |
| HG4 | 5.30 | 0.23 | 0.047 | 1.25 | 0.327 | Crash Rate _(Avg) =53.62 - 1.416 Year |
| HG5 | 24.965 | 0.051 | 0.00 | 0.22 | 0.666 | Crash Rate _(Avg) =123.9 + 2.775 Year |
| PDO GROUP | | | | | | |
| RUN OFF ROAD AND OVERTURNING CRASH TYPE | | | | | | |
| HG1 | 35.02 | 0.01 | 0.00 | 0.05 | 0.829 | Crash Rate _(Avg) =160.3 + 1.926 Year |
| HG2 | 21.93 | 0.11 | 0.00 | 0.54 | 0.503 | Crash Rate _(Avg) =120.0 + 3.853 Year |
| HG3 | 16.85 | 0.63 | 0.54 | 7.02 | 0.057 | Crash Rate _(Avg) =69.41 + 10.68 Year |
| HG4 | 6.44 | 0.35 | 0.19 | 2.24 | 0.209 | Crash Rate _(Avg) =71.96 + 2.305 Year |
| HG5 | 21.44 | 0.08 | 0.00 | 0.36 | 0.58 | Crash Rate _(Avg) =86.68 - 3.079 Year |
| REAR END CRASH TYPE | | | | | | |
| HG1 | 56.81 | 0.61 | 0.51 | 6.31 | 0.066 | Crash Rate _(Avg) =176.4 + 34.12 Year |
| HG2 | 10.34 | 0.16 | 0.00 | 0.81 | 0.419 | Crash Rate _(Avg) =96.98 + 2.229 Year |
| HG3 | 28.26 | 0.69 | 0.62 | 9.15 | 0.039 | Crash Rate_(Avg)=201.7 + 20.43 Year |
| HG4 | 14.21 | 0.28 | 0.10 | 1.56 | 0.28 | Crash Rate _(Avg) =141.9 + 4.239 Year |
| RIGHT ANGLE AND SIDESWIPE CRASH TYPE | | | | | | |
| HG1 | 12.48 | 0.03 | 0.00 | 0.16 | 0.709 | Crash Rate _(Avg) =81.36 - 1.195 Year |
| HG2 | 47.90 | 0.08 | 0.00 | 0.36 | 0.58 | Crash Rate _(Avg) =156.0 + 6.89 Year |
| HG3 | 13.06 | 0.59 | 0.49 | 5.92 | 0.072 | Crash Rate _(Avg) =89.29 + 7.600 Year |
| NON MOTOR VEHICLE CRASH TYPE | | | | | | |
| HG1 | 17.53 | 0.44 | 0.30 | 3.14 | 0.151 | Crash Rate _(Avg) =83.32 + 7.430 Year |
| HG2 | 104.17 | 0.47 | 0.34 | 3.64 | 0.129 | Crash Rate _(Avg) =35.03 + 47.48 Year |
| HG3 | 48.56 | 0.37 | 0.219 | 2.4 | 0.196 | Crash Rate _(Avg) =120.3 + 18.00 Year |

Results of Adjustment of “After” Group for Trend over Time

Tables 15, 16, and 17 show the “before” speed limit change crash rate values (CR_{BEFORE}), original “after” speed limit change crash rate values ($CR_{AFT(Orig)}$), and the “adjusted” after speed limit change crash rate values ($CR_{AFT(Adj)}$) along with the slope of the trend line of the corresponding case used to calculate the adjusted crash rate value. The difference between the “before” years average ($Y_{AVG(Bef)}$) and the “after” years average ($Y_{AVG(Aft)}$) takes a constant value of 3 in all the cases. The tables show only the cases in which the trends were significant.

Table 15 shows the crash rate adjustment for the homogeneous group 5 of crash type 2 of the injury crash group. Table 16 shows the crash rate adjustment for homogeneous groups 2 and 3 of crash type 5 of the injury crash group. Table 17 shows the crash rate adjustment for the homogeneous group 3 of crash type 2 of the PDO crash group.

