Final Report

Effectiveness of Rumble Stripes on Roadway Safety in Mississippi

Study No. 196

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16. Abstract

Although traffic deaths are caused by an array of factors, in the United States more than half of all roadway fatalities are caused by roadway departures [FHWA 2006]. In 2003, there were 25,562 roadway departure fatalities, accounting for 55 percent of all roadway fatalities in the United States. Roadway departure includes run-off-the-road (ROR) and head-on fatalities. In 2003, more than 16,700 people died in ROR crashes (39 percent of all roadway fatalities), and head-on crashes represented 12 percent of all fatal crashes [FHWA 2006]. On average, one roadway departure fatality crash occurred every 23 minutes. An average of one roadway departure injury crash occurred every 43 seconds [FHWA 2006]. In short, roadway departures are a significant and serious problem in the United States.

MDOT through the Traffic Engineering Division is committed to improve Mississippi highway safety. MDOT has invested valuable resources to implement a series of safety improvement programs such as the "Rumble Stripes" program. Unfortunately, there is a dearth of studies documenting the impact of Rumble Stripes on roadway safety. Thus, this study summarizes an effort funded by the MDOT to quantitatively document the safety impact of rumble stripes in Mississippi. Both descriptive and inferential statistics were used to determine the safety impact. Thirteen road segments were selected to collect and process the data for this research project. The results presented in this paper intend to serve as a sample of the impact of this type of programs. Furthermore, other projects and other departments of transportations might benefit with implementing the analysis presented here as an avenue to quantify the safety impact of rumble stripes an other safety programs.

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FORWARD

This manual provides a valuable resource for people who analyze the impact of roadway safety programs. Safety analysis is difficult and often require data that is not available or require extensive manipulation. This Mississippi Department of Transportation Study No. 196 "Effectiveness of Rumble Stripes on Roadway Safety in Mississippi" was conducted by the University of Southern Mississippi in collaboration with MDOT. This document will be of particular interest to individuals who plan and evaluate the benefits of investments in public roadways safety. Other audiences for this document include policymakers, transportation professionals, and students in related fields.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This document presents the results of evaluating the safety impact of Rumble Stripes on Highway Safety in Mississippi. The evaluation is based on a nationwide literature review of Rumple Stripes; (2) data obtained from the MDOT and (3) a statistical analysis of the compiled Mississippi data and the nationwide literature findings.

The results of the statistical analysis indicate the following:

- Analysis 1 - Rumble Stripe Presence on the Roadway Vs. Number of Overall Crashes.

  Results: There is statistically no significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area.

- Analysis 2 - Rumble Stripes on the Roadway Vs. Number of Roadway Departures.

  Results: There is statistically a significant difference in the number of roadway departures between the period before construction and the period after construction. The use of rumble stripes on the roadway produces a decrease in the roadway departures.

- Analysis 3 - Lighting Conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) Vs. Number of Overall Crashes.

  Results: There is statistically no significant difference in the number of crashes between the period before construction and the period after construction in the studied roadway segments considering the lighting conditions.

- Analysis 4 - Lighting Conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) Vs. Number of Roadway Departures.

  Results: There is statistically a significant difference in the number of roadway departures between the period before construction and the period after construction. The use of rumble stripes on the roadway produces a reduction in the roadway departures under different lighting conditions.

- Analysis 5 - Roadway Conditions (Dry/Wet/Snow) Vs. Number of Overall Crashes.

  Results: There is statistically no significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area considering the roadway conditions.

- Analysis 6 - Roadway Conditions (Dry/Wet/Snow) Vs. Number of Roadway Departures

  Results: There is statistically a significant differences on the number of roadway departures under different road conditions. The use of rumble stripes on the roadway produces a definite reduction in the roadway departures under different roadway conditions.

- Analysis 7 - Rumble Stripes on the Roadway Vs. Crash Severity (5: Property Damage, 4: Complaint of Pain, 3: Moderate, 2: Life threatening, 1: Fatal).

  Results: There is no statistically significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area considering the injury severity.

- Analysis 8 - Rumble Stripes on the Roadway Vs. Crash Severity of Roadway of Roadway Departures (5: Property Damage, 4: Complaint of Pain, 3: Moderate, 2: Life threatening, 1: Fatal).

  Results: There is statistically a significant difference in the number of roadway departures between the period before construction and the period after construction. The use of rumble stripes on the roadway produces a definite decrease in the severity crashes based on roadway departures.

ECONOMIC AND SOCIETAL IMPACT OF RUMBLE STRIPES

An analysis evaluating the cost impact of Rumble Stripes was conducted. While there are many way of calculating this impact, the analysis of the research team focused the cost of roadway departures based on the crash cost information provided by AASHTO for Mississippi based on the Severity Classification. More specifically, the research team compared cost before and after the construction project based on number of roadway departures per month per mile utilizing and the crash cost from AASHTO.

In this study, the savings of the projects on crash cost was 79.0% for projects with only marking and 86.2% for projects with rumble strips/stripes. This means that providing markings on roadways provides a 79% savings based on crash severity. The use of Rumble Stripes provides an additional 7.2% savings over markings only.

IN SUMMARY

It was found that all agencies that participated in the study consider the safety of drivers on Mississippi roadways of paramount importance. It was also found that all MDOT agencies were very willing to collaborate in the data consolidation process. However, collecting, archiving and retrieving information was not a main priority for any of these agencies. Additionally, no general guidelines for data structuring was communicated among the agencies. Therefore, it was evident that input into the data gathering process before the data is collected rather than after the fact, could greatly improve the process of assessing the impact of Rumble Stripes or any other program. By defining the data to be collected, the method for collecting the data, the formatting of the data, and the timeframes for collecting the data (before, during and after construction), all the participating agencies would be able to share information and to demonstrate the impact of their performance to the stakeholders.

It is suggested that the creation of a data structure will allow agencies to share common data for common purposes and reduces the cost of the data collection efforts and analysis. It is also suggested to evaluate all MDOT safety initiatives to identify the most effective method to increase driver safety.

Chapter 1:
BACKGROUND ON EFFECTIVENESS OF RUMBLE STRIPES ON ROADWAY SAFETY

1.1. PROBLEM STATEMENT

The Mississippi Department of Transportation (MDOT), according to its mission statement, is responsible for providing a safe intermodal transportation network [MDOT 2006]. However in 2001 the National Safety Council ranked Mississippi as the worst state in three categories for motor vehicle safety. These three categories include; the greatest number of traffic deaths (1) per million miles driven, (2) per 10,000 vehicles registered, and (3) per 100,000 population. [Breazeale 2001].

Although traffic deaths are caused by an array of factors, in the United States more than half of all roadway fatalities are caused by roadway departures [FHWA 2006]. In 2003, there were 25,562 roadway departure fatalities, accounting for 55 percent of all roadway fatalities in the United States. Roadway departure includes run-off-the-road (ROR) and head-on fatalities. In 2003, more than 16,700 people died in ROR crashes (39 percent of all roadway fatalities), and head-on crashes represented 12 percent of all fatal crashes [FHWA 2006]. On average, one roadway departure fatality crash occurred every 23 minutes. An average of one roadway departure injury crash occurred every 43 seconds [FHWA 2006]. In short, roadway departures are a significant and serious problem in the United States.

The MDOT through the Traffic Engineering Division is commitment to improve Mississippi highway safety. MDOT has invested valuable resources to implement a series of safety improvement programs such as the Rumble Stripes program. Despite MDOT's high commitment and efforts to improve highway safety, MDOT does not know the impact of the Rumble Stripe program in reducing crashes. In other words, MDOT lacks quantifiable evidence that demonstrates the effectiveness of this program.

The MDOT Traffic Engineering Division initiative to quantify the effectiveness of the "Rumble Stripes" programs will provide the decision makers with the much-needed factual information. This factual information will help to make continuous enhancements in safety programs, which will led to Mississippi roadway safety improvements. These improvements will come by identifying and implementing the most cost effective roadway safety programs, therefore, improving Mississippi's rank within the National Safety Council regarding roadway safety.

1.2. OVERVIEW

The MDOT has placed or has under contract (as of Jan 2005) 1094 lane miles of rumble stripes on Mississippi roads such as: (1) I-59; (2) US-98; and (3) SR 589 [Jordan, 2005, Lindly 2003]. The objective of this project is to evaluate the safety impact of the Rumble Stripes program. This objective will be achieved by (1) collecting historical and field data from selected Mississippi roadways, before and after the construction of Rumble Stripes; (2) reviewing nationwide literature on Rumble Stripes effectiveness; and (3) analyzing the compiled Mississippi data and the nationwide literature findings. The following is a brief description of these three components:

a- Collecting historical and field data from selected Mississippi roadways, before and after the construction of Rumble Stripes: The collection of historical and field data in Mississippi will begin by consolidating MDOT and other governmental entities' historical data. The data consolidation will include: (a) characteristics of the road (such as locations, conditions before, and after the construction), (b) traffic parameters (such as volume before, and after construction), and (c) accident information (such as: location, time, severity, and cause of the crash). The historical data collection will be followed by gathering current and accurate field data. This field data will include: (a) characteristics of the road (such as: field inspection of the Rumble Stripes), (b) traffic parameters in the road (such as: volume and speed), and (c) crash information in the road (such as: location, time, and cause).

b- Reviewing nationwide literature on Rumble Stripes effectiveness: Another important component of this study will be a literature review on Rumble Stripes effectiveness. This review will focus on identifying the impact of Rumble Stripes in other states. Additionally, nationwide effectiveness criterion disseminated by: U.S. Department of Transportation's Federal Highway Administration [FHWA 2003], the American Association of State Highway and Transportation Officials [AASHTO 2003], American Traffic Safety Services Association [ATSSA 2003] and the National Highway Traffic Safety Administration [NHTSA 2006] will be considered. All this information will be evaluated for its possible implications on the Mississippi Rumble Stripes program.

c- Analyzing the compiled Mississippi data and the nationwide literature findings: Finally, the data analysis will begin by establishing correlations between traffic parameters (such as: volume and speed) and crashes in the road prior to the construction of Rumble Stripes. A second correlation between the traffic parameters and crashes in roads after the construction of Rumble Stripes will be established. Using these two correlations (traffic parameters->crashes prior to the Rumble Stripes and after the Rumble Stripes) the impact of Rumble Stripes on crash reduction will be identified.

1.3. METHODOLOGY

The proposed methodology for this project is based on the idea of dividing the project into stages. Each stage will have a pre-defined set of goals to be accomplished and will require approval from MDOT Traffic Engineering Division personnel (before proceeding to the next stage). In addition to the goals, each stage will have tangible deliverables which are provided in Table 1 below.

Table 1-1 Project Proposed Stages With Their Corresponding Goals and Deliverables

Stages	Goals	Deliverables
Stage 1	Review the latest nationwide literature on Rumble Stripes Review criterion disseminated by FHWA, AASHTO, ATSSA regarding Rumble Stripes Establish Rumble Stripes effectiveness measurement criterion and variables based on the literature review Report findings to MDOT of the nationwide Rumble Stripes criterion and variables. Interact with MDOT personnel from the Traffic Engineering Division (Robert W. Dean, Jim C. Willis, etc) to approve the specific study parameters (programs, variables, etc)	Report “Synopsis of Nationwide Rumble Stripes Programs”, which will criterion and measurable variables. This report is expected to have between 5 to 10 pages
Stage 2	Interact with MDOT to select roads with Rumble Stripes and comparable roads without Rumble Stripes to be used in this research project Interact with MDOT personnel to obtain access to Mississippi historical data regarding road characteristic, traffic parameters and crash data. Compile road data (such as: location, safety programs, conditions before and after construction, etc) Arrange the road data into a useful format for the study Interact with MDOT and seek verification of completeness of the road data compiled Seek approval of MDOT Traffic Engineering Division personnel before proceeding	Report “Roads in Mississippi with Rumble Stripes”, which will include the “Rumble Stripes” locations, conditions before and after construction. This report is expected to have between 5 and 10 pages Presentation of: 1- Major Rumble Stripes criterion and measurable variables 2- Mississippi Roads with Rumble Stripes. This presentation will have between 10 and 20 slides

Stages	Goals	Deliverables
Stage 3	Compile historical traffic parameter data (such as: volume and speed in the work zone) Arrangement the traffic parameter data into a useful format for the study Interact with MDOT and seek verification of completeness of the traffic data compiled. Seek approval of MDOT Traffic Engineering Division personnel before proceeding	Report "Traffic Parameters in Mississippi roads with Rumble Stripes", which will include the road's locations, conditions before and after "Rumble Stripes" programs. This report is expected to have between 3 and 8 pages
Stage 4	Compile historical crash information (such as: location, time, severity, and cause of the accident) Arrangement the crash information data into a useful format for the study. Interact with MDOT and seek verification of completeness of the crash information data compiled Seek approval of MDOT Traffic Engineering Division personnel before proceeding.	Report "Current Status of crash in Mississippi Roads with Rumble Stripes, which will include location, time, severity and cause of the crash. This report is expected to have between 5 and 10 pages. Presentation of: 1- Traffic Parameters of Mississippi Roads with Rumble Stripes. 2- Status of Crash in Mississippi Roads with Rumble Stripes This presentation will have between 10 and 20 slides
Stage 5	Appraise compiled historical data to determine the additional data that needs to be collected from the field to support the assessment of the Rumble Stripes Report to MDOT Traffic Engineering Division personnel and seek approval to proceed.	Report "Appraisal of Mississippi Rumble Stripes Historical Data", which will be a compilation of the previous three reports. This report will be prepared following guidelines of a conference (to be defined) and will have between 6 and 12 pages. Presentation of the "Appraisal of the Rumble Stripes Mississippi Historical Data". This presentation will have between 10 and 20 slides.

Stages	Goals	Deliverables
Stage 6	Interact with MDOT personnel from the Traffic Engineering Division to prepare field data collection plan Prepare field data collection plan including variables, sites, dates, measurement procedure, etc. MDOT will gather the field data according to the plan prepared by USM. Report to MDOT and seek approval to proceed	Report "Field Data Collection Plan for the Selected Roads with Rumble Stripes which will include variables, sites, dates and measurement procedures for the sites and teams. This report is expected to have between 3 and 8 pages. Presentation of the "Field Data Collection Plan for the Selected Roads with Rumble Stripes". This presentation will have between 4 and 10 slides.
Stage 7	Collect field data from the selected sample Roads with Rumble Stripes Interact with MDOT data collection team every 2 weeks to obtain status update Interact with MDOT Traffic Engineering personnel every 6-8 weeks to provide an update on the field data collected.	N/A
Stage 8	Compare MDOT historical data with collected field data Merge MDOT historical data with collected field data Interact with MDOT personnel to give an update of the merged data	Report "Historical Vs. Field Data Comparison in Mississippi of Roads with Rumble Stripes which will include characteristics of the roads with Rumble Stripes, traffic parameters and crash information. This report is expected to have between 5 and 10 pages.

Stages	Goals	Deliverables
Stage 9	Analyze the historical and field data to identify whether or not the roads with Rumble Stripes and without Rumble Stripes before construction were statistically equivalents Analyze the data to identify whether or not there is a statistically significant difference between the roads with Rumble Stripes and without Rumble Stripes after construction. Establish links between before and after the construction of Rumble Stripes. Compare Mississippi findings with the nationwide findings	N/A
Stage 10	Prepare a draft report of the findings Report to MDOT findings of the data analysis and seek input from the MDOT Traffic Engineering Division	Report “DRAFT Effectiveness of Rumble Stripes on Highway Safety in Mississippi”, which will include the most relevant finding of the study. This report is expected to have between 10 and 20 pages Presentation of the “Effectiveness of Rumble Stripes on Highway Safety in Mississippi”. This presentation will have between 12 and 24 slides
Stage 11	Fine-tune the draft report based on Traffic Engineering Division recommendations Issue final report Obtain final approval from the MDOT Traffic Engineering Division	Report “Effectiveness of Rumble Stripes on Highway Safety in Mississippi”, which will include the most relevant finding of the study as well as recommendation from MDOT. This report is expected to have between 10 and 20 pages
Stage 12	Provide up to 4 presentations to MDOT, FHWA and/or any other federal or state agencies of the Traffic Engineering Division effort on the assessment of rumble Stripes on Mississippi highway.	Presentations of the “Effectiveness of Rumble Strips on Highway Safety in Mississippi”. These presentations will be done upon request of federal/state agencies and will have between 12 and 24 slides.

1.4. ANTICIPATED BENEFITS

The assessment of Rumble Stripes on Mississippi Roadways will provide both tangible and intangible benefits to MDOT and Mississippi road users (taxpayers). Some of those benefits are as follows:

- Furnish a quantifiable measure of the effectiveness of the program
- Provide evidence regarding improvement of safety to federal agencies requiring such information
- Improve Mississippi's National Safety Council ranking by reducing the loss of motorists, pedestrians, law enforcement officers, firefighters, paramedics, and children
- Enhance public perception of MDOT management through the reduction of crashes in the state of Mississippi
- Provide a framework for assessing other safety programs implemented by MDOT

1.5- URGENCY

As documented in the literature, half of all roadway fatalities are caused by roadway departures. Therefore, it is critical to expedite the assessment of the safety programs such as the Rumble Stripes program, especially in Mississippi with its all time peek volume and worst safety ranking in the nation.

It is essential that assessment methods be developed to evaluate the effectiveness of the resources invested in the Rumble Stripes program. Therefore, it is imperative that MDOT promptly demonstrate its commitment to roadway safety by continuing to fund safety programs and funding studies to measure their effectiveness (as the one propose here).

CHAPTER 2: STATE-OF-THE-ART: EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY

2.1. INTRODUCTION TO ROADWAY FATALITIES

The United States (U.S.) heavily relies on the roadway infrastructure. As shown in Table 2-1 a considerable number of highway miles are driven in vehicles every year. Unfortunately, the number of fatalities is also staggering with accidents becoming more frequent, resulting in situations as the one depicted in Figure 2-1.

Figure 2-1. Crash Sample Picture [Public Roads 2004]

Every year over 40,000 fatalities occur on the U.S. highways (See Table 2-1) with most of these fatalities due to roadway departures. On average, one roadway departure fatality occurs every 23 minutes, and a roadway departure injury occurs every 43 seconds. It is estimated that the annual cost of roadway departure is $100 billion [FHWA Resource Center 2006].

Table 2-1. Highway Vehicle Miles and Fatalities from 2001- 2004
[DOT 2007a, DOT 2007b]

Year	Highway Millions Vehicle Miles	Highway Fatalities
2001	2,797,287	42,196
2002	2,855,508	43,005
2003	2,890,450	42,643
2004	2,962,513	Not Available

The Federal Highway Administration (FHWA) indicates that improvements in infrastructure have helped keep the fatalities number from increasing. However, higher traffic volumes have counteracted any real reductions in the number of fatalities due to roadway departure [Public Roads 2005]. These roadway departures are caused by multiple factors. These factors can be categorized into three groups: Environmental, Human and Design. Table 2-2 shows the three groups with some examples. It is also possible that a combination of factors causes a roadway departure such as: inattentive drivers, poor environmental conditions, or poor road designs.

Table 2-2. Factors that Cause Roadway Departure

Group	Sample
Environment	Weather or animal crossings
Human	Inattention or drowsiness
Design	Substandard curves, unimproved shoulders, travel lanes that are too narrow

Therefore, countermeasures to prevent or lessen the effects of the factors that cause roadway departures are important steps towards improving the safety of the Nation's roadways. Roadway departure countermeasures must be designed to keep the motorists in lanes and on the roads, enable the drivers to recover and safely return errant vehicles to the roadway, and keep vehicle occupants from greater harm if a vehicle does leave the roadway [Public Roads 2005].

This chapter will focus on a project funded by the MDOT to determine the safety effectiveness of one roadway departure countermeasure, rumble stripes, in Mississippi. More specifically, this paper presents a series of nationwide assessments that have attempted to measure the impact of rumble stripes on roadway departures. The paper will also present characteristics of rumble stripes, the project research methodology and the findings of meta-analysis on the effect of Rumble Stripes.

2.2. CHARACTERISTICS OF RUMBLE STRIPS AND STRIPES

Two of the countermeasures used to increase roadway safety (especially by preventing roadway departures) are Rumble Strips and Rumble Stripes. Although in many cases Rumble Strips and Rumble Stripes have been used interchangeable, they do not have the same design characteristics.

Rumble strips are raised or grooved patterns on the roadway shoulder or center lines. Figure 2-2 shows the dimensions and a schematic profile of Rumble Strips used by the Alaska DOT. Figure 2-3 provides a picture of a Rumble Strip on a Roadway segment. Rumble Strips provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane [FHWA 2006a]. Noise and vibration produced by shoulder rumble strips are effective alarms for drivers who are leaving the roadway. They are also helpful in areas where motorists battle rain, fog, snow, or dust [FHWA 2007b]. The Rumble Strips give a warning to inattentive drivers. Rumble Strips help drivers stay on the road during inclement weather when visibility is poor [FHWA 2006]. Rumble Strips also help reduce highway hypnosis-a condition where white lines and yellow stripes on long, monotonous stretches of straight freeway can mesmerize and wreak havoc with a driver's concentration [FHWA 2007b].

. **Lateral Width:** 400mm (16")

. **Longitudinal Milling Pattern:** 175mm (7") cut, 13mm (½") deep, 125mm (5") flat

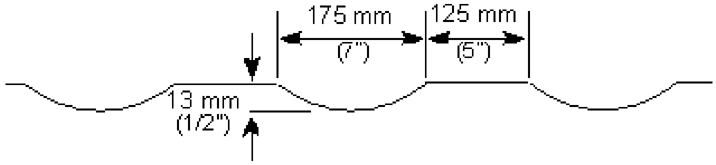


Figure 2-2. Dimensions and Schematics Profile of Rumble Strips [FHWA 2007c]

Figure 2-3. Rumble Strip on a Roadway [Safe Roads 2003]

Rumble Strips can be grouped in three types. The most common type of strip is the continuous shoulder rumble strip. These are located on the road shoulder to prevent roadway departure crashes on expressways, interstates, parkways, and two-lane rural roadways. Centerline rumble strips are used on some two-lane rural highways to prevent head-on collisions. Transverse rumble strips are installed on approaches to intersections, toll plazas, horizontal curves, and work zones [FHWA 2007a].

Rumble Stripes are a combination of pavement markings and rumbles strips, with the markings applied on top of the rumble strips. Rumble Stripes enhance visibility as the vertical face of the rumble strip provides a raised texture that enhances the retroreflectivity performance of the striping material [Public Roads 2004] as presented in Figure 2-4. Because the vertical edges of the strips are painted, the paint line is more visible at nighttime and during wet conditions [Public Roads 2005].

Figure 2-4. Rumble Stripe Sample on Roadways
[Amparano, Morena, 2006] & [*ATSSA 2006* - Picture by Jim Willis-MDOT]

2.3. RESEARCH METHODOLOGY

A descriptive research methodology was followed to summarize the available literature on the effectiveness of rumble stripes on highway safety. As part of the research methodology, a systematic literature review and a meta-analysis were performed. The meta-analysis combined the results from a number of previous studies in an attempt to summarize the evidence of rumble stripes impact on highway safety. The meta-analysis included a qualitative component (pre-determined search criteria) and a quantitative component (integration of numerical information) [CHP, 2005].

The qualitative component of the meta-analysis is challenging for most research projects. Various factors, such as very general keywords, can generate an unbearable amount of data to be analyzed. Using very specialized or precise technical keywords can produce zero results or very limited data. Combining the correct keywords with different databases will have a significant impact on the results of the research.

A slight variation in the search criteria (keyword and database) could result in differences in the outcome. Therefore, it is important to explicitly state the search criteria used. The keywords used in this project are presented in Table 2-4. These two keywords were used after several preliminary searches with a variety of keywords related to the subject. The databases used in this project were limited to the seven databases presented in Table 2-3. These databases were used based on the studied subject and recommendations from MDOT.

Table 2-3. Databases: Name, URL Location and Information used to Search

Database's Name	URL	Information
Transportation Research Board (TRIS)	http://trisonline.bts.gov/	TRIS Online provides links to full text and to resources for document delivery or access to documents where such information is available. These may include links to publishers, document delivery services, and distributors.
Federal Highway Administration (FHWA)	http://www.fhwa.dot.gov/search.html	FHWA search provides information regarding the outcomes of partnerships with the state and local agencies to meet the nation's transportation needs. The information provided relates to the FHWA work done cooperatively with governmental agencies, industry, and research community partners to research, develop, test, and implement the latest proven technological advancements including intelligent transportation systems.
National Cooperative Highway Research Program (NCHRP)	http://safety.transportation.org/Default.aspx	This web site offers access to a Safety Portal, where parties engaged in developing and implementing comprehensive state highway safety plans can exchange information, ask questions, and get expert advice from the developers of the AASHTO Strategic Highway Safety Plan implementation guides
National Highway Traffic Safety Administration (NHTSA)	http://www.nhtsa.dot.gov/nhtsasearch/index.asp	NHTSA site has valuable information and statistics related to the many ways that NHTSA works to reduce deaths, injuries and economic losses resulting from motor vehicle crashes. The site is organized by three major sections: 1- Vehicles and Equipment, 2- Traffic Safety and Vehicle Occupants, and 3- General Information.
Transportation Research Board - Research In Progress (TRB-RiP)	http://rip.trb.org	TRB-RiP database contains over 7,800 current or recently completed transportation research projects. Most of the RiP records are projects funded by Federal and State Departments of Transportation. University transportation research is also included.
The National Work Zone Safety Information Clearinghouse (WZSRD)	http://wzsafety.tamu.edu/searches/research.stm	WZSRD database contains 1686 records of journal articles, research reports, research projects, and other types of publications that are related to work zone safety. Each publication record includes bibliographic information, a summary, and a link to full text if available. Each project record includes a description, sponsor, and contact information.
American Traffic Safety Services Association (ATSSA).	http://www.atssa.com/	ATSSA site contains tools to discover the latest news on technology in the roadway safety community and an electronic clearing house of technical issues that affect road safety.

Table 2-4. Keywords/Phrases Used for the Search

Keywords
Rumble Stripes
Rumble Strips *(Only used in some databases)*

2.4. IMPACT OF RUMBLE STRIP/STRIPES NATIONWIDE

For a number of years, the Federal Highway Administration (FHWA) has actively endorsed the use of rumble strips as a way to reduce roadway departure crashes [Public Roads 2005]. There have been a number of Rumble Strip and Rumble Stripe projects implemented across the U.S. A FHWA report indicates that the following states have implemented extensive rumble strip programs: Kansas, Michigan, Minnesota, Mississippi, Oklahoma, and Pennsylvania, among others [Public Roads 2005]. Some studies have been performed documenting the roadway safety improvements due to the Rumble Strip and Rumble Stripes installation. This section provides a synthesis of studies on Rumble Strip and Rumble Stripes with their outcomes.

1- The Missouri Department of Transportation (MoDOT) has been implementing numerous countermeasures to address visibility issues with older drivers. The MoDOT identified eight essential strategies to improve roadway safety, one of which is the installation of shoulder, edgeline and centerline rumble strips/rumble stripes. MoDOT has already installed several miles of center and edgeline rumble strips and rumble stripes [State of Missouri 2007]. However, no information was found regarding studies to quantify the safety impact of rumble stripes on Missouri roadways.
2- The Michigan Department of Transportation has evaluated rumble stripes by placing a pavement marking over pre-existing shoulder rumble strips, creating a double edge line system [Filcek et al 2004]. Retroreflectivity of both the standard flat line, and the shoulder rumble stripe, were measured after one year of service, including the winter maintenance activities. The results indicate that dry and wet rumble stripe markings provide 6 and 20 times more retroreflectivity, respectively, than the standard flat edge line markings. These results demonstrate that rumble stripes have higher wet retroreflectivity than the standard flat lines, and that the rumble stripe may be protected from snow removal equipment as indicated by the higher dry retroreflectivity values. A pavement marking protected from snow removal equipment will increase the durability of the marking, extending its service life, and reducing yearly pavement marking costs. [ATSSA 2006].
3- The Michigan Department of Transportation through a research project revealed that the milled-in rumble strip demonstrates a design advantage by allowing vehicle tires to partially drop into them, providing a vibration to the vehicle that translates up to the steering wheel. Whereas rolled and concrete intermittent designs can provide some outside noise to alert a drifting driver, the milled design produces a louder noise and adds a vehicle vibration that most certainly increases the potential for alerting a drowsy or distracted driver [Public Roads 2005].
4- The Michigan Department of Transportation reports that milled rumble strips installed on Michigan roadways have reduced drift-off-the-road crashes by 40 percent, through the entire range of traffic volumes studied [Morena 2003].
5- The Mississippi Department of Transportation has also experimented with rumble stripes on edge lines at several sites. They concluded that in addition to the excellent audible

warning, rumble stripes provide increased retroreflectivity of pavement markings similar to that of profiled markings [Willis and Dean, 2004].

6- The Texas Department of Transportation is currently evaluating the wet night visibility of various types of pavement marking materials, including rumble stripes [Carlson, et Al 2005] The results of the first year of the project indicate an overall advantage of a rumble stripe versus a standard flat line of the same marking material with the rumble stripe providing an additional 25 ft of visibility distance. The study indicated that the rumble stripe provides similar visibility to the standard flat line in low rainfall events, but better visibility in medium and heavy rainfall events [ATSSA 2006].
7- The Nevada Department of Transportation indicates that the installation of milled rumble strips, adjacent to the travel way, is a surefire way to warn drivers that their vehicles are about to leave the travel lane so they can take corrective action [ATSSA 2002]. Nevada found that with a cost benefit ratio ranging from more than 30:1 to more than 60:1, rumble strips are more cost effective than many other safety features, including guardrails, culvert-end treatments, and slope flattening [FHWA 2007a]. The Nevada department of transportation is currently funding a project to evaluate the effectiveness and feasibility of centerline rumble strips installed in Nevada with respect to placement, operational and safety effects, cost, and service life, and develop guidelines for installations of centerline rumble strips in Nevada [TRB-RiP 2007a].
8- The Kentucky Department of Transportation has installed several miles of Rumble Strips and as reported in the Growing Traffic in Rural America [The Road Information Program 2005]. Rumble Strips have been found to reduce run off the road crashes by between 25 to 43 percent [Agent et al 2003].
9- The Maine Department of Transportation surveyed 50 State DOTs and identified a cost benefit ratio of 50:1 for milled rumble strips on rural interstates nationwide [FHWA 2007a].
10- The Delaware Department of Transportation has installed several miles of rumble strips. One Delaware case worth noting was the Rumble Strips project on U.S Route 301 (a two-lane, undivided rural highway with a high fatality rate). After the rumble strips were installed, the head-on collision rate decreased 90 percent, and fatalities decreased to zero. These dramatic safety improvements were achieved despite a 30 percent increase in traffic. [FHWA 2007a].
11- The New York Department of Transportation has been installing rumble strips for many years. A New York study showed a significant change in the number of roadway departure crashes, injuries, and fatalities after rumble strips were installed on the New York State Thruway. Roadway departure crashes were reduced 88 percent, from a high of 588 crashes in 1993 to 71 in 1997. Total injuries were reduced 87 percent, from a 1992 high of 407 to 54 in 1997. Fatalities were reduced 95 percent, from 17 in 1991 and 1992 to 1 fatality in 1997 [FHWA 2007a].
12- The Virginia Department of Transportation won the 2001 National Highway Safety Award for its experiment with continuous shoulder Rumble Strips on the State's 917-mile interstate highway system from 1997 to 2000. During this project, the roadway departure crashes were reduced by 51.5 percent, saving an estimated 52 lives. It is estimated that continuous Rumble Strips technology has prevented 1,085 injuries and 1,150 ROR crashes, with a total cost savings of $31.2 million [FHWA 2007a].

13- The Minnesota Department of Transportation has also begun exploring rumble strips as a potential solution to high crash rates on the State's rural roads. Today, the State has instituted a comprehensive policy that mandates placing edgeline rumble strips on all rural multilane and two-lane highway projects where shoulders are constructed, reconstructed, or overlaid, and where the posted speed limit is 80 kph (50 mph) or greater and shoulders are 1.8 meters (6 feet) or greater in width. According to Gary Dirlam, District 3 traffic engineer for the Minnesota Department of Transportation (Mn/DOT), the department reviewed several reports, including the 1999 FHWA summary report, *Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways* (FHWA-RD-00-032), which estimated that approximately one single-vehicle, run-off-the-road incident (at an average cost of $62,200) could be prevented every 3 years based on an investment of $217 to install continuous shoulder rumble strips for 1 kilometer of roadway [Public Roads 2005].

14- The California Department of Transportation has also installed several miles of rumble strips on highways including centerlines to replace the double yellow strips as stated by Fitzpatrick [NCHRP 2005].

15- The Alaska Department of Transportation conducted a research study to document the success and problems of Rumble Strips with the intent of making recommendations concerning future installations. At the time of the study (2003), crash data was not included because the data collection was ongoing. From the study the following observations were made: 1-Appear to be effective as lane delineations; 2- Snow and ice buildup in rumble strips is generally not a problem; 3- Rumble strips do not appear to produce an external, measurable volume (db) increase over general traffic noise; 4- Pavement deterioration is not a problem [NCHRP 2005].

16- The Kansas Department of Transportation is currently conducting a project with the primary objective of investigating and testing in the field the human factors and safety aspects of center-of-lane and center-line rumble strips on two-lane Kansas state rural highways without shoulders. The advantages and disadvantages, including potential legal liability issues, of using a rumble strip on the centerline of two-lane roads will be investigated. A two- stage study will take place. The first stage will assess the feasibility, potential legal, operational and driver expectancy problems, installation, and the impact of rumble strips on various vehicles. Stage two of the study will focus on the design, implementation and evaluation of field tests on center-of-lane rumble strips on two-lane rural highways in Kansas. The hundreds of miles of Kansas highways with no shoulder would result in a payoff of millions of dollars in reduced crash costs [TRB-RiP 2007b].

17- The Kentucky Department of Transportation is currently funding a research project to determine the safety benefits of shoulder and centerline rumble strips [TRB-RiP 2007c].

2.5. SUMMARY

It can be summarized that, as documented in the literature, fatalities due to roadway departure are at staggering levels. Therefore, it is critical to expedite the assessment of safety countermeasures (such as Rumble Strips and Stripes), especially in Mississippi which has one of the worst safety records in the nation.

In this paper, the characteristics of Rumble Stripes and Rumble Stripes supported by the Federal Highway Administration studies were presented. Then, based on a systematic literature review of the nationwide implementation and studies on Rumble Strips and Stripes, a synthesis of the current state-of-the-art knowledge regarding the safety impacts of these countermeasures was provided.

The results presented in this paper are very important for the scholarly community. They can be used as the foundation for similar studies in other states and it has the potential to directly benefit construction education by serving as an example of good practice in engineering education

CHAPTER 3:
MDOT DIVISIONS AND THEIR DATA TO ASSESS EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY.

3.1. INTRODUCTION TO RUMBLE STRIP/STRIPES

This chapter presents an overview of the agencies involved in collecting the data needed to assess the impact of the Rumble Stripes on Highway Safety. Furthermore, this paper provides a description of data collected and its structure. Finally, the results of the lessons learned are presented. They could serve as the foundation for similar studies and/or case studies to facilitate students learning through meaningful real world scenarios.

3.2. OVERVIEW OF AGENCIES INVOLVED IN COLLECTING DATA

Collecting, processing, archiving and retrieving of data/information are a costly, demanding and necessary activity of all organizations. Each organization's division manages data/information in a different way for a variety of purposes to fulfill their primary responsibility. This primary responsibility is important to understand in requesting the appropriate data from the different divisions. The following is a brief description of the responsibilities of MDOT Divisions involved in collecting data to be used to assess the effectiveness of rumble stripes on highway safety.

3.2.1 Mississippi Department of Transportation

The Mississippi Department of Transportation is responsible for providing a safe intermodal transportation network that is planned, designed, constructed and maintained in an effective, cost efficient, and environmentally sensitive manner. In order to provide the framework for accomplishing MDOT's mission, a set of seven goals has been developed. These goals are multimodal, comprehensive in scope and interdependent. Table 3-1 shows the goals of MDOT [MDOT, 2006].

Table 3-1. Mississippi Department of Transportation Goals [MDOT, 2006]

Goal 1: Accessibility and Mobility: Improve Accessibility and Mobility for Mississippi's People, Commerce and Industry.
Goal 2: Safety: Ensure High Standards of Safety in the Transportation System.
Goal 3: Maintenance and Preservation: Maintain and Preserve Mississippi's Transportation System.
Goal 4: Environmental Stewardship: Ensure that Transportation System Development is Sensitive to Human and Natural Environment Concerns.
Goal 5: Economic Development: Provide a Transportation System that Encourages and Supports Mississippi's

Economic Development.

Goal 6: Awareness, Education and Cooperative Processes: Create Effective Transportation Partnerships and Cooperative Processes that Enhance Awareness of the Needs and Benefits of an Intermodal System.