Table 15
Crash rate for rear end injury of homogeneous group 5

| INJURY GROUP - CRASH TYPE 2 -REAR END COLLISION | | | | | | |
|--|-----------------------------------|------------------|----------------------|----------------------------|---|-------------------------------|
| CRASH CASE | Year of Speed Limit Change | CR BEFORE | CR AFT (Orig) | Slope of Trend Line | $Y_{AVG(Aft)} - Y_{AVG(Bef)}$ | CR_{AFT} (Adj) |
| HG - 5 | 1999 | 71.1 | 37.6 | 10.6 | 3 | 5.7 |
| | 2000 | 108.6 | 99.2 | 10.6 | 3 | 67.3 |
| | 2001 | 21.1 | 69.8 | 10.6 | 3 | 37.9 |
| | 2002 | 75.7 | 383.1 | 10.6 | 3 | 351.2 |
| | 2003 | 110.3 | 47.9 | 10.6 | 3 | 16.0 |

Table16
Crash rate for non motor vehicle injuries of homogeneous groups 2 and 3

| INJURY GROUP | | | | | | |
|---|-----------------------------------|------------------|--------------------------------|----------------------------|--|------------------------------|
| CRASH TYPE 5-NON MOTOR VEHICLE CRASHES | | | | | | |
| CRASH CASE | Year of Speed Limit Change | CR BEFORE | CR_{AFT} (Orig) | Slope of Trend Line | Y_{AVG(Aft)} - Y_{AVG(Bef)} | CR_{AFT(Adj)} |
| HG - 2 | 1999 | 22.1 | 126.3 | 9.5 | 3 | 97.6 |
| | 2000 | 50.7 | 17.04 | 9.5 | 3 | -11.7 |
| | 2001 | 46.2 | 81.5 | 9.5 | 3 | 52.8 |
| | 2002 | 67.0 | 579.8 | 9.5 | 3 | 551.0 |
| | 2003 | 61.4 | 51.8 | 9.5 | 3 | 23.1 |
| HG - 3 | 1999 | 86.9 | 58.4 | 6.7 | 3 | 38.1 |
| | 2000 | 103.3 | 64.0 | 6.7 | 3 | 43.6 |
| | 2001 | 58.1 | 71.3 | 6.7 | 3 | 51.0 |
| | 2002 | 69.1 | 92.1 | 6.7 | 3 | 71.7 |
| | 2003 | 67.6 | 74.1 | 6.7 | 3 | 53.7 |

Table 17
Crash rate for rear end pdo crashes of homogeneous group 3

| PDO GROUP | | | | | | |
|--|-----------------------------------|------------------|--------------------------------|----------------------------|--|------------------------------|
| CRASH TYPE 2-REAR END COLLISION | | | | | | |
| CRASH CASE | Year of Speed Limit Change | CR BEFORE | CR_{AFT} (Orig) | Slope of Trend Line | Y_{AVG(Aft)} - Y_{AVG(Bef)} | CR_{AFT(Adj)} |
| HG - 3 | 1999 | 59.6 | 222.2 | 20.4 | 3 | 160.9 |
| | 2000 | 378.7 | 278.5 | 20.4 | 3 | 217.2 |
| | 2001 | 82.36 | 167.6 | 20.4 | 3 | 106.3 |
| | 2002 | 155. | 110.4 | 20.4 | 3 | 49.1 |
| | 2003 | 61.2 | 122.5 | 20.4 | 3 | 61.2 |

Results of Paired T-Test Comparison

Upper-tailed paired sample t-tests were performed on all pairs of values obtained after adjustment of “after” crash rate values for each crash type and severity. Table 18 presents the results of the single tailed paired sample t-test conducted on each homogeneous group of each crash type and each severity type. The paired sample t-test was conducted only on those crash types that had sufficient pairs of values in the fatality group (i.e., 4 of the 12 shown in table 14). Table 18 shows that in the four fatality crash cases listed, no significant increase in crash rate was found after a speed limit change in any of the years.

In the injury crash group, for the run-off road crash case of homogeneous group 5, rear end crash case of homogeneous group 2, and non motor vehicle crash case of homogeneous group 4, a significant increase in crash rate was observed after a speed limit increase. In all the other injury crash cases, no significant increase in crash rate was found.