Goal 7: Finance: Provide a Sound Financial Basis for the Transportation System

Four offices within MDOT actively participated in this project: 1- District 6 Office, 2- District 5 Office, 3- Planning Division and 4- Traffic Engineering Division.

1 - District 6 Office: Responsible for coordinating, planning, design, construction and maintenance of the intermodal transportation network within fourteen counties. These counties include: Hancock, Harrison, Jackson, Pearl River, Stone, George, Lamar, Forrest, Perry, Greene, Jones, Wayne, Jasper, and Clarke. Figure 3-1 shows a map of the MDOT Districts. District 6 is located in the south east portion of the state

2 - District 5 Office: Responsible for coordinating, planning, design, construction and maintenance of the intermodal transportation network within ten counties. The counties include: Hinds, Madison, Rankin, Leake, Scott, Neshoba, Newton, Noxubee, Kemper, and Lauderdale. Figure 3-1 shows a map of the MDOT Districts. District 5 is located in the central portion of the state

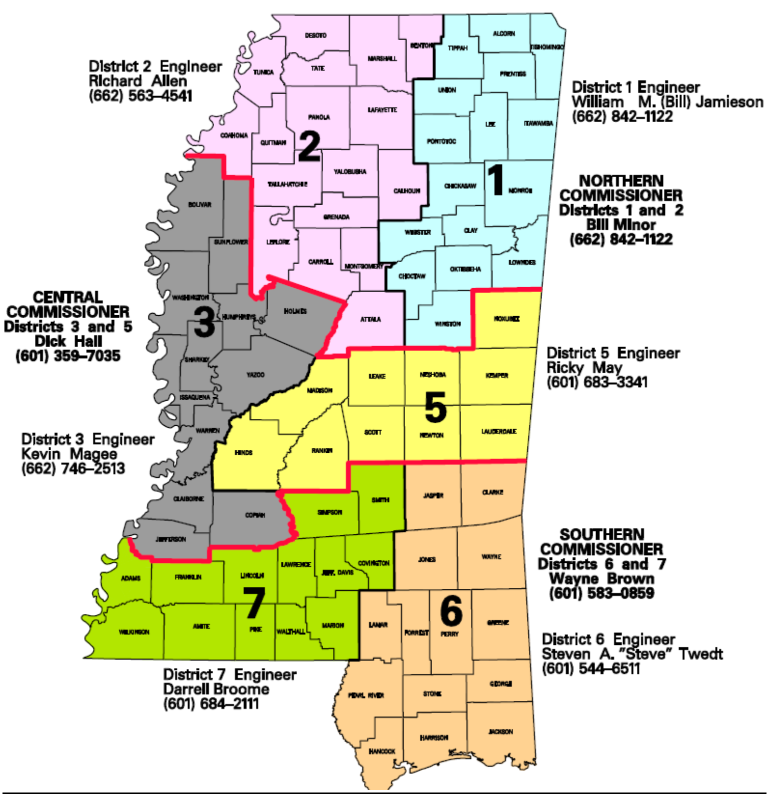


Figure 3-1. MDOT District Offices

3 - Planning Division: Provides the Legislature, MDOT and the Federal Highway Administration with information to support program planning and decisions. Table 3-2 shows the planning division fundamental functions to provide support for planning and decisions [MDOT Planning Division, 2006].

Table 3-2. Planning Division Fundamental Functions [MDOT Planning Division, 2006]

Function	Brief Description
The Long Range Statewide Transportation Plan (MLRTP)	Provides the framework for Mississippi's transportation program. This is a 20+ year outlook.
Statewide Transportation Improvement Program (STIP)	Provides a listing of the projects to be accomplished during the next three years.
Traffic Monitoring System for Highways (TMS/H)	Includes the collection and analysis of all traffic data including traffic counts, vehicle classification counts, truck weight surveys, turning movement counts, speed surveys, and occupancy surveys.
Roadway Inventory and Mapping	Provide statistics such as highway dimensions and mileage, structure information, and an extensive array of maps.
A Federal Functional Classification System	Used distinguish highways according to the character of service provided by the facility.
Special Programs and Studies	Administer programs including Urbanized Area support (places larger than 50,000), Federal Aid to all Urban areas (places above 5,000), Transit Planning grants, Transportation Enhancement program, Latin American Trade Study, Environmental Noise studies, Intermodal Connector Improvement Program, Great River Road Transportation Committee, etc.
Specialized Reports and Feasibility Studies	Prepare for decision makers include activities such as the Highway Performance Monitoring System (HPMS), Statistical reports on state, city and county highway finance, and analyses of interchanges and highway improvements.

<u>4 - Traffic Engineering Division:</u> Ensures that safe, efficient traffic control measures are standardized throughout the state maintained highway system. It is responsible for the development of programs to add, upgrade or revise existing traffic control devices. This task compels studies to determine and recommend appropriate speed zones as well as the development and distribution of policies for the application of traffic control devices in accordance with established guidelines. The Traffic Engineering Division also directs the

in-house manufacture and distribution of MDOT erected signs. Personnel travel statewide to install and maintain signs and signals on assigned sections of state maintained highways [MDOT Traffic Engineering Division, 2006].

3.3. ARCHIVED DATA, STRUCTURE AND MEANS OF RETRIEVAL

Upon identifying the divisions their roles in collecting data pertinent to this research project, the MDOT project leader contacted the different divisions and provided a brief description of the project and the research team. The research team followed-up this initial contact by requesting a meeting with the representatives of the agencies to provide an overview of the project and initiate the consolidation of the data that had been collected. During this initial contact an informal interview was conducted with the division representative to explicitly identify the data that the agency had already collected the structure and the media in which the data was stored, as well as the retrieval means of the division. Upon agreeing with the division concerning the data to be retrieved, a mechanism to transfer the data was established. As expected and evidenced below, each agency used a different structure to archive the data. The following are some examples of the data that was obtained for the project.

3.3.1. Planning Division - Mississippi Department of Transportation

In order to fulfill its mission, the MDOT Planning Division has placed a number of traffic recording devices around the state. This office handled mainly pictorial and numerical information. The planning division archived the information both in hard copies and electronic media. Some of the information received by the research team was in hardcopy and some was received in electronic files. One of the first pieces of information received by the research team was a series of maps showing geographical information of gathered data. Figure 3-2 shows the map that was provided to the research team that illustrates the location of each the stations. From this map, recording devices in the studied area were selected to retrieve traffic volume counts that corresponded with the segments part of the study shown in Table 3-3.

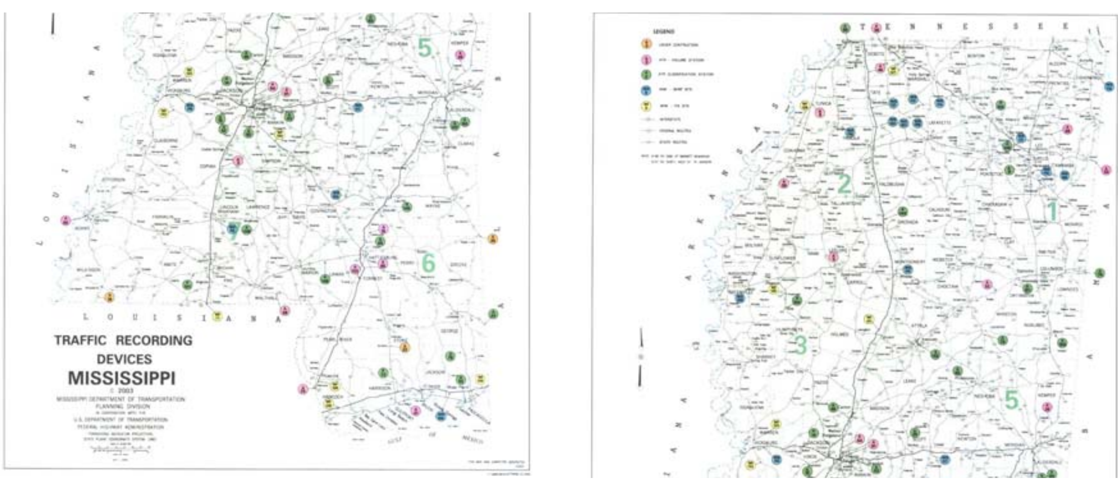


Figure 3-2. Traffic Recording Devices – Mississippi

Table 3-3. Road Segments Included in the Study

ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)
1	US 98 in George County from the Greene County line to SR 63/Dist 6	US 98	Greene County line	SR 63
2	US 98 in Greene County from east of SR 198 in McLain to the George County line/Dist 6	US 98	Greene County from east of SR 198 in McLain	George County line
3	US 98 in Perry County from the Forrest County line east 7.5 miles/Dist 6	US 98	Forrest County line	East 7.5 miles into Perry County
4	US 98 in Forrest County from Interstate 59 to the Perry County line/Dist 6	US 98	Forrest County from Interstate 59	Perry County line
5	SR 589 in Lamar County from Haden Road north to US 98/Dist 6	SR 589	in Lamar County from US 98 north	to US 98
6	SR 589 in Lamar County from US 98 north to the Covington County line/Dist 6	SR 589	in Lamar County from US 98 north	to the Covington County line
7	SR 43 in Hancock County from SR 603 to Dummyline Road/Dist 6	SR 43	in Hancock County from SR 603	to Dummyline Road
8	SR 43 in Hancock County from Dummyline Road to Salem Road/Dist 6	SR 43	in Hancock County from Dummyline Road	to Salem Road
9	SR 43 in Pearl River County from Pinetucky Road to SR 26/Dist 6	SR 43	in Pearl River County from Pinetucky Road	to SR 26
10	US 11 in Pearl River County from Minkler Road to Charwood Drive/Dist 6	US 11	in Pearl River County from Minkler Road	to Charwood Drive
11	11 in Pearl River County from Charwood Drive to the north corporate limits of Poplarville/Dist 6	US 11	in Pearl River County from Charwood Drive	to the north corporate limits of Poplarville
12	Scooba-Noxubee County Line (7 ½ Miles of 4 lane) in Kemper County /Dist 5	US45	Scooba 0.644 North of	Noxubee County Line
13	Porterville-Scooba (9 ¾ Miles of 4 lane)/Dist 5	US45	Porterville	Scooba
14	Lauderdale to Porterville (10 Miles of 4 lane)/Dist 5	US45	Lauderdale	Porterville

Although the Planning Division did not have a GIS system to link the traffic recoding devices (presented in the Figure 3.2) and the road segments included in the study (presented in Table 3-3), the Planning Division had extensive data regarding the recording devices in the studied area. Several computers files with data from the stations from several years were received by the research team. Figure 3-4 shows a sample of files that were received by the research team. Figure 3-5 shows a sample of the data contained in the data files.

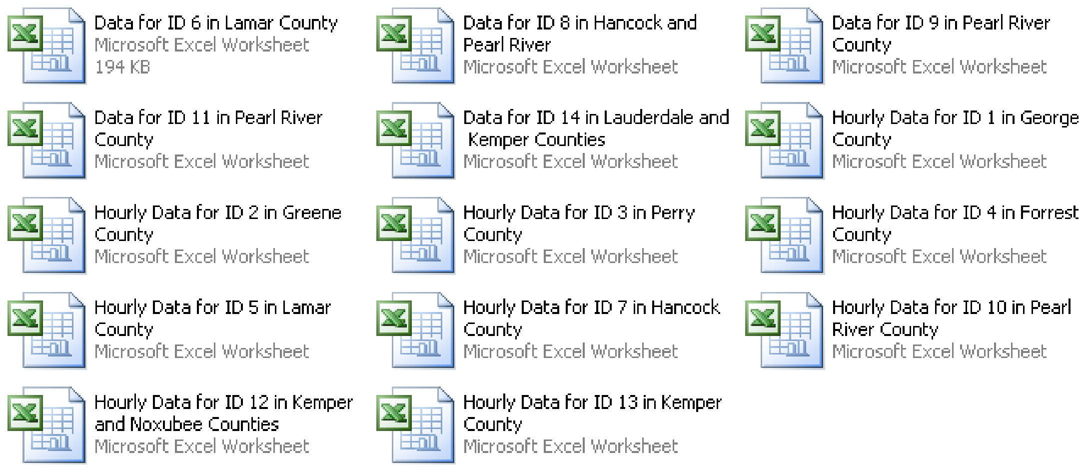


Figure 3-4. Sample Data Files from the Planning Division

Summary of ID 6: SR 589 in Lamar County from US 98 to Covington CL						
ID	Route	Location	Type of Count	2000 AADT	2004 AADT	2006 AADT
6	SR 589	From SR 98 to Epley Rd	Volume	4300	5000	5100
6	SR 589	From Epley Rd to SR 42	Volume	4200	4300	4400
6	SR 589	From SR 42 to Covington CL	Volume	1800	2200	2200

Summary / Volume-US 98 to Epley Rd / Volume-Epley Rd to SR 42 / Volume-SR 42 to (

Figure 3-5. Sample data contained in the data files

The information provided by the Planning Division represented a wide range of timeframe in different locations. Figure 3-6 shows the Annual Average Daily Traffic (AADT) data for a particular location including a map with the specific location of the count. Additionally, for some locations the Planning Division was able to provide direction distribution of the traffic as shown in Figure 3-7.

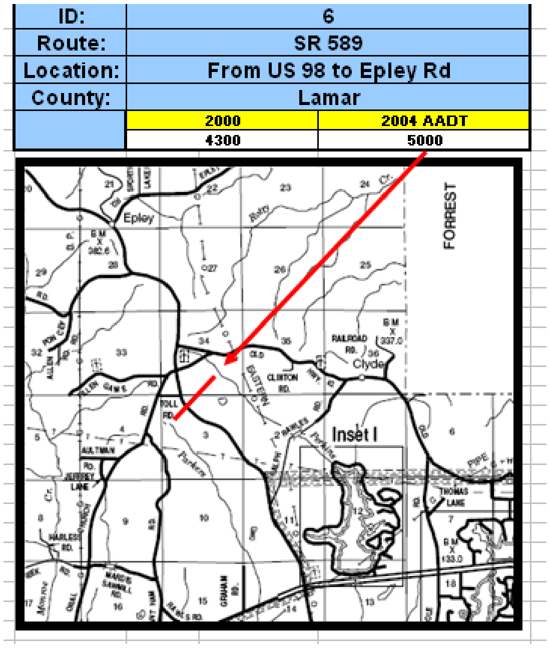


Figure 3-6. Sample Annual Average Daily Traffic (AADT) Information

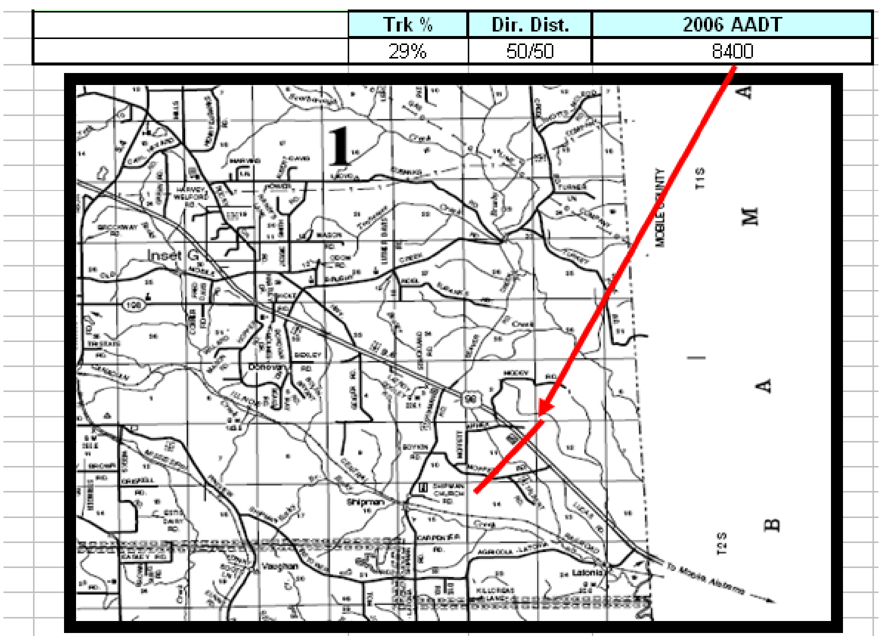


Figure 3-7. Sample Annual Average Daily Traffic (AADT) Distribution and Location

The Planning Division also provided hourly count information for some locations. Figure 3-8 shows a sample hourly count information collected on Monday 1/30/06 and Wednesday 2/1/06 on a particular segment.

ID:	1		
Route:	US 98		
Location:	From AL State Line to SR 63		
County:	George		
Dates of Count:	Monday 1/30/06		Wednesday 2/1/06
Time	Westbound	Eastbound	Total
0	44	30	74
100	41	25	66
200	33	23	56
300	53	24	77
400	84	68	152
500	123	83	206
600	138	142	279
700	177	212	388
800	195	232	427
900	207	263	470
1000	229	235	463
AM Peak 1100	245	233	478
1200	240	244	484
1300	258	273	531
1400	281	278	558
1500	278	272	550
PM Peak 1600	283	287	570
1700	252	271	523
1800	195	228	423
1900	153	153	306
2000	120	120	240
2100	105	95	200
2200	80	85	164
2300	62	50	112

2006- AL State line to SR 63 / 2003- AL State line to SR 63 / Volume only- SR 63 to G

Figure 3-8. Sample Hourly Count

It is important to highlight the fact that the Planning Division data was organized and structured in a way that was most suitable for the initial intent of the data. However, very little field standardization was found in the data and consolidation of the data was not a trivial task.

3.3.2. District 6 Office - Mississippi Department of Transportation

Due to the complexity and diversity of responsibilities of the District 6 Office, the information is collected, used and stored using multiple formats. The District 6 Office archived the information both in hard copies and electronic media. Some of the information received by the research team was in hardcopy and some was received in electronic files. This office handled descriptive, pictorial and numerical information. Information ranged from specific in nature (either by location or day) to very broad. One of the first pieces of information received by the research team was a list of construction projects suitable to assess the effectiveness of the rumble stripes on highway safety. Figure 3-9 shows the list of project segments as chosen by District 6. This list was then used as the foundation to collect all relevant traffic flow and crash information relevant to the project.

COMPLETION DATE	
12-30-2005	US 98 in George County from the Greene County line to SR 63 has rumble stripe.
7-31-2004	US 98 in Greene County from east of SR 198 in McLain to the George County line has a rumble strip.
8-26-2004	US 98 in Perry County from the Forrest County line east 7.5 miles has rumble stripe.
6-14-2002	US 98 in Forrest County from Interstate 59 to the Perry County line has no rumble strip or rumble stripe.
7-5-2002	SR 589 in Lamar County from Haden Road north to US 98 has rumble stripe.
8-1-2002	SR 589 in Lamar County from US 98 north to the Covington County line has no rumble strip or rumble stripe.
8-26-2005	SR 43 in Hancock County from SR 603 to Dummyline Road has rumble stripe.
3-17-2004	SR 43 in Hancock County from Dummyline Road to Salem Road has no rumble stripe.
8-26-2004	SR 43 in Pearl River County from Pinetucky Road to SR 26 has no rumble stripe.
6-14-2002	US 11 in Pearl River County from Minkler Road to Charwood Drive has no rumble stripe.

Figure 3-9. Project List District 6

The district office also provided detailed information regarding the construction projects. Figure 3-10 shows examples of a construction drawing provided by the District 6 Office.

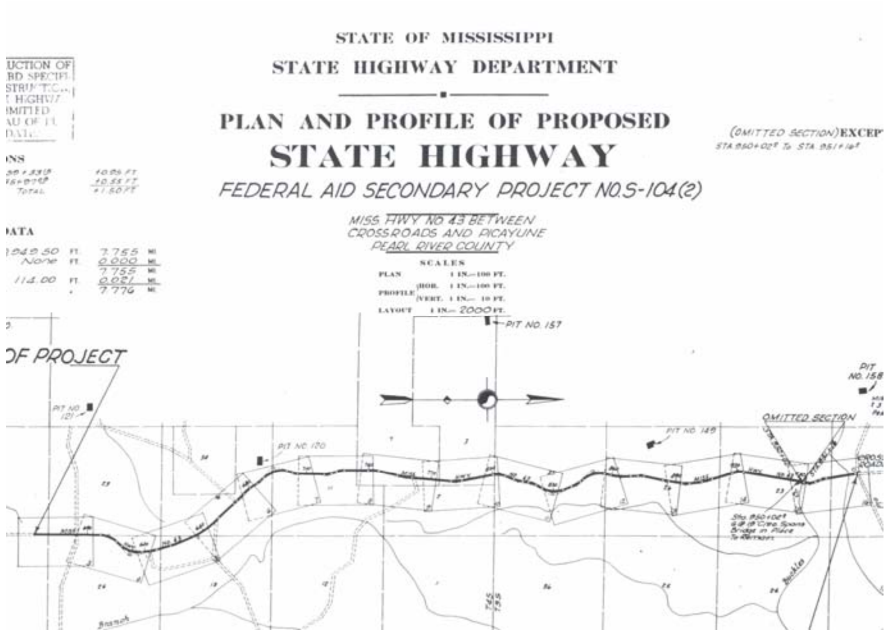


Figure 3-10. Sample Section Information

3.3.3. District 5 Office - Mississippi Department of Transportation

Similar to the District 6 Office, the District 5 Office has multiple responsibilities and therefore collected, used and stored information using multiple formats. It is interesting to note that although both district offices are part of the same department of transportation (Mississippi) and both have similar responsibilities, the format used to collect, store and retrieve the information was different between the two districts.

The first piece of information provided by this district was the list of construction projects most suitable for the assessment. Figure 3-11 shows the list of project segments as chosen by District 5.

In addition to the list of construction projects this district also provided detailed information on each project. Figure 3-12 shows sample project information files from the District 5. Figure 3-13 shows a file opened for a particular selected highway section. Figure 3-14 shows the scope of work for modifications to a segment of highway. It is worth noting that this division provided all the information in digital form.

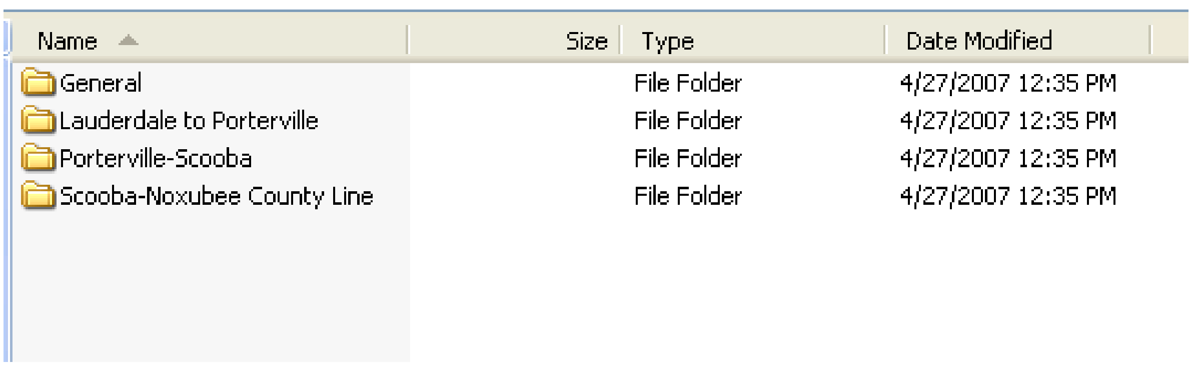


Figure 3-11. Project List District 5

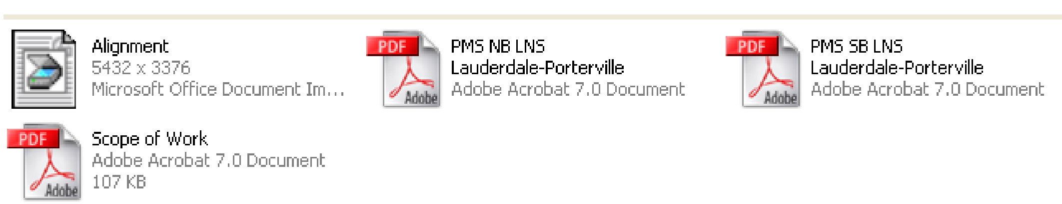


Figure 3-12. Sample Project Information

Mississippi Department of Transportation

Transportation Management Information System

RDD680 Report

Date: 03/27/2007
Time: 12:20:48
Analysis Section ID: 1672

County:	Kemper [35]	Begin Distance:	0.000 mi	DDA: N	Federal Functional Class: 02
Route:	45 N. Bound Lns	End Distance:	0.582 mi	District: 5	National Highway System: Y

Pavement Type:	Overlay Flexible	Number of Lanes in Section:	2	Plan Length:	0.582 mi
Structure Number:	3.71	Total Number of Lanes:	4	Measured Length:	0.582 mi
Divided Highway:	Y	Total Lane Width:	28.0 ft / 8.40 m	Paved Shoulder:	N
		Left Shoulder Width:	6.0 ft / 1.80 m		
		Right Shoulder Width:	8.0 ft / 2.40 m		

Begin Station No.:	149+25	Begin Latitude:	32.577820	Begin Longitude:	-88.502655
End Station No.:	180+00	End Latitude:	32.586693	End Longitude:	-88.501762
Begin Landmark:	Lauderdale Co. Line				
End Landmark:	0.582 Mi. N. Of Lauderdale Co. Line				
Memo:	Overlay #1 Was Placed After Original Construction In Lieu Of Removingstriping				

Lanes **Landmarks**

Figure 3-13. Sample Section Information

MISSISSIPPI DEPARTMENT OT TRANSPORTATION

SECTION 904- NOTICE TO BIDDERS NO. 69 **CODE:**

DATE: 06/0 4/2004

SUBJECT: Scope of Work

PROJECT: MP-5000-00(024) / 302669 - LAUDERDALE & KEMPER COS.

The contract documents do not include an official set of construction plans, but may, by reference, include some Standard Drawings when so specified in a Notice to Bidders entitled 'Standard Drawings'. All other references to plans in the contract documents and Standard Specifications for Road and Bridge Construction are to be disregarded.

Work on the project shall consist of the following:

Overlay approximately 10.5 miles of existing asphalt pavement on US Hwy. 45 from just north of Lauderdale at approximately station 26+44 northerly to Porterville at approximately

Figure 3-14. Sample Scope of Work

3.3.4. Traffic Engineering Division - Mississippi Department of Transportation

In order to fulfill its mission, MDOT Traffic Engineering Division continuously collects safety related information. All the information provided by this office to the research team was in electronic files. Several files were provided to the research team to analyze the safety conditions of the studied area. Although all the data was electronically stored, there were very limited (if any) common fields between this information and information provided by the planning division and/or the districts office.

The main data provided by this division was crash information for each of the segments provided by the district offices. Figures 3-15 and 3-16 shows the sample data files as provided by the Traffic Engineering Division. Figure 3-17, 3-18, and 3-19 provides sample crash information with components and their elements.

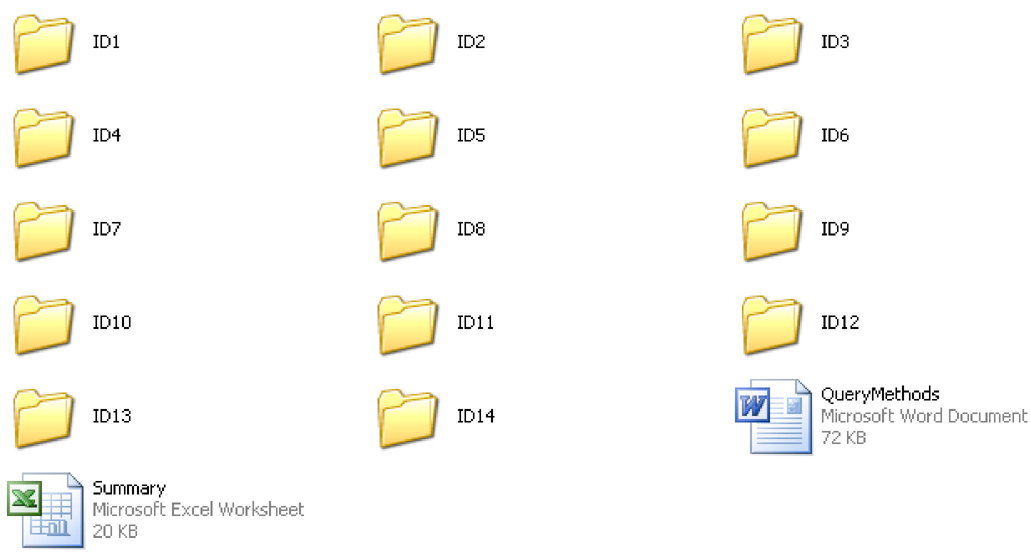


Figure 3-15. Sample Data Files from the Traffic Engineering

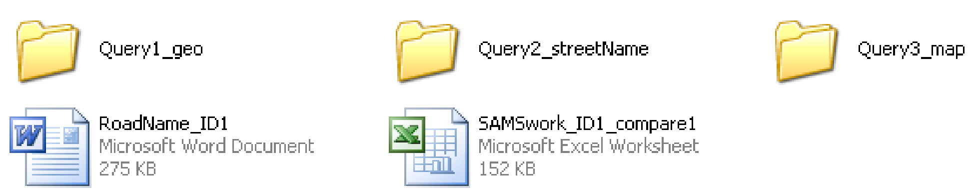


Figure 3-16. Sample Data Files from the Traffic Engineering

	B	C	D	E	F	G	H	I
1	ROUTE I	SAMS ROUTE NAMI	STREET NAME	INTERSECTING ROUTE	INTERSECTING STREET NAME	SAMS INT ROUTE N	COUNTYNAN	SAMS CITYNA
4	198	MS 198	LONDON ST	198	RATLIFF ST	MS 198	George [20]	LUCEDALE
5	063		SOUTH				George [20]	
6			WEST CAMELLIA ROAD		TWIN CREEK ROAD		George [20]	
7	26	MS 26	WINTER ST.	63	COWART STREET	MS 63	George [20]	LUCEDALE
8			026 WEST		HENERY COCHRAN		George [20]	
9			063		VENTURA DR.		George [20]	
10			063 SOUTH		WALMART PL.		George [20]	
11			063 WALMART		063	MS 63	George [20]	
12			063 WINTER ST.		AUTO ZONE		George [20]	
13			08 SUNSET DR		FAIRGROUNDS		George [20]	
14			098		HWY 63		George [20]	
15			1205 MILL ST EAST		FOUNTAIN LAKE RD		George [20]	
16			13185 HWY 613		HWY 613	MS 613	George [20]	
17			132 NATHANS LANE		TUT RD		George [20]	
18			13TH ST		GRAND AVE		George [20]	
19	163		163	163	WALMART PARKING LOT		George [20]	LUCEDALE
20			163 SOUTH		WALMART PARKING LOT		George [20]	LUCEDALE
21	163		163 SOUTH	26	WINTER ST	MS 26	George [20]	LUCEDALE

Figure 3-17. Sample Crash Information with Components and their Elements

	H	I	J	K	L	M	N	O	P	Q
1	COUNTYNAN	SAMS CITYNA	INTERSECTION DIS	INTERSECTION DIST U	INTERSECTION DIST DI	REPORTED DA	REPORTED TI	SAMS CRASH I	VEHICLE COU	SAMS INJURY
4	George [20]	LUCEDALE	0.15	F	W	02/21/2006	12:05	1876478	2	
5	George [20]		0			09/03/2002	12:31	3970484	3	
6	George [20]					09/08/2005	05:40	1812614	1	
7	George [20]	LUCEDALE	200	F	S	10/08/2006	15:10	3470592	2	
8	George [20]		0			11/16/2002	12:41	4011012	2	
9	George [20]		0			09/10/2002	17:32	4027514	2	
10	George [20]		0			12/30/2003	13:04	4108442	2	
11	George [20]		0			03/04/2003	13:25	4032498	2	
12	George [20]		0			10/21/2002	11:48	3998293	3	
13	George [20]		500	F		01/13/2003	08:49	4013364	1	
14	George [20]		0			12/26/2002	03:45	4058866	1	
15	George [20]		0.08	M	S	10/27/2002	18:05	4021189	2	
16	George [20]		0.5	F	W	05/06/2005	14:20	3446778	2	
17	George [20]		300	F	N	10/06/2005	16:07	1812613	2	
18	George [20]					06/27/2005	19:17	3444162	2	
19	George [20]	LUCEDALE				05/04/2004	14:57	1768515	2	
20	George [20]	LUCEDALE				11/15/2004	11:25	1819635	2	
21	George [20]	LUCEDALE				08/22/2005	17:15	1819487	2	

Figure 3-18. Sample Crash Information with Components and their Elements

	Q	R	S	T	U	V	W	X
1	SAMS INJURY C	SAMS FATAL C	SAMS STAT INJURY SEVER	SAMS STAT DUI I	LIGHT CONDITION DES	ROAD CONDITION DESC	SAMS CRASH TYPE DESC	SAMS INTR
4			5		Daylight	Dry	Parked vehicle	
5	0	0	5		Daylight	Dry	Angle	
6	1		4		Dark-Unlit	Dry	Fixed Object	
7			5	0	Daylight	Dry	Hit and Run	
8	0	0	5		Dawn	Dry	Rear end slow or stop	
9	0	0	5		Daylight	Dry	Rear end slow or stop	
10	0	0	5		Daylight	Dry	Angle	
11	0	0	5		Daylight	Dry	Parked vehicle	
12	0	0	5		Daylight	Dry	Rear end slow or stop	
13	0	0			Daylight	Dry	Parked vehicle	
14	0	0	5		Dark-Unlit	Dry	Run off Road - Straight	
15	1	0	4		Dark-Unlit	Dry	Parked vehicle	
16			5	0	Daylight	Dry	Parked vehicle	
17			5		Daylight	Dry	Parked vehicle	
18			5	0	Daylight	Dry	Angle	
19			5		Daylight	Dry	Left turn same roadway	
20			5		Daylight	Dry	Rear end slow or stop	
21			5		Daylight	Dry	Rear end slow or stop	

Figure 3-19. Sample Crash Information with Components and their Elements

3.4. LESSONS LEARNED

The use of rumble stripes to improve the safety of drivers is of paramount importance for all the MDOT Divisions and Districts that graciously share their information with the research team. All the divisions and districts were very willing to collaborate in the data consolidation process.

However, collecting, archiving and retrieving information was not a main priority for any of the divisions and districts. Additionally, no general guidelines for data structuring was communicated among the divisions and districts. Therefore, it is evident that input into the data gathering process before the data is collected rather than after the fact, could greatly improve the process of accessing the impact of other safety programs currently implemented by the department. By defining the data to be collected, the method for collecting the data, the formatting of the data, the timeframes for collecting the data (before, during and after construction) all the participating divisions and districts would be able to share information and demonstrate the impact of their performance to the stakeholders.

Additionally, this collection effort demonstrated that the data was available and the divisions and districts were willing to provide the data to the research team. The research team was able to combine, reform, integrate and analyze the data to produce quantifiable results.

Finally, although each division and district participating in this project had a different mission and collected different data, it is possible to create a data structure that allow these divisions and districts to share common data for common purposes and reduce the cost of the data collection efforts.

3.5. SUMMARY

Maintenance and construction programs are arguably one of the most important functions of states DOT (as represented by the percentage of the budget invested). MDOT through the Traffic Engineering Division, is committed to improve Mississippi highway safety. MDOT has invested valuable resources to implement a series of safety improvement programs such as the Rumble Stripes program. Despite MDOT’s high commitment and efforts to improve highway safety, MDOT does not know the impact of the Rumble Strip program in reducing crashes. In other words, MDOT lacks quantifiable evidence that demonstrates the effectiveness of this program. This paper focused on the agencies involved in collecting and storing the data as well as the data used to measure the effectiveness of the Rumble Stripes program. The content of this paper was then used as the foundation for the statistical analysis.

This work followed a descriptive research methodology to systematically collect data from the several agencies involved in construction projects. The first step in the data collection was for MDOT to contact the divisions and districts and provide brief information about the project and research. Then the research team met with the each division and district to discuss the overall purpose of the project and request the required data. Then the divisions and districts were responsible for assembling the collected data and sending it to the researchers.

The results presented in this chapter demonstrate the importance of inter-division and district collaboration. Furthermore, this paper provide an example of data collected, archiving mechanism and retrieval procedures of each agency involved in this project. Therefore, the results could be used as lessons learned and serve as the foundation for similar studies.

CHAPTER 4:
DATA STRUCTURING FOR STATISTICAL ANALYSIS OF:
EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY

4.1. INTRODUCTION TO ROADWAY FATALITIES

The United States (U.S.) heavily relies on the roadway infrastructure. As shown in Table 1 a considerable number of highway vehicle miles are driven every year. Unfortunately, the number of fatalities is staggering with accidents becoming more frequent, resulting in situations as the one depicted in Figure 4-1.