In the PDO group, the run off road and overturning PDO crash case for homogeneous group 1 and homogeneous group 5 and rear end crash case of homogeneous group 2 were found to have a significant increase in crash rate with speed limit increase. However, in all other PDO cases, no significant change in crash rate with an increase in speed limit was observed.

Thus, of the 39 homogeneous crash types tested using the paired sample t-test, 6 cases demonstrated a significant increase in crash rate following an increase in speed limit. This observation demonstrates that, in general, with an indeterminate amount of speed limit increase, there is a significant increase in the crash rates for run-off road and overturning crashes, rear-end crashes, and non-motor vehicle crashes in the injury and PDO level of severity. This trend may not have appeared significant in the fatality group because of insufficient pairs of observations in this group.

Table 18

Statistical comparison of homogeneous group crash rates

| CRASH TYPE | MEAN | | | STD DEV | | | SE MEAN | | | 95% Lower Bound | T | P | TEST RESULT |
|---|--------|--------|--------|---------|--------|--------|---------|------|-------|--------------------|-------|-------|-----------------|
| | BEF | AFT | DIFF | BEF | AFT | DIFF | BEF | AFT | DIFF | | | | |
| FATALITY GROUP | | | | | | | | | | | | | |
| CRASH TYPE 1 - RUN OFF ROAD | | | | | | | | | | | | | |
| CT1_HG2 | 11.6 | 34.9 | 23.3 | 5.1 | 22.7 | 26.6 | 2.5 | 11.3 | 13.3 | -8.0 | 1.75 | 0.089 | Not Significant |
| CT1_HG3 | 127.2 | 18.7 | -108.4 | 139.4 | 13.5 | 152.9 | 80.5 | 7.8 | 88.3 | -366.3 | -1.23 | 0.828 | Not Significant |
| CRASH TYPE 2 - HEAD ON AND RIGHT ANGLE | | | | | | | | | | | | | |
| CT2_HG1 | 63.1 | 75.3 | 12.2 | 63.4 | 53.5 | 9.9 | 44.8 | 37.8 | 7.0 | -31.99 | 1.74 | 0.166 | Not Significant |
| CT2_HG2 | 50.0 | 12.2 | -37.7 | 11.6 | 1.8 | 13.5 | 8.2 | 1.2 | 9.5 | -97.96 | -3.96 | 0.921 | Not Significant |
| INJURY GROUP | | | | | | | | | | | | | |
| CRASH TYPE 1 - RUN OFF ROAD | | | | | | | | | | | | | |
| CT1_HG1 | 216.2 | 169.7 | -46.6 | 319.8 | 146.9 | 362.7 | 143.0 | 65.7 | 162.2 | -392.34 | -0.29 | 0.606 | Not Significant |
| CT1_HG2 | 98.6 | 204.1 | 105.4 | 37.8 | 138.9 | 111.2 | 16.9 | 62.2 | 49.7 | -0.56 | 2.12 | 0.051 | Not Significant |
| CT1_HG3 | 123.4 | 103.5 | -19.9 | 67.1 | 34.6 | 54.8 | 30.4 | 15.4 | 24.5 | -72.22 | -0.81 | 0.769 | Not Significant |
| CT1_HG4 | 105.3 | 47.5 | -57.8 | 60.2 | 20.2 | 66.5 | 30.1 | 10.1 | 33.2 | -136.02 | -1.74 | 0.91 | Not Significant |
| CT1_HG5 | 48.5 | 133.3 | 84.87 | 21.7 | 80.5 | 76.5 | 9.7 | 36.0 | 34.2 | 11.91 | 2.48 | 0.034 | Significant |
| CRASH TYPE 2 - REAR END | | | | | | | | | | | | | |
| CT2_HG1 | 147.0 | 115.9 | -31.0 | 132.1 | 28.2 | 110.6 | 66.1 | 14.1 | 55.2 | -161.21 | -0.56 | 0.693 | Not Significant |
| CT2_HG2 | 37.9 | 130.1 | 92.1 | 19.5 | 51.7 | 58.3 | 8.7 | 23.1 | 26.1 | 36.61 | 3.54 | 0.012 | Significant |
| CT2_HG3 | 69.5 | 160.79 | 91.29 | 46.75 | 86.1 | 113.9 | 23.4 | 43.1 | 56.9 | -42.83 | 1.6 | 0.104 | Not Significant |
| CT2_HG4 | 85.0 | 149.9 | 64.8 | 108.4 | 124.8 | 203.6 | 54.2 | 62.4 | 101.8 | -174.79 | 0.64 | 0.285 | Not Significant |
| CT2_HG5 | 77.3 | 95.7 | 18.3 | 36.3 | 144.8 | 149.4 | 16.2 | 64.7 | 66.8 | -124.18 | 0.27 | 0.399 | Not Significant |
| CT2_HG6 | 47.7 | 61.3 | 13.9 | 4.9 | 19.9 | 20.4 | 2.1 | 8.8 | 9.1 | -5.86 | 1.49 | 0.105 | Not Significant |
| CRASH TYPE 3 - RIGHT ANGLE AND HEAD ON | | | | | | | | | | | | | |
| CT3_HG1 | 197.5 | 141.8 | -55.6 | 151.8 | 94.3 | 141.9 | 67.9 | 42.1 | 63.5 | -190.91 | -0.88 | 0.785 | Not Significant |
| CT3_HG2 | 109.95 | 154.84 | 44.89 | 68.32 | 205.62 | 246.46 | 30.556 | 91.9 | 110.2 | -190.00 | 0.41 | 0.352 | Not Significant |
| CRASH TYPE 4 - TURNING ANGLE AND SIDESWIPE | | | | | | | | | | | | | |
| CT4_HG1 | 24.0 | 25.8 | 1.8 | 4.0 | 12.3 | 15.4 | 2.0 | 6.1 | 7.7 | -16.34 | 0.24 | 0.411 | Not Significant |
| CT4_HG2 | 85.0 | 97.2 | 12.1 | 27.0 | 15.5 | 39.8 | 12.1 | 6.9 | 17.8 | -25.72 | 0.68 | 0.266 | Not Significant |