Figure 4-1. Crash Sample Picture [Public Roads 2004]

Every year on U.S highways, there are over 700 fatalities, 40,000 injuries, and 52,000 property-damage-only accidents [Mohan & Gautam, 2002]. Most of the 700 fatalities are due to roadway departures. On average, one roadway departure fatality occurs every 23 minutes, and a roadway departure injury occurs every 43 seconds. It is estimated that the annual cost of roadway departure is $100 billion [FHWA Resource Center 2006]

The Federal Highway Administration indicates that improvements in infrastructure have helped keep the fatalities number from increasing. However, higher traffic volumes have counteracted any real reductions in the number of fatalities due to roadway departure [Public Roads 2005].

Therefore, countermeasures to prevent or lessen the occurrence of roadway departures are important steps towards improving the safety of U.S. roadways. Roadway departure countermeasures must be designed to keep the motorists in lanes and on the roads, enable the drivers to recover and safely return errant vehicles to the roadway, and keep vehicle occupants from greater harm if a vehicle does leave the roadway [Public Roads 2005].

This paper will focus on a project funded by MDOT to determine the safety effectiveness of one roadway departure countermeasure, rumble stripes, in Mississippi. More specifically, this paper presents a focuses on the process implemented to restructure and consolidate the data obtained from multiple divisions and districts to be able to measure the impact of rumble stripes on highway safety.

The content of this paper was later used as the foundation for statistical analysis. The results presented in this paper reveal the importance of inter division and district collaboration and the need to establish a common data structure to facilitate the exchange of information among divisions and districts.

4.2. Overview Of The MDOT Divisions and District Offices and their Collected Data

Collecting, processing, archiving and retrieving data/information is costly, demanding and necessary and is the responsibility of MDOT divisions and district offices. Each division and district office manages data/information in a different way for a variety of purposes to fulfill their primary responsibility/mission.

The first step in consolidating the data was to identify the divisions and district offices with needed data, and their responsibility/roles in collecting data. Figure 4-2 shows the information needed for this project and the particular MDOT division and/or district responsible for the data.

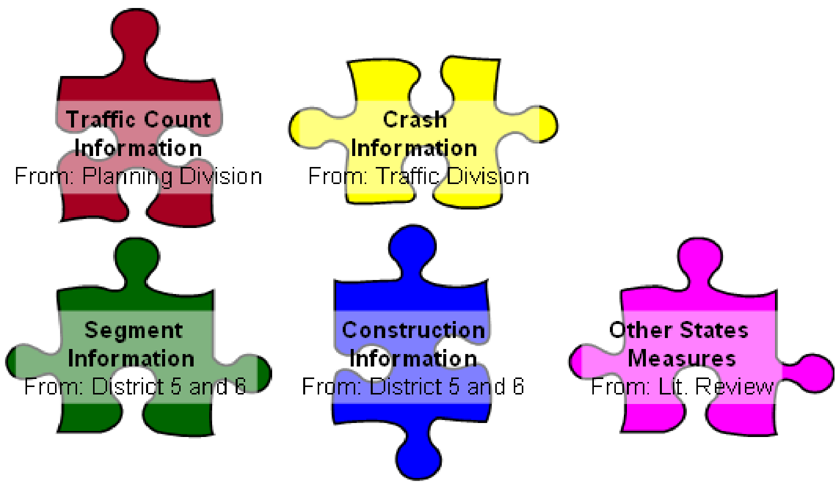


Figure 4-2. Data Needed for the Study and Sources

Then, the MDOT leader of this project contacted the divisions and district offices and provided a brief description of the project and the research team. The research team followed-up this initial contact by requesting a meeting with the representatives of the divisions and district offices to provide an overview of the project and initiate the turn-over of the data that had been collected by the divisions and district offices.

During this initial meeting, an informal interview was conducted with the divisions and district offices representative to explicitly identify the data that the divisions and district offices had already collected, the structure, and the media in which the data was stored as well as the retrieval means of the agency. Upon agreeing with the divisions and district offices concerning the data to be retrieved, a mechanism to transfer the data was established. As expected and evidenced below, each divisions and district offices used a different structure to archive the data. The following is a brief description of the data collected by different divisions and district offices involved in Rumble Strip/Stripes on Mississippi roads.

4.2.1. Districts 5 and 6 Data - Mississippi Department of Transportation (MDOT)

The MDOT District 5 and 6 Offices had all the construction documents developed through the engineering phase prior to construction as well as all the construction documents generated during the construction process. Given the diversity of the information handled by this office, there was no common structure in the data archived. This office handled descriptive, pictorial and numerical information. Information ranged from specific in nature (either by location or day) to very broad. One of the most valuable pieces of information provided by the district offices to the research team was the segments that could be used for this project as shown Table 4-1.

Table 4-1. Road Segments Included in the Study

ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)
1	US 98 in George County from the Greene County line to SR 63/Dist 6	US 98	Greene County line	SR 63
2	US 98 in Greene County from east of SR 198 in McLain to the George County line/Dist 6	US 98	Greene County from east of SR 198 in McLain	George County line
3	US 98 in Perry County from the Forrest County line east 7.5 miles/Dist 6	US 98	Forrest County line	East 7.5 miles into Perry County
4	US 98 in Forrest County from Interstate 59 to the Perry County line/Dist 6	US 98	Forrest County from Interstate 59	Perry County line
5	SR 589 in Lamar County from Haden Road north to US 98/Dist 6	SR 589	in Lamar County from US 98 north	to US 98
6	SR 589 in Lamar County from US 98 north to the Covington County line/Dist 6	SR 589	in Lamar County from US 98 north	to the Covington County line
7	SR 43 in Hancock County from SR 603 to Dummyline Road/Dist 6	SR 43	in Hancock County from SR 603	to Dummyline Road
8	SR 43 in Hancock County from Dummyline Road to Salem Road/Dist 6	SR 43	in Hancock County from Dummyline Road	to Salem Road
9	SR 43 in Pearl River County from Pinetucky Road to SR 26/Dist 6	SR 43	in Pearl River County from Pinetucky Road	to SR 26
10	US 11 in Pearl River County from Minkler Road to Charwood Drive/Dist 6	US 11	in Pearl River County from Minkler Road	to Charwood Drive
11	11 in Pearl River County from Charwood Drive to the north corporate limits of Poplarville/Dist 6	US 11	in Pearl River County from Charwood Drive	to the north corporate limits of Poplarville
12	Scooba-Noxubee County Line (7 ½ Miles of 4 lane) in Kemper County /Dist 5	US45	Scooba 0.644 North of	Noxubee County Line
13	Porterville-Scooba (9 ¾ Miles of 4 lane)/Dist 5	US45	Porterville	Scooba
14	Lauderdale to Porterville (10 Miles of 4 lane)/Dist 5	US45	Lauderdale	Porterville

4.2.2. Planning Division Data - Mississippi Department of Transportation (MDOT)

The MDOT Planning Division had placed a number of traffic recording devices around the state. The data/information collected from these devices was mainly handled/presented in pictorial and numerical form. One of the most valuable pieces of information provided by the Planning

Division to the research team was traffic volume in the studied area. Figure 4-3 to Figure 4-6 shows a sample of type of traffic volume data obtained from the Planning Division.

	A	B	C	D	E	F	G	H
3	ID	Location	Date1	Date2	Time	Westbound	Eastbound	Total
4	1	1	Monday 1/30/06	Wednesday 2/1/06	0	44	30	74
5	1	1	Monday 1/30/06	Wednesday 2/1/06	100	41	25	66
6	1	1	Monday 1/30/06	Wednesday 2/1/06	200	33	23	56
7	1	1	Monday 1/30/06	Wednesday 2/1/06	300	53	24	77
8	1	1	Monday 1/30/06	Wednesday 2/1/06	400	84	68	152
9	1	1	Monday 1/30/06	Wednesday 2/1/06	500	123	83	206
10	1	1	Monday 1/30/06	Wednesday 2/1/06	600	138	142	279
11	1	1	Monday 1/30/06	Wednesday 2/1/06	700	177	212	388
12	1	1	Monday 1/30/06	Wednesday 2/1/06	800	195	232	427
13	1	1	Monday 1/30/06	Wednesday 2/1/06	900	207	263	470
14	1	1	Monday 1/30/06	Wednesday 2/1/06	1000	229	235	463
15	1	1	Monday 1/30/06	Wednesday 2/1/06	AM Peak 1100	245	233	478
16	1	1	Monday 1/30/06	Wednesday 2/1/06	1200	240	244	484
17	1	1	Monday 1/30/06	Wednesday 2/1/06	1300	258	273	531
18	1	1	Monday 1/30/06	Wednesday 2/1/06	1400	281	278	558
19	1	1	Monday 1/30/06	Wednesday 2/1/06	1500	278	272	550
20	1	1	Monday 1/30/06	Wednesday 2/1/06	PM Peak 1600	283	287	570
21	1	1	Monday 1/30/06	Wednesday 2/1/06	1700	252	271	523
22	1	1	Monday 1/30/06	Wednesday 2/1/06	1800	195	228	423
23	1	1	Monday 1/30/06	Wednesday 2/1/06	1900	153	153	306
24	1	1	Monday 1/30/06	Wednesday 2/1/06	2000	120	120	240
25	1	1	Monday 1/30/06	Wednesday 2/1/06	2100	105	95	200
26	1	1	Monday 1/30/06	Wednesday 2/1/06	2200	80	85	164
27	1	1	Monday 1/30/06	Wednesday 2/1/06	2300	62	50	112
28	1	2	Tuesday 2/11/03	Thursday 2/13/03	0	34	39	73
29	1	2	Tuesday 2/11/03	Thursday 2/13/03	100	39	57	95
30	1	2	Tuesday 2/11/03	Thursday 2/13/03	200	91	91	182
31	1	2	Tuesday 2/11/03	Thursday 2/13/03	300	149	109	258
32	1	2	Tuesday 2/11/03	Thursday 2/13/03	400	144	161	305
33	1	2	Tuesday 2/11/03	Thursday 2/13/03	500	167	195	362

Figure 4-3. A Sample of the Hourly Traffic Volume Data Received from Planning

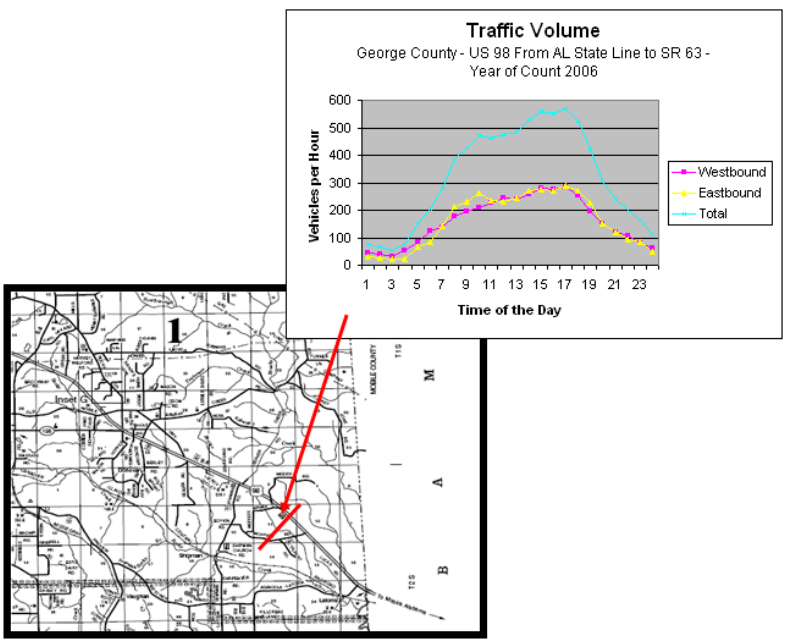


Figure 4-4. A Sample of the Hourly Traffic Volume Data Received from Planning

ID	Location #	Location Description	Route	County	AADT 1 Year	AADT 1 Volume	AADT 2 Year	AADT 2 Volume
1	1	From SR 63 to Greene CL	US 98	George	2002	6500	2005	7200
2	1	From Perry CL to Old Hwy 24	US 98	Greene	2001	8500	2004	8900
2	2	From Perry CL to Old Hwy 24	US 98	Greene	2003	10000	2006	8000
2	3	From SR 57 to Vernal River Rd	US 98	Greene	2003	7300	2006	6500
2	4	From Vernal River Rd to George CL	US 98	Greene	2003	7700	2006	7500
3	1	From Mahned Rd to SR 29	US 98	Perry	2003	10000	2006	9700
3	2	From SR 29 to SR 198	US 98	Perry	2001	8700	2004	10000
3	3	From SR 198 (W) to Eight Mile Rd	US 98	Perry	2003	8400	2006	8700
4	1	From I-59 to US 49	US 98	Forrest	2003	13000	2006	23000
5	1	From WPA to Old Hwy 24	SR 589	Lamar	2001	2000	2004	2000
6	1	From US 98 to Epley Rd	SR 589	Lamar	2000	4300	2004	5000
6	2	From Epley Rd to SR 42	SR 589	Lamar	2000	4200	2004	4300
6	3	From SR 42 to Covington CL	SR 589	Lamar	2000	1800	2004	2200
8	1	From Dummyline Rd to Pearl River CL	SR 43	Hancock	2003	4000	2006	6400
8	2	From Pearl River CL to Salem Rd	SR 43	Pearl River	2003	4000	2006	6400
9	1	From Pinetucky Rd to SR 26	SR 43	Pearl River	2003	1600	2006	1900
10	1	From Derby Whitesand Rd to SR 26	US 11	Pearl River	2004	1900	2006	3300
11	1	From Derby Whitesand Rd to SR 26	US 11	Pearl River	2003	1900	2006	3300
11	2	From SR 26 to North St	US 11	Pearl River	2003	6200	2006	6300
11	3	From North St to Lamar St	US 11	Pearl River	2003	4800	2006	5200
11	4	From Lamar St to Springhill Rd	US 11	Pearl River	2003	1500	2006	1700
14	1	From Old Lauderdale Rd to Kemper CL	US 45	Lauderdale	2003	3600	2006	3700
14	2	From Lauderdale CL to Dekalb-Porterville Rc	US 45	Kemper	2003	3600	2006	3700

Figure 4-5. Annual Average Daily Traffic over Time Received from Planning

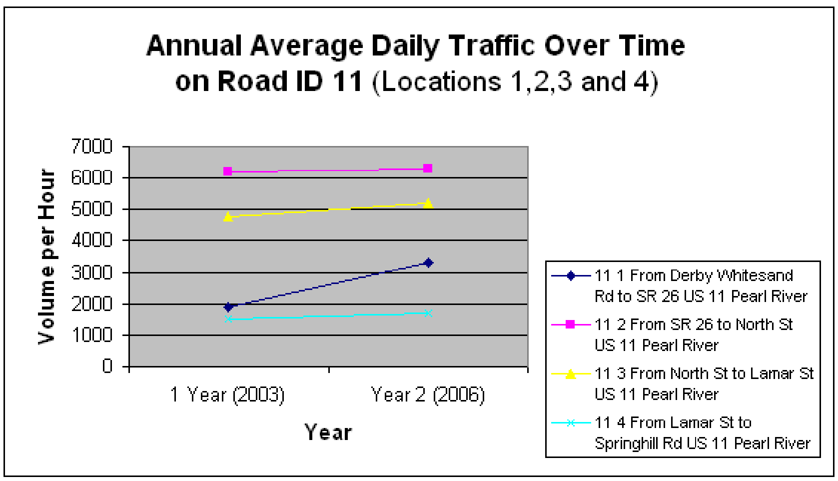


Figure 4-6. A Sample of the Annual Average Daily Traffic Over Time Receive from Planning

4.2.3. Traffic Engineering Division Data – Mississippi Department of Transportation (MDOT)

The MDOT Traffic Engineering Division continuously collects safety related information. All information provided by this office to the research team was in electronic files. Several files were provided to the research team to analyze the safety conditions of the studied area. Although, all the data was electronically stored, given the diversity of the data, few (if any) of the fields were common to all the data stored. The most valuable pieces of information provided by the Traffic Engineering Division to the research team were the crash data. Figure 4-7 to 4-9 show a sample of crash data obtained from the Traffic Engineering Division.