(Table 18 Continued.)

| CRASH TYPE | MEAN | | | STD DEV | | | SE MEAN | | | 95% Lower Bound | T | P | TEST RESULT |
|--|-------|-------|-------|---------|-------|-------|---------|-------|-------|--------------------|-------|-------|-----------------|
| | BEF | AFT | DIFF | BEF | AFT | DIFF | BEF | AFT | DIFF | | | | |
| CRASH TYPE 5 - NON MOTOR VEHICLE CRASH | | | | | | | | | | | | | |
| CT5_HG1 | 191.5 | 161.2 | -30.3 | 187.2 | 95.5 | 156.9 | 83.7 | 42.7 | 70.2 | -180.00 | -0.43 | 0.656 | Not Significant |
| CT5_HG2 | 49.5 | 142.6 | 93.1 | 17.4 | 231.8 | 224.7 | 7.7 | 103.6 | 100.5 | -121.15 | 0.93 | 0.203 | Not Significant |
| CT5_HG3 | 77.00 | 51.6 | -25.3 | 18.0 | 12.7 | 27.2 | 8.0 | 5.7 | 12.2 | -51.39 | -2.08 | 0.947 | Not Significant |
| CT5_HG4 | 24.5 | 63.5 | 38.9 | 13.3 | 29.2 | 36.4 | 5.9 | 13.0 | 16.3 | 4.15 | 2.39 | 0.038 | Significant |
| CT5_HG5 | 117.1 | 199.5 | 82.4 | 71.4 | 157.9 | 174.4 | 31.9 | 70.64 | 78.01 | -83.89 | 1.06 | 0.175 | Not Significant |
| PDO GROUP | | | | | | | | | | | | | |
| CRASH TYPE 1 - RUN OFF ROAD AND OVERTURNING | | | | | | | | | | | | | |
| CT1_HG1 | 117.3 | 256.9 | 139.6 | 44.5 | 135.2 | 108.5 | 19.9 | 60.5 | 48.5 | 36.14 | 2.88 | 0.023 | Significant |
| CT1_HG2 | 88.5 | 402.6 | 314.1 | 30.9 | 667.7 | 665.5 | 13.8 | 298.6 | 297.6 | -320.42 | 1.06 | 0.175 | Not Significant |
| CT1_HG3 | 62.9 | 103.5 | 40.5 | 30.0 | 41.6 | 67.6 | 13.4 | 18.6 | 30.2 | -23.96 | 1.34 | 0.126 | Not Significant |
| CT1_HG4 | 84.3 | 135.1 | 50.7 | 40.7 | 80.9 | 83.7 | 18.2 | 36.2 | 37.4 | -29.08 | 1.36 | 0.123 | Not Significant |
| CT1_HG5 | 42.1 | 64.1 | 22.0 | 8.1 | 16.5 | 22.5 | 3.6 | 7.4 | 10.1 | 0.48 | 2.18 | 0.047 | Significant |
| CRASH TYPE 2 - REAR END | | | | | | | | | | | | | |
| CT2_HG1 | 161.0 | 158.9 | -2.0 | 69.5 | 100.0 | 100.4 | 31.2 | 44.7 | 44.9 | -97.80 | -0.05 | 0.517 | Not Significant |
| CT2_HG2 | 97.4 | 148.0 | 50.6 | 41.0 | 71.6 | 46.4 | 18.3 | 32.0 | 20.7 | 6.38 | 2.44 | 0.036 | Significant |
| CT2_HG3 | 147.5 | 118.9 | -28.5 | 135.1 | 70.4 | 105.1 | 60.4 | 31.5 | 47.0 | -128.74 | -0.61 | 0.712 | Not Significant |
| CT2_HG4 | 94.2 | 221.0 | 126.8 | 36.2 | 216.7 | 197.6 | 16.1 | 96.93 | 88.38 | -61.62 | 1.43 | 0.112 | Not Significant |
| CRASH TYPE 3 - RIGHT ANGLE AND SIDESWIPE | | | | | | | | | | | | | |
| CT3_HG1 | 82.5 | 79.9 | -2.7 | 38.7 | 24.1 | 46.9 | 17.3 | 10.7 | 21.0 | -47.43 | -0.13 | 0.548 | Not Significant |
| CT3_HG2 | 112.9 | 119.4 | 6.4 | 64.3 | 43.6 | 83.2 | 28.7 | 19.5 | 37.2 | -72.93 | 0.17 | 0.436 | Not Significant |
| CT3_HG3 | 106.3 | 118.2 | 11.9 | 59.9 | 33.8 | 49.3 | 26.7 | 15.1 | 22.1 | -35.12 | 0.54 | 0.309 | Not Significant |
| CRASH TYPE 4 - NON MOTOR VEHICLE CRASH | | | | | | | | | | | | | |
| CT4_HG1 | 121.5 | 168.8 | 47.3 | 37.5 | 97.5 | 97.8 | 16.7 | 43.6 | 43.7 | -45.99 | 1.08 | 0.170 | Not Significant |
| CT4_HG2 | 84.4 | 137.8 | 53.4 | 17.7 | 51.6 | 61.2 | 7.9 | 23.1 | 27.4 | -4.99 | 1.95 | 0.061 | Not Significant |
| CT4_HG3 | 177.2 | 302.1 | 124.8 | 95.1 | 329.1 | 322.4 | 42.5 | 147.2 | 144.2 | -182.62 | 0.87 | 0.218 | Not Significant |

CONCLUSIONS

Study Summary

This study investigated the effect of a speed limit increase on crash rates on rural two-lane highways in Louisiana, using six-year crash data (1999-2004) to observe the impact that speed limit increases have had on crash rates in Louisiana in the past. The crash data contained details of all the roadway sections and the speed limits of each section for each year. The crash rates were calculated for all the sections for all the years, and the sections that underwent a speed limit change were separated according to the year of speed change from the sections that did not undergo a speed limit change over the entire period.

The approach focused on grouping the crashes according to crash type and severity level, and then using a classification procedure to identify homogeneous groups of factors affecting the crash rate within each crash and severity type. The homogeneous groups were established so that, within each group, all factors affecting crash rate except speed limit, remain relatively constant. Thus, the effect of speed limit change on crash rate was retained within the analysis while the impact of other factors was reduced through grouping of the data.