	B	C	D	E	F	G	H	I
1	ROUTE I	SAMS ROUTE NAM	STREET NAME	INTERSECTING ROUTE	INTERSECTING STREET NAME	SAMS INT ROUTE N	COUNTYNAM	SAMS CITYNA
4	198	MS 198	LONDON ST	198	RATLIFF ST	MS 198	George [20]	LUCEDALE
5	063		SOUTH				George [20]	
6			WEST CAMELLIA ROAD		TWIN CREEK ROAD		George [20]	
7	26	MS 26	WINTER ST.	63	COWART STREET	MS 63	George [20]	LUCEDALE
8			026 WEST		HENERY COCHRAN		George [20]	
9			063		VENTURA DR.		George [20]	
10			063 SOUTH		WALMART PL.		George [20]	
11			063 WALMART		063	MS 63	George [20]	
12			063 WINTER ST.		AUTO ZONE		George [20]	
13			08 SUNSET DR		FAIRGROUNDS		George [20]	
14			098		HWY 63		George [20]	
15			1205 MILL ST EAST		FOUNTAIN LAKE RD		George [20]	
16			13185 HWY 613		HWY 613	MS 613	George [20]	
17			132 NATHANS LANE		TUT RD		George [20]	
18			13TH ST		GRAND AVE		George [20]	
19	163		163	163	WALMART PARKING LOT		George [20]	LUCEDALE
20			163 SOUTH		WALMART PARKING LOT		George [20]	LUCEDALE
21	163		163 SOUTH	26	WINTER ST	MS 26	George [20]	LUCEDALE

Figure 4-7. Sample Crash Information with Components and their Elements

	H	I	J	K	L	M	N	O	P	Q
1	COUNTYNAM	SAMS CITYNA	INTERSECTION DIS	INTERSECTION DIST U	INTERSECTION DIST DI	REPORTED DA	REPORTED TI	SAMS CRASH I	VEHICLE COU	SAMS INJURY
4	George [20]	LUCEDALE	0.15	F	W	02/21/2006	12:05	1876478	2	
5	George [20]		0			09/03/2002	12:31	3970484	3	
6	George [20]					09/08/2005	05:40	1812614	1	
7	George [20]	LUCEDALE	200	F	S	10/08/2006	15:10	3470592	2	
8	George [20]		0			11/16/2002	12:41	4011012	2	
9	George [20]		0			09/10/2002	17:32	4027514	2	
10	George [20]		0			12/30/2003	13:04	4108442	2	
11	George [20]		0			03/04/2003	13:25	4032498	2	
12	George [20]		0			10/21/2002	11:48	3998293	3	
13	George [20]		500	F		01/13/2003	08:49	4013364	1	
14	George [20]		0			12/26/2002	03:45	4058866	1	
15	George [20]		0.08	M	S	10/27/2002	18:05	4021189	2	
16	George [20]		0.5	F	W	05/06/2005	14:20	3446778	2	
17	George [20]		300	F	N	10/06/2005	16:07	1812613	2	
18	George [20]					06/27/2005	19:17	3444162	2	
19	George [20]	LUCEDALE				05/04/2004	14:57	1768515	2	
20	George [20]	LUCEDALE				11/15/2004	11:25	1819635	2	
21	George [20]	LUCEDALE				08/22/2005	17:15	1819487	2	

Figure 4-8. Sample Crash Information with Components and their Elements

	Q	R	S	T	U	V	W	X
1	SAMS INJURY C	SAMS FATAL C	SAMS STAT INJURY SEVER	SAMS STAT DUI I	LIGHT CONDITION DES	ROAD CONDITION DESC	SAMS CRASH TYPE DESC	SAMS INTR
4			5		Daylight	Dry	Parked vehicle	
5	0	0	5		Daylight	Dry	Angle	
6	1		4		Dark-Unlit	Dry	Fixed Object	
7			5	0	Daylight	Dry	Hit and Run	
8	0	0	5		Dawn	Dry	Rear end slow or stop	
9	0	0	5		Daylight	Dry	Rear end slow or stop	
10	0	0	5		Daylight	Dry	Angle	
11	0	0	5		Daylight	Dry	Parked vehicle	
12	0	0	5		Daylight	Dry	Rear end slow or stop	
13	0	0			Daylight	Dry	Parked vehicle	
14	0	0	5		Dark-Unlit	Dry	Run off Road - Straight	
15	1	0	4		Dark-Unlit	Dry	Parked vehicle	
16			5	0	Daylight	Dry	Parked vehicle	
17			5		Daylight	Dry	Parked vehicle	
18			5	0	Daylight	Dry	Angle	
19			5		Daylight	Dry	Left turn same roadway	
20			5		Daylight	Dry	Rear end slow or stop	
21			5		Daylight	Dry	Rear end slow or stop	

Figure 4-9. Sample Crash Information with Components and their Elements

4.3. THE RESTRUCTURING AND CONSOLIDATION OF THE AVAILABLE DATA FOR THE ANALYSIS

The restructuring and consolidation of the data was driven by the main objective of the project which was to evaluate the effectiveness of Rumble Stripes on highway safety. To achieve this main objective, eleven specific statistical analyses were established aiming to determine if there was any correlation between the studied variables. The eleven analyses were as follows:

Analysis 1 – Rumble Stripe on the Road Vs. Number of Overall Crash
Analysis 2 – Rumble Stripe on the Road Vs. Number of Roadway Departure

Analysis 3 – Rumble Stripe Overtime Vs. Number of Overall Crash
Analysis 4 – Rumble Stripe Overtime Vs. Number of Roadway Departure
Analysis 5 – Lighting Conditions (Day/Night) Vs. Number of Overall Crash.
Analysis 6 – Lighting Conditions (Day/Night) Vs. Number of Roadway Departure
Analysis 7 – Road Conditions (Wet/Dry) Vs. Number of Overall Crash.
Analysis 8 – Road Conditions (Wet/Dry) Vs. Number of Road Way Departures.
Analysis 9 – Rumble Stripe on Road Vs -Crash Severity of Overall Crashes
Analysis 10 – Rumble Stripe on Road Vs Crash Severity of Road Way Departure
Analysis 11 – Rutting Condition Vs. Number of Overall Crash.
Analysis 12 – Rutting Condition Vs. Number of Road Way Departures.

Based on the eleven analyses, the following data was required:

- Construction starting and ending data of each studied segment
- Crashes in each of the studied segments
- Crash types/descriptions (Roadway departures, Overturn, etc)
- Crash dates
- Lighting conditions (Dark / Lighten)
- Road condition (Dry / Wet / Snow)
- Crash Injury Severity (Property Damage Only, Complain of Pain, Moderate, Life Threatening, Fatal)
- Rutting Condition

Upon comparing the required statistical analysis and the data available from the MDOT division and/or district, it was recognized that there were four distinctive data sets (as shown in Figure 4-10): 1- Segments Information, 2- Crash Information 3- Traffic Volume Information, and 4- Pavement Analysis.

Segments Information Data Set
Segment ID
Project Name
Route
Starting Point
Ending Point
Intersecting Roads
Construction Start Date
Construction Ending Date

Crash Information Data Set
Segment ID
Date
Crash type/description
Lighting conditions
Road conditions
Crash Injury Severity

Traffic Volume Data Set
Segment ID
Date
Traffic Count

Pavement Analysis Data Set
Segment ID
Date
Rutting Conditions

Figure 4-10. Data Sets for Analyses

The following is a brief description of the restructuring of the data from the different MDOT division and/or district involved:

4.3.1. Restructuring Districts 5 and 6 Data - Mississippi Department of Transportation (MDOT) Data

The segment information received from Districts 5 and 6 (shown in Table 4-1) was modified to include all the elements of the "Segment Information" data set. Figure 4-11 shows a portion of the enhanced segment information with all the needed elements.

ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)	Desc	Map	Intersecting Roads	Project Dates (Start)	Project Dates (Ending)	BEFORE Data Traffic Flow and Incidents (Years)	AFTER Data Traffic Flow and Incidents (Years)
1	US 98 in George County from the Greene County line to SR 63/Dist 6	US 98	Greene County line	SR 63	has rumble stripe.		McInnis Ln - Billy Knight Rd Ben Eubanks Rd. Cutoff Rd. Merril Rd. Unknown Rd. Nicholson Ln N Bexley Rd. S Bexley Rd. Darlenes Ln Unknown Rd. Main St. – CF Eubanks Rd. Ernest Pipkins Rd.	04/08/2004	09/31/2004	From 01/01/2002 To 03/31/2004	From 10/01/2004 To 12/31/2006
2	US 98 in Greene County from east of SR 198 in McLain to the George County line/Dist 6	US 98	Greene County from east of SR 198 in McLain	George County line	has a rumble strip		Old MS 24 Unknown Rd. Hwy 57 Dewey McInnis Rd. – Jim Powell Rd. Midway Church Rd. Merritt Rd. Gatlin Creek Rd. Harry Eubanks Rd. Miller Loop Tom Miller Rd. Merritt Rd. Miller Loop Oscar Howard Rd. – Vernay Rd.	04/10/2003	11/28/2003	From 01/01/2001 To 03/31/2003	From 12/01/2003 To 12/31/2006

Figure 4-11. Enhanced Segment Information

The Segment Id, Project Name, District, Route, Starting and Ending Points were used as received without re-structuring. Intersecting roads were found and added to the information to facility the collection of the crash and traffic volume information. The Project Start Date and Ending Date were used to identify the before and after periods to collect and perform comparative analysis.

The date field in the received data was defined as "Ordinal" because it represented an intrinsic order. Additionally, the year and month were extracted from the date and defined as "Ordinal" with values between 1 and 12 representing each month of the year as shown in Figure 4-12. The month information was extracted allow further analysis based on the month.

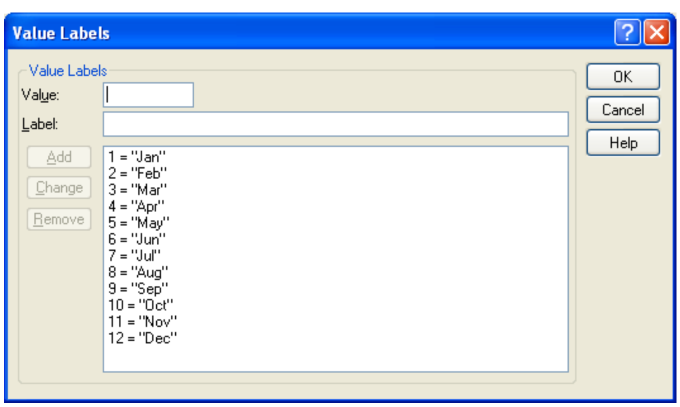


Figure 4-12. Month Values for Statistical Analysis

4.3.2. Restructuring Planning Division Data - Mississippi Department of Transportation (MDOT)

The traffic volume information received from the MDOT Planning Division (shown in Figure 4-4) was re-structured to two variables: Time of the Day and Volume. The variable Time of the Day was defined as "Ordinal" and since the "Volume" variable represented magnitude it was defined as "Scale".

The Time of the Day variable was assigned a number between 0 and 23 representing a 24 hours clock which begins at midnight (which is 0000 hours). The Volume variable was organized by direction (bound) of the traffic and contained the number of vehicles per hour that passed each studied segment each hour. Figure 4-13 shows a sample a 24 hour count.

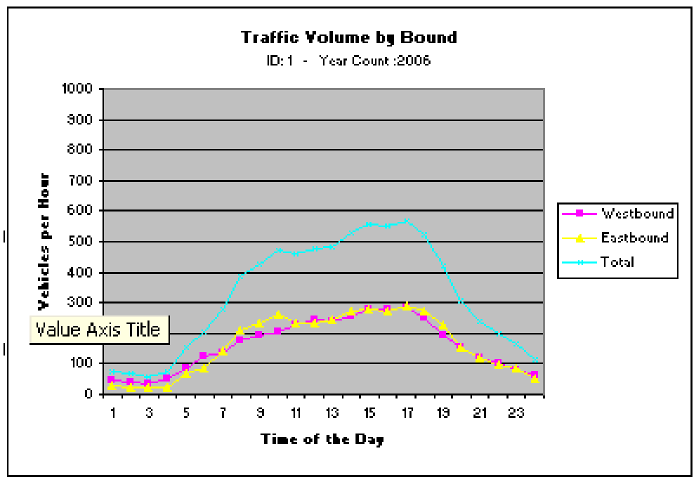


Figure 4-13. Sample 24 hour Traffic Count

4.3.3. Restructuring Traffic Engineering Division Data - Mississippi Department of Transportation (MDOT)

The crash information received from the Traffic Engineering Division (shown in Figure 4-9 to 4-11) was restructured to six variables: Segment ID, Date, Crash type/description
Lighting conditions, Road conditions and Crash Injury Severity.

The variables Date was defined as "Ordinal" as previously described. A New variable named Construction Status was created and received a value between 0 and 2, where 0 was assigned to "During" (Construction), 1 was assigned to the "Before" (construction), and 2 was assigned to the "After" (Construction) as shown in Figure 4-14.

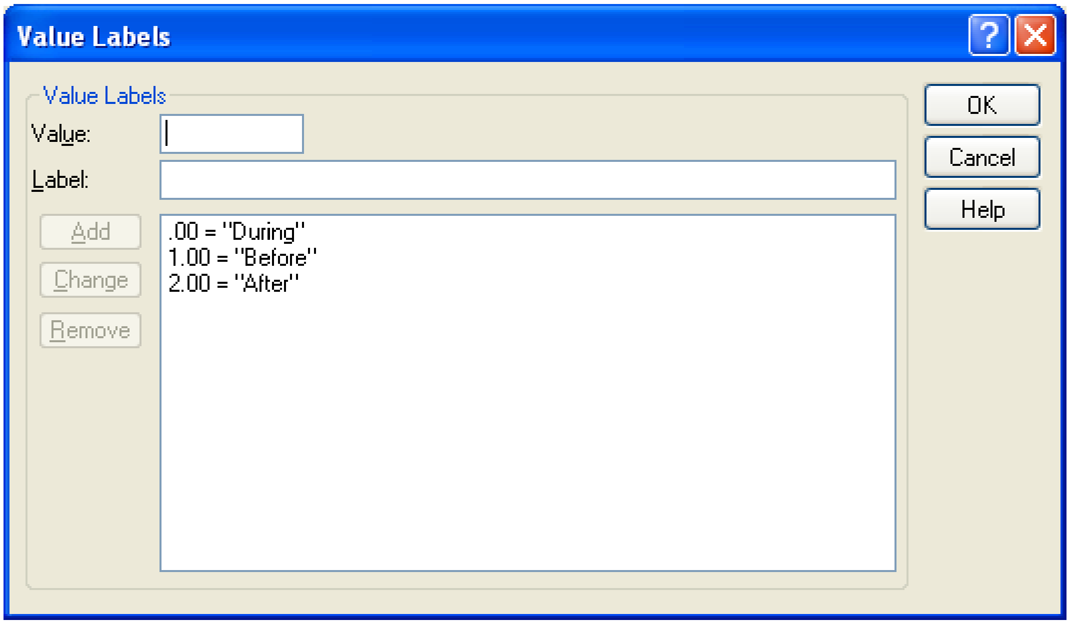


Figure 4-14. Construction Status for Statistical Analysis

The variable Crash Type/Description was defined as “Nominal” because the data values represented categories with no intrinsic order. The Crash Type/Description variable received a value between 1 and 4 for (Run Off Road and Overturn) as shown in Figure 4-15 and all other Crash Type/Description received no value in this variable.

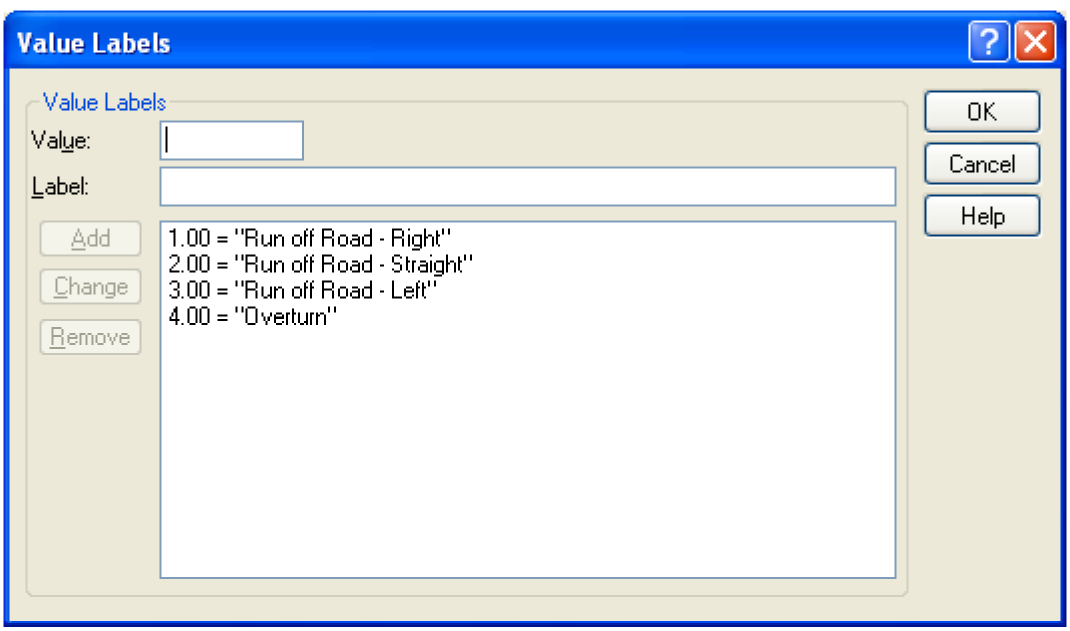


Figure 4-15. Crash Type/Description for Statistical Analysis

The Lighting Condition was defined as "Nominal" because the data values represented categories with no intrinsic order. This variable received a value between 1 and 5 as shown in Figure 4-16.

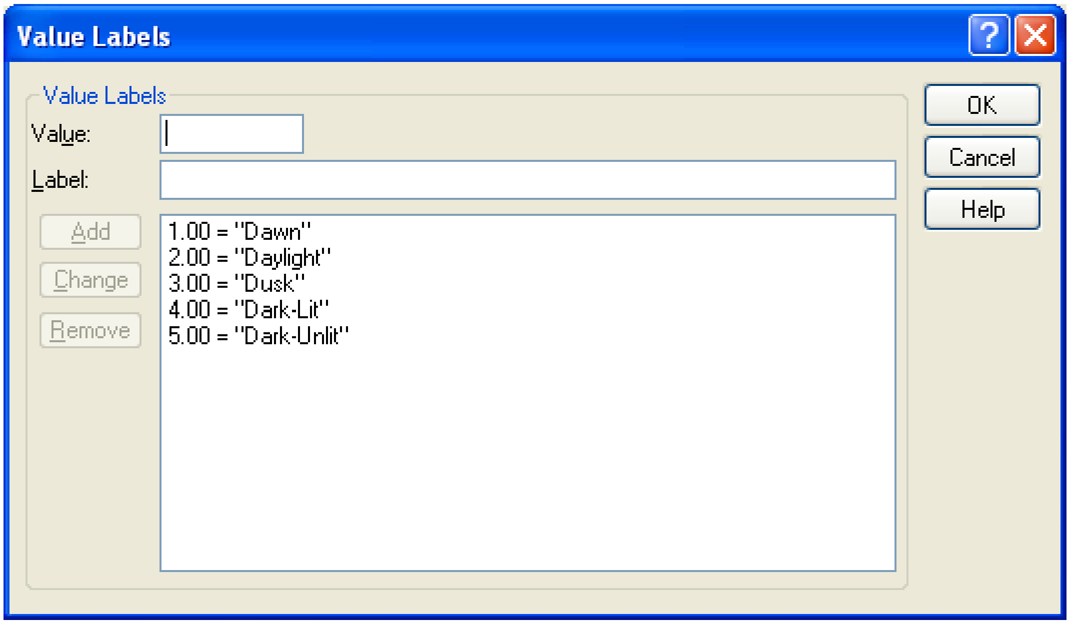


Figure 4-16. Lighting Conditions for Statistical Analysis

The Road Conditions and Crash Injury Severity were also defined as "Nominal" with the value shown in Figure 4-17.

Figure 4-17. Road Conditions and Crash Injury Severity for Statistical Analysis

4.4. Consolidation of all the Data

After restructuring the information received from each divisions and districts, the next step was to consolidate (or integrate) all of the data sets into one master data file. The variables "Segment ID" and "Date" were identified as the common field among all the data sets. The dashed arrows pointing in two directions, in Figure 4-18 show these two variables common among all the data sets. Therefore, "Segment ID" and "Date" were used as key fields and the data from all the data sets was copied into one master data set with the fields shown in Table 4-2. As a result of this consolidation, a total of 1564 records were integrated into the master data set as shown in Table 4-3.

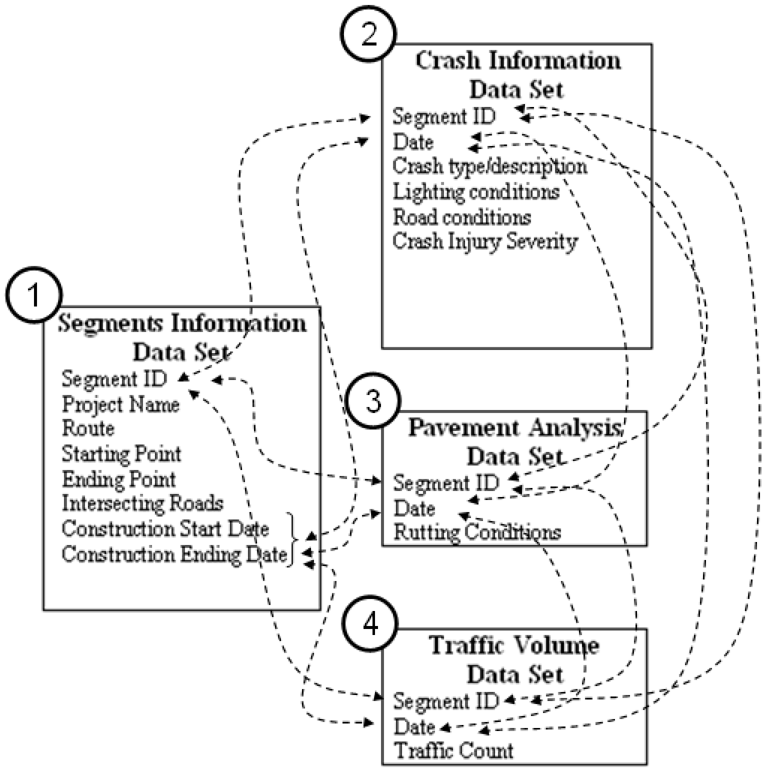


Figure 4-18. Data Set Consolidation

Table 4-2. Date Set Variables, Type of Variables and Value Codes

Variable	Type of Variable	Value Codes	Source
Segment ID	Nominal	Not Applicable	1,2,3,4
Before Date	Ordinal	Not Applicable	1
After Date	Ordinal	Not Applicable	1
Accident Year	Ordinal	Not Applicable	Generated
Accident Month	Ordinal	1: Jan → 12: Dec	Generated
Months Before	Scale	Not Applicable	Generated
Months After	Scale	Not Applicable	Generated
Crash Type/Description		1: Run off Road – Right 2: Run off Road – Straight 3: Run off Road – Left 4: Overturn	2
Lighting Conditions		1: Dawn 2: Day Light 3: Dusk 4: Dark-Lit 5: Dark-UnLit	2
Road Conditions	Nominal	1: Dry 2: Wet 3: Snow	2
Crash Injury Severity	Ordinal	1: Fatal 2: Life Threatening 3: Moderate 4: Complain of Pain 5: Property Damage	2
Traffic Count	Scale	Not Applicable	4
Rutting Conditions	Scale	Not Applicable	3
Construction Status	Ordinal	0: During 1: Before 2: After	Generated

Table 4-3. Number of Records Restructured From the Data Sets

Source	Records after Restructuring
Total Records in the Master Data Set	1564

4.5. LESSONS LEARNED

The use of rumble stripes to improve the safety of drivers is of paramount importance for all the Mississippi Department of Transportation divisions and districts that graciously share their information with the research team. It is important to highlight that all divisions and districts were very willing to collaborate in the data consolidation process. However, collecting, archiving and retrieving information was not a main priority for any of these divisions and districts. Additionally, no general guidelines for data structuring was communicated among the divisions and districts. Therefore, it is evident that input into the data gathering process before the data is collected rather than after the fact, could greatly improve the process of accessing the impact of other safety programs currently implemented by MDOT. By defining the data to be collected, the method for collecting the data, the formatting of the data, the timeframes for collecting the data (before, during and after construction), all the participating divisions and districts would be able to share information and to demonstrate the impact of their performance to stakeholders. It was also learned that the restructuring of the data was of paramount importance for the consolidation of the data. Identifying the variable types and the possible values for each variable facilitated the comparison of variables to decide whether or not to use the same variable or to create a new variable for each data set. The identification of common data components among the data set was critical for the consolidation of all data sets. The use of the common data components to transfer data among data sets proved to be an effective way to complete the data sets with information from another data set (another agency).

The research team was able to combine, reform, integrate and analyze the data to produce quantifiable results.

Finally, although each division and district participating in this project had a different mission and collected different data, it is possible to create a data structure that allow these divisions and districts to share common data for common purposes and reduce the cost of the data collection efforts.

4.6. SUMMARY

Maintenance and construction programs are arguably one of the most important functions of states DOT (as represented by the percentage of the budget invested). MDOT through the Traffic Engineering Division is commitment to improve Mississippi highway safety. MDOT has invested valuable resources to implement a series of safety improvement programs such as the Rumble Stripes program. Despite MDOT's high commitment and efforts to improve highway safety, MDOT does not know the impact of the Rumble Strip program in reducing crashes. In other words, MDOT lacks quantifiable evidence that demonstrates the effectiveness of this program. This paper focused on the process implemented to structure the data obtained from multiple divisions and districts used to measure the effectiveness of the Rumble Stripes program. The content of this paper was them used as the foundation for the statistical analysis.

During the construction period, there are temporary traffic disruptions which increase the number of accidents with associated deaths and injuring thousand of people every year. One of the special measures implemented in construction zones by several departments of transportation around the United States to reduce the number of crashes is the increase of law enforcement surveillance. This chapter focused on the process implemented to structure the data obtained from multiple agencies to be able to measure the impact of law enforcement in construction zones. The content of this chapter was later used as the foundation for the statistical analysis.

The results presented in this chapter reveal that segmentation of the data and the structure of the data is a major barrier to assess the impact of law enforcement surveillance in construction zones. Due to the willingness of the divisions and districts to collaborate in the data consolidation process, it was possible to restructure and consolidate the data to perform statistical analysis. It is also expected that the restructuring process presented in this chapter could be used by other research teams to perform similar analysis of law enforcement surveillance or others methods implemented around the U.S. to reduce the deaths and injuries in road construction zones.

Chapter 5:
STATISTICAL ANALYSIS TO ASSESS EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY

5.1. INTRODUCTION

Although traffic deaths are caused by an array of factors, in the United States more than half of all roadway fatalities are caused by roadway departures [FHWA 2006]. In 2003, there were 25,562 roadway departure fatalities, accounting for 55 percent of all roadway fatalities in the United States. Roadway departure includes run-off-the-road (ROR) and head-on fatalities. In 2003, more than 16,700 people died in ROR crashes (39 percent of all roadway fatalities), and head-on crashes represented 12 percent of all fatal crashes [FHWA 2006]. On average, one roadway departure fatality crash occurred every 23 minutes. An average of one roadway departure injury crash occurred every 43 seconds [FHWA 2006]. In short, roadway departures are a significant and serious problem in the United States.

MDOT through the Traffic Engineering Division is committed to improve Mississippi highway safety. MDOT has invested valuable resources to implement a series of safety improvement programs such as the Rumble Stripes program. Despite MDOT's high commitment and efforts to improve highway safety, MDOT does not know the impact of the Rumble Strip program in reducing crashes. In other words, MDOT lacks quantifiable evidence that demonstrates the effectiveness of this program.

This paper presents an overview of the agencies involved in collecting the data need to assess the impact of the Rumble Stripes on Highway Safety. Furthermore, this paper provides a description of data collected and its structure. Finally, the results of the lessons learns are presented. They could serve as the foundation for similar studies and/or case students to facilitate students learning through meaningful real world scenarios

5.2. OVERVIEW OF STATISTICAL ANALYSIS

Statistical analysis pertains to collection, analysis, interpretation, and presentation of data as well as drawing valid conclusions and making reasonable decisions on the basis of such analysis [Wikipedia 2006]. In most research projects the statistical analysis involves three major steps, done in roughly this order: Cleaning and organizing the data for analysis (Data Preparation), describing the data (Descriptive Statistics), testing hypotheses and models (Inferential Statistics)

5.2.1 Data Preparation

It involves checking or logging the data in checking the data for accuracy entering the data into the computer transforming the data and developing and documenting a database structure that integrates the various measures.

5.2.2. Descriptive Statistics

They are used to describe the basic features of the data in a study. They provide simple summaries about the sample and the measures. Together with graphical analysis, they form the basis of virtually every quantitative analysis of data. Descriptive statistics are used to present quantitative descriptions in a manageable form. They are used to simplify large amounts of data in a sensible way. Descriptive statistics involves the examination across cases of one variable at a time. With descriptive statistics the researchers are simply describing what the data shows. The three major characteristics of a single variable are its distribution, central tendency and dispersion.

2.a. Distribution is a summary of the frequency on individual values for a variable. One of the most common ways to describe a single variable is with a frequency distribution. Graphical forms such as histograms or bar charts are effective tools for depicting frequency distributions [Trochim 2006].

2.b. Central Tendency of a variable is the estimate of the "center" of a distribution of its values. The three major types of estimates of central tendency of a variable are its mean, median and mode. The mean is the variable's average value. The median is the score found at the exact middle of a set of variable values. The mode is the most frequently occurring value for the variable [Trochim 2006].

2.c. Dispersion refers to the spread of the values of the variable around the central tendency. The two most common measures of dispersion of a variable are its range and standard deviation. The range is the highest value of the variable minus the lowest value. The standard deviation is more accurate reflection of dispersion by reducing the effect of outlier values of a variable [Trochim 2006].

5.2.3. Inferential Statistics:

Focus on trying to reach conclusions that extend beyond the raw data. Inferential statistics are used to make inferences from the descriptive statistics to more general conditions; where the descriptive statistics simply is used to describe what's going on with the data. The inferential statistical "tools" available for use within SPSS are Chi-square, *T* test, Regression, General Linear Model, and Correlation [SPSS 2006].

3.a. Chi-square test: It is used in situations where you have two categorical variables and want to test their independence.

3.b. *t* test: It is used for comparing mean values of two sets of numbers. The comparison will provide a statistic basis to determine if there is a statistically significant difference between the numbers.

3.c. Regression: It is used to determine the effect of one or more predictor variables on an outcome variable. Regression allows you to make statements about how well independent variables will predict the value of a dependent variable.

3.d. Analysis of Variance (ANOVA): Analysis of variance is used to determine if there are differences between groups on the basis an outcome variable. In SPSS the majority of procedures used for conducting analysis of variance (ANOVA) can be found under the *General Linear Model* [SPSS 2006].

3.e. Correlation: It is a measure of the relation between two or more variables. Correlation coefficients can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation. The most widely-used type of correlation coefficient is *Pearson* correlation *r*. The Pearson correlation assumes that the two variables are measured on at least interval scales, and it determines the extent to which values of the two variables are "proportional" to each other. The value of correlation or correlation coefficient does not depend on the specific measurement units used. The correlation is high if the data can be summarized by a straight line. This line is called the regression line or least squares line, because it is determined such that the sum of the squared distances of all the data points from the line is the lowest possible. In order to evaluate the correlation between variables, it is important to know the significance of the correlation. The significance level calculated for each correlation is a primary source of information about the reliability of the correlation. The test of significance is based on the assumption that the distribution of the deviations from the regression line for the dependent variable, *y*, follows the normal distribution, and that the variability of the residual values are the same for all values of the independent variable *x* [StatSoft 2006]. Figure 5-1 shows some data samples with it corresponding r values.

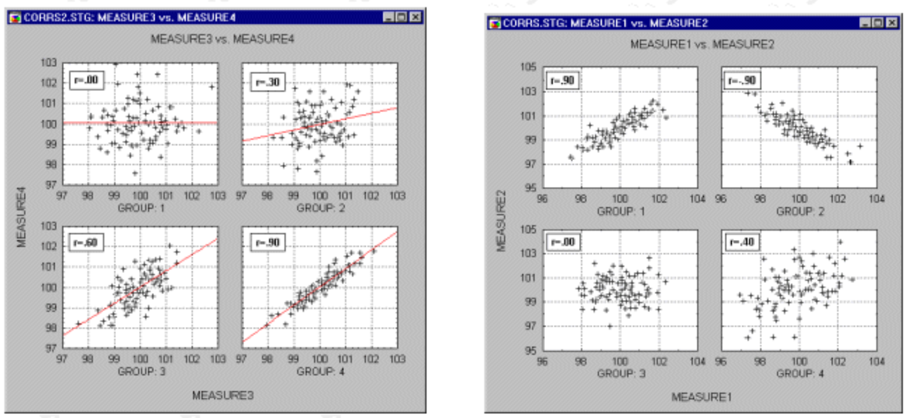


Figure 5-1. Sample data with corresponding r values.

5.3. Statistical Software

A statistical package is a computer application that is specialized for statistical analysis. It enables the research teams to obtain the results of standard statistical procedures and statistical significance tests, without requiring low-level numerical computations or programming. In addition to providing the results of standard statistical procedures, statistical packages provide facilities for data management [Wikipedia 2006]. There several commercially available statistical packages in the market, the following is a brief description of some of the packages available:

1. <u>AM Software:</u> It has been developed by the American Institutes for Research. This software is used primarily for the analysis of data from educational surveys (such as the National Assessment of Educational Progress). It is used for a stratified unequal-probability (weighted) cluster or multistage samples. Additional information can be found at http://am.air.org/legal.asp
2. <u>Bascula:</u> It has been developed by Statistics Netherlands. It computes adjustment weights using auxiliary variables. It incorporates various weighting techniques. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/bascula.html

3. CENVAR: It has been developed by the U.S. Bureau of the Census (International Programs Center). This software designs range from simple random samples of elements to more complex stratified, multistage cluster designs. Additional information can be found at http://www.census.gov/ipc/www/imps/cv.htm
4. CLUSTERS: It has been developed by Professor Vijay K VERMA of the ESRC Research Centre at the University of Essex. The program computes sampling errors taking into account the actual sample design.
5. Epi Info: It has been developed by the Centers for Disease Control and World Health Organization. This software uses stratified sampling, with or without clustering; multistage samples; unequal-probability samples. Additional information can be found at http://www.cdc.gov/EpiInfo/
6. Generalized Estimation System (GES): It has been developed is by Statistics Canada. The focus of this software is on calibration estimation using generalized regression (GREG) estimator theory. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/genest.html
7. IVEware: It has been developed by the University of Michigan. The authors are T.E. Raghunathan, Michael Elliott and colleagues. This software is used for complex designs with stratification and clustering. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/iveware.html
8. PCCARP: It has been developed by the Iowa State University Statistical Laboratory. This software is used for multistage stratified samples. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/pccarp.html
9. R survey package: It has been developed is by R Project (the R Foundation). The authors are Thomas Lumley from the Department of Biostatistics at the University of Washington. This software is used for incorporating stratification, clustering, and possibly multistage sampling. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/r.html
10. SAS/STAT: It is been developed by the SAS Institute Inc. This software can be used for a complex multistage sample design that includes stratification, clustering, replication, and unequal probabilities of selection. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/sas.html
11. Stata: It has been developed by StataCorp. This software can be used for stratified designs, cluster sampling, and variance estimation. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/stata.html
12. SUNDANN: It has been developed by the Research Triangle Institute. This software's multiple design options allow users to analyze data from stratified, cluster sample, or multistage sample designs. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/sudaan.html
13. VPLX: It has been developed by the U.S. Bureau of the Census. The author is Dr. Robert Fay. This software is used for Stratified and clustered designs. Additional information can be found at http://www.hcp.med.harvard.edu/statistics/survey-soft/vplx.html
14. WesVar: It has been developed by Westat, Inc. This software uses variance estimates based on replicate weights, either generated within the program or user-provided. Additional information can be found at http://www.hcp.med.harvard.edu/ statistics/survey-soft/wesvarpc.html

15. SPSS: It has been developed by SPSS. This software is used for both design and estimation. It accommodates stratification, clustering, and multistage sampling. Additional information can be found at http://www.spss.com/spss/

The statistical package used for the statistical analysis in this project was SPSS. The version of SPSS used 15.0 for Windows. The primary reason for using this software was that it met the needs of the project and was the statistical software most commonly used at the University of Southern Mississippi. The following section provides a description of SPSS.

5.4. SPSS Description

SPSS for Windows is a statistical and data management package for analysts and researchers. SPSS for Windows provides a broad range of capabilities for the entire analytical process. SPSS Inc. is a leading worldwide provider of predictive analytics software. They have been in business for more than 40 years, and have more than 250,000 customers (academic institutions, healthcare providers, market research companies and government agencies) [SPSS 2008].

Government agencies use SPSS predictive analytics software to detect fraud, non-compliance with laws or regulations, and to protect public safety and provide homeland security. Educational institutions use predictive analytics to manage resources by predicting demand for programs. Non-profit organizations use these technologies to anticipate program demand and raise funds. Scientific and healthcare organizations carry out lifesaving research, improve patient outcomes, and manage their business operations effectively, through the use of predictive analytics [SPSS 2008].

Predictive analytics include the analysis of past, present, and projected future outcomes using advanced analytics, and decision optimization for determining which action will drive the optimal outcome. The recommended action is then delivered to the systems or people that can effectively implement it [SPSS 2008].

5.5. Descriptive Statistical Analysis

The statistical analysis began by analyzing traffic trends and characteristics of the studied road segments. Several divisions of the Mississippi Department of Transportation provided to the research team a wealth of data to perform the analysis. A total of 14 segments were originally included in the study as shown in Table 5-1.