The no speed limit change sections in each homogeneous group were observed for their natural trend. Then, any significant trend in crash rate was used to adjust the after speed limit change crash rate for the same group in the speed limit change group. In this way, natural trends in crash rates were accounted for and were not allowed to affect the results of the analysis.

To test the significance of a speed limit increase on the crash rate, a single-tailed paired sample t-test was conducted on the before and after speed limit change crash rate pairs obtained for 39 of the 47 homogeneous groups of crash type and severity type. Based on the results, the null hypothesis that an increase in speed limit had no effect on crash rate was rejected for 6 out of the 39 cases.

Conclusions

Based on the analyses and results reported in the previous chapter, the following conclusions were drawn from the present study:

- The hypothesis that an increase in speed limit does not lead to an increase in crash rate was rejected at the 5 percent level of significance in 6 out of 39 crash type groups investigated in this study. The six crash type groups found to display a significant increase in crash rate with an increase in speed limit were:
 - Injury, run-off-road crashes on straight road sections, where the pavement surface contained no deep ruts, and the pavement was between 23 and 29 feet wide
 - Injury, rear-end crashes involving male drivers on road sections with traffic signals and pavement width greater than 21 feet.
 - Injury, non-motor vehicle crashes in non-residential areas on roads with pavement width wider than 21.5 feet
 - Property-damage-only (PDO) run-off-road and overturning crashes that occur after 10.30 p.m. at night on open roads with curved alignment, and pavement widths that are greater than 21.5 feet wide

- PDO run-off-road and overturning crashes that occur at dawn, dusk, during the day, or at night on roads with limited lighting, on roads with straight alignment and pavement widths in excess of 23 feet
- PDO rear-end crashes in non-commercial areas (i.e. non-business such as residential, manufacturing, and industrial areas) on roads with pavements wider than 27 feet.
- Failure to reject the null hypothesis in the rest of the 33 cases may be due to the high variance in the average crash rate in the analysis. In tables 15-17 the crash rates used in 3 of the 39 cases considered in the analysis are shown, and it is clear that the crash rate before (third column in tables 15-17) and crash rate after adjustment (last column), display a wide degree of variation in each year. The paired t-test used the values paired by year in which the speed limit occurred.
- The classification procedure employed in this study was found to be effective in grouping the contributing factors in only a few of the crash categories. In some cases, the classification procedure was able to capture less than 10% of the influence of factors affecting crash rates (see table 13). Those cases where the classification procedure was more successful were:
 - Turning angle and side swipe fatality crash type, which captured 84.7% of the variance of the model and for which the alignment condition was the most important determining factor for the crash rate value of this group.,
 - Non motor vehicle fatality crash type which captured 64.6% of the variance and for which the pavement width was the most determining factor.

- Turning angle and side swipe injury crash type, which captured 56.5% of the variance and for which pavement width and violations were the most determining factor.
- Based on the results of the trend plot for the no speed limit change group (table 14) the following crash types were found to have a significant increase in crash trend from 1999-2004, even without a speed limit increase:
 - Rear end injury crashes of homogeneous group 5
 - Non motor vehicle injury crashes of homogeneous group 2 and 3
 - Rear end PDO crashes of homogeneous group 3
 - Non Motor Vehicle Crashes
- As noted in the literature review, according to the National Safety Council, the economic costs of motor-vehicle crashes in the year 2004 has been estimated as \$1,130,000 per fatal crash, \$49,700 per injury crash and \$7,400 per PDO crash. Equating these values to the number of crashes before and after a speed limit change in each of the 6 significant categories identified in this study, permits estimation of the economic impact of a speed limit increase on two-lane highways in Louisiana. If the speed limit were increased to the same degree that the speed limit has been increased on individual two-lane, rural road sections in Louisiana in the past, the estimated total cost among those crash types identified as being significantly affected by a speed limit increase in this study would be as shown in table 19 below. It is possible that it could be higher due to increases in crash rates among those crash types not identified as being significantly affected by a speed limit increase.

Table 19
Estimated annual cost of an increase in speed limit

| Severity | Crash Type | Average No. Of Crashes Per Annum Before Speed Change | Average No. Of Crashes Per Annum After Speed Change | Annual Cost Before Speed Limit Increase | Annual Cost After Speed Limit Increase | % Increase In Cost |
|-----------------|--|---|--|--|---|---------------------------|
| Injury | Run-off road crashes of HG5 | 102 | 224 | \$5.1m | \$11.1m | 120% |
| | Rear-end crashes of HG 2 | 51 | 55 | \$2.5m | \$ 2.7m | 8% |
| | Non-motor vehicle crashes of HG 4 | 27 | 58 | \$1.3m | \$2.9m | 115% |
| PDO | Run-off road & overturning of HG 1 | 79 | 157 | \$0.6m | \$1.2m | 100% |
| | Run-off road & overturning crash of HG 5 | 113 | 216 | \$0.8m | \$1.6m | 100% |
| | Rear-end crashes of HG 2 | 258 | 308 | \$1.9m | \$ 2.3m | 19% |

RECOMMENDATIONS

This study has shown that the crash rate of certain types of crashes on two-lane rural roads has increased significantly with an increase in speed limit in Louisiana in the past. However, for the remaining types of crashes, we have insufficient evidence to prove that crash rate has increased in response to an increase in speed limit.

An increase in speed limit that leads a motorist to increase their speed from, say, an average of 55 mph on two-lane rural roads in Louisiana to, say, 65 mph, will save approximately 5 minutes on a 30-mile journey, or less than 10 minutes on a journey that took him or her an hour before. Considering that the National Household Travel Survey reports that the average rural trip length in Louisiana in 2001 was 10.3 miles, rural travelers would save on average less than 2 minutes per trip (NHTS, 2001).

It is recommended that the speed limit on two-lane rural roads in Louisiana not be increased except on sections where an engineering study determines that it would be safe to increase the speed limit on that section.

REFERENCES

- Agent, K.R., J. G. Pigman, and J. M. Weber. "Evaluation of Speed Limits in Kentucky." In *Transportation Research Record 1640*, Paper No. 98-1542, TRB, National Research Council, Washington, D.C., 1998.
- Answer Tree TM 1.0 User's Guide, Statistical Package for Social Sciences (SPSS) Inc., 1998.
- Cirillo, J.A. "Interstate System Accident Research—Study II—Interim Report II." *Public Roads*, Vol. 35, No. 3. 1968
- Cowley, J.E. "The Relationship between Speed and Accidents: A Literature Review", J.E. Cowley & Associates, Melbourne, Australia, March 1987.
- Dougherty, G. W. Jr. "Increasing the Speed Limit in Georgia: Have Rural Highways Become More Dangerous?" University of Georgia. May 2000.
- FHWA. "Evaluation of Design Consistency Methods for Two-Lane Rural Highways." Publication No. FHWA-RD-99-173, USDOT, August 2000.
- FHWA, Highway Statistics 2003. <http://www.fhwa.dot.gov/policy/ohim/hs03/re.htm>. Date Accessed: 6-6-2005.
- Fildes, B.N., G. Rumbold, and A. Leening. "Speed Behavior and Drivers' Attitude to Speeding." Report 16, Monash University Accident Research Center, Monash, Victoria, Australia, June 1991.
- GAO, "Highway Safety- Federal and State Efforts to Address Rural Road Safety Challenges", Publication No. GAO-04-663, May 2004.
- Garber, N.J., and R. Gadiraju. "Speed Variance and Its Influence on Accidents." University of Virginia, Charlottesville, July, 1988, pp. 56.
- Harkey, D.L., H.D. Robertson, and S.E. Davis. "Assessment of Current Speed Zoning Criteria." In *Transportation Research Record 1281*, Transportation Research Board, National Research Council, Washington, D.C., 1990. pp. 40–51.
- Hauer, E. (1971), "Accidents, Overtaking and Speed Control." In *Accident Analysis and Prevention*, Vol. 3, pp. 1–13.
- Insurance Institute of Highway Safety. Speed Limit Laws 2005. http://www.iihs.org/safety_facts/state_laws/speed_limit_laws.htm. Date Accessed: 06-10-2005.

Institute of Transportation Engineers (ITE), Traffic Engineering Handbook: Fourth Edition (J.L. Pline, ed.), Prentice Hall, Englewood Cliffs, New Jersey, 1992.

Kloeden, C.N., G. Ponte and A.J. McLean. "Traveling Speed and the Risk of Crash Involvement on Rural Roads." Road Accident Research Unit, Adelaide University, South Australia, July 2001.

Kloeden, C.N., A.J. McLean, V.M. Moore, and G. Ponte. Traveling Speed and the Risk of Crash Involvement. Vol. I—Findings. NHMRC Road Accident Research Unit, University of Adelaide, Australia, Nov 1997, pp. 60.

Lave, C. (1985). "Speeding, Coordination, and the 55-mph Limit." *The American Economic Review*, Vol. 75, pp. 1159–1164.

Louisiana Highway Safety Commission (LHSC). Speed Report Highlights, 2003. http://lhsc.lsu.edu/TrafficReports/dynamic_summary/summary.asp?year=2003#I. Date Accessed: 06-06-2005.

Munden, J.W. "The Relation between a Driver's Speed and his Accident Rate." Report LR 88. Road Research Laboratory, Crowthorne, England, 1967.

Najjar, Y. M., R.W. Stokes, E. R. Russell, H.E. Ali and Xiaobin "Carol" Zhang. "Impact of New Speed Limits on Kansas Highways". Report No. K-TRAN: KSU-98-3, Kansas State University, Manhattan, Kansas. November 2000.

National Household Travel Survey, 2001. <http://nhts.ornl.gov/2001>. Date Accessed: 07-17-2006.

National Highway Traffic Safety Administration (NHTSA). "Report to Congress: The Effect of Increased Speed Limits in the Post-NMSL Era", for Federal Highway Administration, U. S. Department of Transportation, Washington, D.C. 1998.

NHTSA. Summary of State Speed Limit Laws, 2001. <http://www.nhtsa.dot.gov/people/injury/enforce/speedlaws501/toc/laspeed.pdf>. Date Accessed: 06-18-2005.

NHTSA. "Traffic Safety Facts – Speeding" For U.S. Department of Transportation, 1995.

National Safety Council, and Children's Safety Network, Economics and Data Analysis Resource Center, December, 2005.

Reed R. "Impact of the Speeding Fine Function on Driver Coordination on State Highways."

National Transportation Center, Morgan State University, Baltimore, MD, November 2001.

Shinar, D. "Psychology on the Road: The Human Factor in Traffic Safety." Wiley, New York. 1978.

Solomon, D. "Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle". Bureau of Public Roads, U.S. Department of Commerce, 1964. pp. 44.

The Road Information Program (TRIP) "Growing Traffic in Rural America: Safety, Mobility and Economic Challenges in America's Heartland." Washington, D.C., March 2005

Thornton, M. and R. W. Lyles. "Freeway Speed Zones: Safety and Compliance Issues." In *Transportation Research Record 1560*, TRB National Research Council, Washington, D.C., 1999.

Transportation Research Board, "Managing Speed - Review of Current Practice for Setting and Enforcing Speed Limits." National Research Council National Academy Press, Washington, D.C., 1998.

West, L.B., Jr., and J.W. Dunn. Accidents, Speed Deviation and Speed Limits. *Traffic Engineering*, Vol. 41, No. 10, 1971. pp. 52-55.

White, S.B., Jr., and A.C. Nelson, Jr. Some Effects of Measurement Errors in Estimating Involvement Rate as a Function of Deviation from Mean Traffic Speed. *Journal of Safety Research*, Vol. 2, No. 2, June, 1970. pp. 67-72.

This public document is published at a total cost of \$581.00. Fifty copies of this public document were published in this first printing at a cost of \$446.00. The total cost of all printings of this document including reprints is \$581.00. This document was published by Louisiana State University, Graphic Services, 3555 River Road, Baton Rouge, Louisiana 70802, and Louisiana Transportation Research Center, to report and publish research findings for the Louisiana Transportation Research Center as required in R.S. 48:105. This material was duplicated in accordance with standards for printing by state agencies established pursuant to R.S. 43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.