The analysis of the studied road segment has been organized as follows:

- a - Traffic Volume Overtime per Segment
- b - Total Crashes per Segment Before and After Construction
- c - Roadway Departures and Overturn per Segment Before and After Construction
- d - Total Crashes per Segment under Different Lighting Conditions Before and After Construction
- e - Roadway Departures and Overturn per Segment under Different Lighting Conditions Before and After Construction
- f - Total Crashes per Segment under Different Road Condition Before and After Construction
- g - Roadway Departures and Overturn per Segment under Different Road Conditions

Before and After Construction

Table 5-1. Road Segments Included in the Study

ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)
1	US 98 in George County from the Greene County line to SR 63/Dist 6	US 98	Greene County line	SR 63
2	US 98 in Greene County from east of SR 198 in McLain to the George County line/Dist 6	US 98	Greene County from east of SR 198 in McLain	George County line
3	US 98 in Perry County from the Forrest County line east 7.5 miles/Dist 6	US 98	Forrest County line	East 7.5 miles into Perry County
4	US 98 in Forrest County from Interstate 59 to the Perry County line/Dist 6	US 98	Forrest County from Interstate 59	Perry County line
5	SR 589 in Lamar County from Haden Road north to US 98/Dist 6	SR 589	in Lamar County from US 98 north	to US 98
6	SR 589 in Lamar County from US 98 north to the Covington County line/Dist 6	SR 589	in Lamar County from US 98 north	to the Covington County line
7	SR 43 in Hancock County from SR 603 to Dummyline Road/Dist 6	SR 43	in Hancock County from SR 603	to Dummyline Road
8	SR 43 in Hancock County from Dummyline Road to Salem Road/Dist 6	SR 43	in Hancock County from Dummyline Road	to Salem Road
9	SR 43 in Pearl River County from Pinetucky Road to SR 26/Dist 6	SR 43	in Pearl River County from Pinetucky Road	to SR 26
10	US 11 in Pearl River County from Minkler Road to Charwood Drive/Dist 6	US 11	in Pearl River County from Minkler Road	to Charwood Drive
11	11 in Pearl River County from Charwood Drive to the north corporate limits of Poplarville/Dist 6	US 11	in Pearl River County from Charwood Drive	to the north corporate limits of Poplarville
12	Scooba-Noxubee County Line (7 ½ Miles of 4 lane) in Kemper County /Dist 5	US45	Scooba 0.644 North of	Noxubee County Line
13	Porterville-Scooba (9 ¾ Miles of 4 lane)/Dist 5	US45	Porterville	Scooba
14	Lauderdale to Porterville (10 Miles of 4 lane)/Dist 5	US45	Lauderdale	Porterville

<u>a - Traffic Volume Overtime per Segment</u>

One of the most valuable pieces of information provided by the Planning Division to the research team was "Traffic Volume Overtime per Segment" in the studied area. The MDOT Planning Division provided historical data regarding traffic flow in various locations of the studied road segments. The traffic volumes provided corresponded to the period before and after the construction on each particular segment. Since construction on each segment of the projects was performed on different dates, the time periods of traffic volume for each segment is different. Figure 5.2 shows the traffic volume for each segment during the timeframe used for the study. Likewise, Figure 5.3 is a graph showing the traffic volume for the different segments. It is important to highlight that the traffic volume of most of the road segments in the study were similar overtime with exception of few segments.

	2000	2001	2002	2003	2004	2005	2006
ID: 1 - US 98 . 1From SR 63 to Greene CL , George			6500	6733.333	6966.667	7200	
ID: 2 - US 98 . 1From Perry CL to Old Hwy 24 , Greene		8500	8633.333	8766.667	8900		
ID: 2 - US 98 . 2From Perry CL to Old Hwy 24 , Greene				10000	9333.333	8666.667	8000
ID: 2 - US 98 . 3From SR 57 to Vernal River Rd , Greene				7300	7033.333	6766.667	6500
ID: 2 - US 98 . 4From Vernal River Rd to George CL , Greene				7700	7633.333	7566.667	7500
ID: 3 - US 98 . 1From Mahned Rd to SR 29 , Perry				10000	9900	9800	9700
ID: 3 - US 98 . 2From SR 29 to SR 198 , Perry		8700	9133.333	9566.667	10000		
ID: 3 - US 98 . 3From SR 198 (W) to Eight Mile Rd , Perry				8400	8500	8600	8700
ID: 4 - US 98 . 1From I-59 to US 49 , Forrest				13000	15000	17000	19000
ID: 5 - SR 589 . 1From WPA to Old Hwy 24 , Lamar		2000	2000		2000		
ID: 6 - SR 589 . 1From US 98 to Epley Rd , Lamar	4300	4475	4650	4825	5000		
ID: 6 - SR 589 . 2From Epley Rd to SR 42 , Lamar	4200	4225	4250	4275	4300		
ID: 6 - SR 589 . 3From SR 42 to Covington CL , La	1800	1900	2000	2100	2200		
ID: 8 - SR 43 . 1From Dummyline Rd to Pearl River CL , Hancock				4000	4800	5600	6400
ID: 8 - SR 43 . 2From Pearl River CL to Salem Rd , Pearl River				4000	4800	5600	6400
ID: 9 - SR 43 . 1From Pinetucky Rd to SR 26 , Pearl River				1600	1700	1800	1900
ID: 10 - US 11 . 1From Derby Whitesand Rd to SR 26 , Pearl River					1900	2600	3300
ID: 11 - US 11 . 1From Derby Whitesand Rd to SR 26 , Pearl River				1900	2366.667	2833.333	3300
ID: 11 - US 11 . 2From SR 26 to North St , Pearl River				6200	6233.333	6266.667	6300
ID: 11 - US 11 . 3From North St to Lamar St , Pearl River				4800	4933.333	5066.667	5200
ID: 11 - US 11 . 4From Lamar St to Springhill Rd , Pearl River				1500	1566.667	1633.333	1700
ID: 14 - US 45 . 1From Old Lauderdale Rd to Kemper CL , Lauderdale				3600	3633.333	3666.667	3700
ID: 14 - US 45 . 2From Lauderdale CL to Dekalb-Porterville Rd , Kemper				3600	3633.333	3666.667	3700

Figure 5-2. Traffic Volume Overtime per Segment

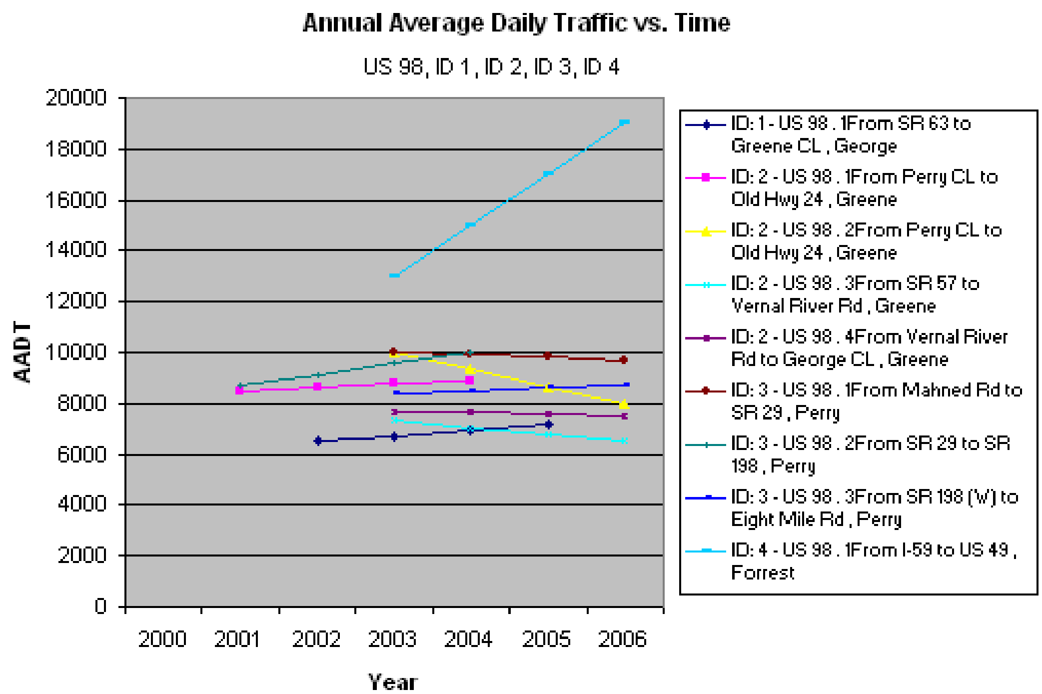


Figure 5-3. Traffic Volume Overtime per Segment

b - Total Crashes per Segment Before and After Construction

Another valuable piece of information provided by the Traffic Engineering Division to the research team was "Total Crashes per Segment Before and After Construction" for the road segment studied. Figure 5-4 is a graphical representation of the data provided by the Traffic Engineering Division for crashes during the studied period of a sample road segment. This descriptive analysis provides the crash history before and after construction within the individual segments. The number in the table corresponds to the number of crashes during the month, and (c) corresponds to a construction period for the segment.

ID:1														
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec		Total
2002	1	1	2	2	2	1	2	2	2	1	0	2		18
2003	1	3	3	0	4	4	4	2	0	1	2	1		25
2004	2	0	1	(c)	(c)	(c)	(c)	(c)	(c)	1	0	0		
2005	1	0	2	1	0	2	1	3	3	3	0	3		19
2006	0	1	2	1	1	3	1	1	1	1	1	1		14

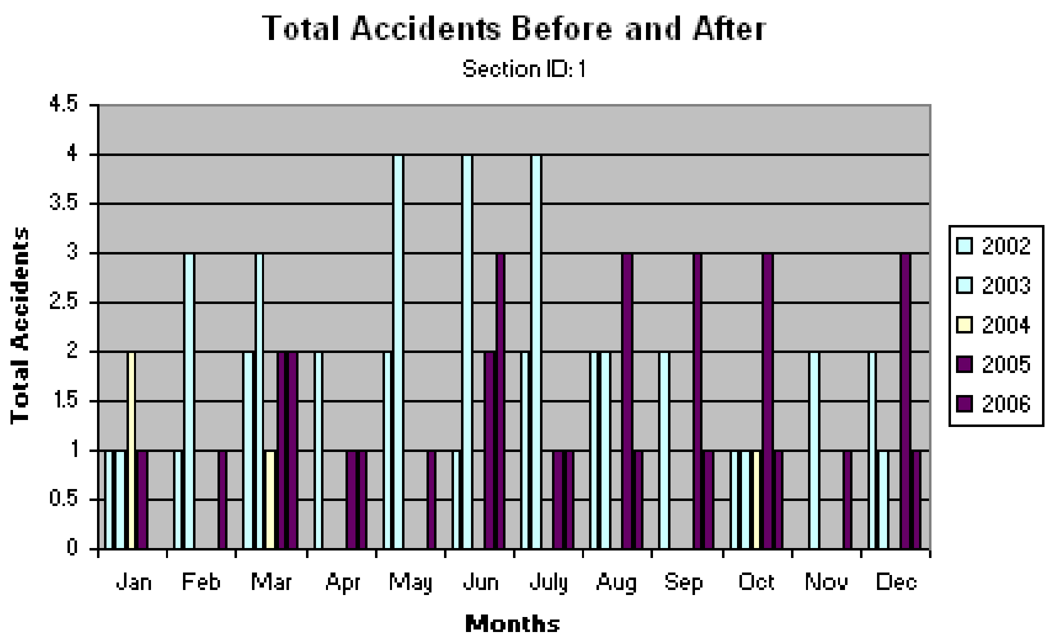


Figure 5-4. Total Crashes of Sample Segment Before and After Construction Organized by Month of the Year

c- Roadway Departures and Overturn per Segment Before and After Construction

This analysis is similar to the previous analysis, showing in a graphical format the trend from before to after the placement of construction. The difference between this analysis and the previous one is these analysis focuses's only on roadway departures and overturn crashes. Since roadway departures are a leading cause of traffic death, the next logical step for the researchers was to determine if roadway departures were impacted by the placement of construction. Figure 5-5 shows a sample of roadway departures and overturn crashes. The numbers in the figure correspond to the number of roadway departures and overturns crashes each month, and (c) corresponds to a construction period for the segment.

ID:13														
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec		Total
1999	2	0	2	1	1	0	0	0	2	1	0	1		10
2000	1	0	1	1	0	1	1	0	3	0	0	2		10
2001	2	1	0	1	(c)	(c)	(c)	(c)	(c)	(c)	(c)	(c)		
2002	(c)	(c)	(c)	(c)	(c)	(c)	(c)	(c)	0	0	2	0		
2003	0	0	0	0	1	4	1	0	0	1	0	0		7
2004	0	0	0	0	0	0	0	0	0	0	0	0		0
2005	0	0	0	0	0	0	0	1	1	0	1	0		3

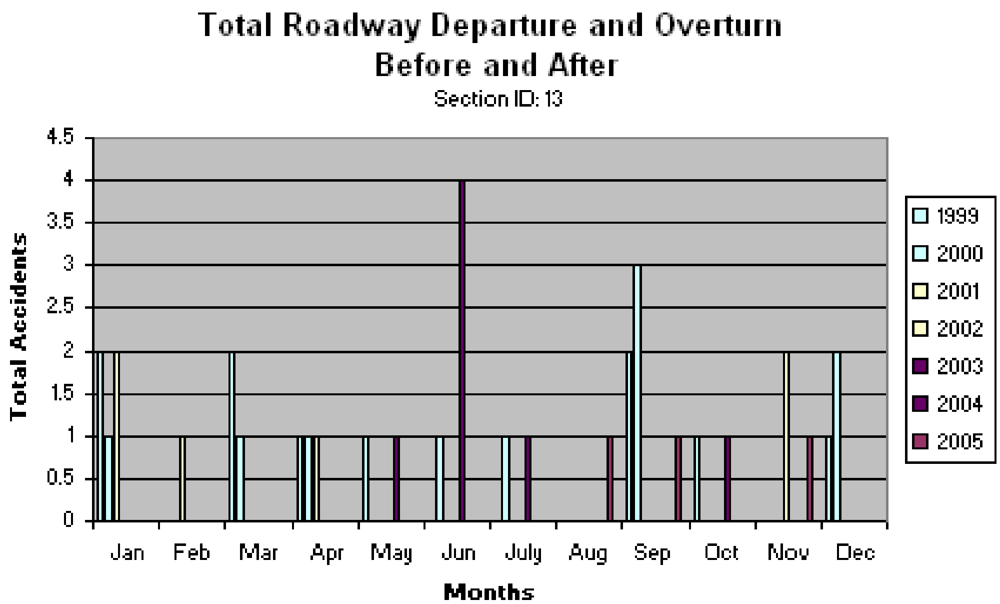


Figure 5-5. Roadway Departures and Overturn of Sample Segment Before and After Construction Organized per Month

<u>d - Total Crashes per Segment under Different Lighting Conditions Before and After Construction</u>

In addition to analyzing the data before and after the impact of construction, the data was also analyzed according to the lighting conditions reported for the crashes. Figure 5-6 and 5-7 show the lighting conditions for all crashes in the studied road segments. Each segment has information regarding five lighting conditions: Dawn, Daylight, Dusk, Dark-Lighten, and Dark-Un-Lighten. For each lighting condition the following information is provided: Number of Months with Crashes (N), minimum number of crashes in any month with crashes (Min), maximum number of crashes (Max), mean number of crashes months with crashes (Mean) and standard deviation (Std. Dev.). It is evident in Figure 5-6 and 5-7 that different lighting conditions has a definite impact on the number of overall crashes both before and after the construction was put in place.

		ID	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dawn	N		2.0	1.0		3.0	3.0	2.0	3.0	2.0		4.0		1.0	21.0
		Min		2.0	1.0		1.0	1.0	6.0	6.0	3.0		4.0		2.0	1.0
		Max		10.0	1.0		6.0	10.0	11.0	8.0	4.0		10.0		2.0	11.0
		Mean		6.0			3.3	4.3	8.5	7.0	3.5		7.0		2.0	
		Std. Dev.		5.7			2.5	4.9	3.5	1.0	0.7		2.6			
	Daylight	N	38.0	27.0	36.0		64.0	24.0	27.0	23.0	42.0	26.0	36.0		29.0	372.0
		Min	1.0	1.0	1.0		1.0	2.0	1.0	2.0	1.0	1.0	1.0		1.0	1.0
		Max	12.0	12.0	12.0		11.0	12.0	12.0	11.0	12.0	12.0	12.0		12.0	12.0
		Mean	5.8	6.7	6.2		5.9	6.8	7.0	6.6	5.5	6.4	6.8		6.3	
		Std. Dev.	2.9	3.6	3.7		2.7	3.2	3.6	2.8	3.3	3.4	3.0		3.9	
	Dusk	N	1.0						1.0				1.0			3.0
		Min	1.0						2.0				6.0			1.0
		Max	1.0						2.0				6.0			6.0
		Mean	1.0						2.0				6.0			
		Std. Dev.														
	Dark-Lit	N			3.0			3.0				1.0	3.0		1.0	11.0
		Min			7.0			1.0				12.0	6.0		1.0	1.0
		Max			12.0			11.0				12.0	11.0		1.0	12.0
		Mean			9.0			7.0				12.0	7.7		1.0	
		Std. Dev.			2.6			5.3					2.9			
	Dark-Unlit	N	6.0	17.0	13.0		34.0	17.0	8.0	15.0	16.0	9.0	13.0		8.0	156.0
		Min	2.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	2.0	1.0		1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	9.0	12.0	12.0	11.0	12.0		9.0	12.0
		Mean	7.8	6.4	7.6		6.8	6.2	3.6	5.2	6.7	5.6	6.9		4.3	
		Std. Dev.	4.0	3.6	4.3		3.9	3.5	2.7	3.6	3.5	3.5	4.4		3.2	

Figure 5-6. Total Accidents per Segment under Different Lighting Conditions
Before Construction

		ID	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	Overall
AFTER	Dawn	N	1.0	1.0			1.0			1.0				6.0	1.0	11.0
		Min	9.0	7.0			4.0			7.0				1.0	10.0	1.0
		Max	9.0	7.0			4.0			7.0				11.0	10.0	11.0
		Mean	9.0	7.0			4.0			7.0				6.7	10.0	
		Std. Dev.												4.4		
	Daylight	N	20.0	28.0	73.0		99.0	40.0	52.0	19.0	41.0	40.0	28.0	73.0	38.0	551.0
		Min	1.0	1.0	1.0		1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	11.0	12.0	12.0	12.0	12.0
		Mean	7.0	7.0	6.8		7.6	7.3	7.1	6.5	7.2	6.9	7.1	6.6	7.3	
		Std. Dev.	3.3	3.5	3.4		3.5	3.3	3.8	3.3	4.1	3.1	3.6	3.3	2.7	
	Dusk	N	1.0	1.0	1.0		4.0	2.0					1.0			10.0
		Min	5.0	11.0	4.0		1.0	3.0					12.0			1.0
		Max	5.0	11.0	4.0		12.0	12.0					12.0			12.0
		Mean	5.0	11.0	4.0		5.8	7.5					12.0			
		Std. Dev.					5.6	6.4								
	Dark-Lit	N	3.0		1.0		7.0	3.0	2.0	4.0	1.0	3.0	1.0	5.0	3.0	33.0
		Min	4.0		12.0		1.0	9.0	9.0	2.0	3.0	1.0	9.0	2.0	4.0	1.0
		Max	10.0		12.0		12.0	10.0	9.0	12.0	3.0	12.0	9.0	12.0	11.0	12.0
		Mean	6.7		12.0		8.1	9.7	9.0	7.3	3.0	7.3	9.0	7.4	7.7	
		Std. Dev.	3.1				4.5	0.6	0.0	5.0		5.7		3.9	3.5	
	Dark-Unlit	N	9.0	17.0	17.0		42.0	17.0	9.0	4.0	13.0	9.0	6.0	31.0	28.0	
		Min	3.0	2.0	1.0		1.0	1.0	3.0	2.0	1.0	2.0	4.0	1.0	1.0	22.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	11.0	12.0	11.0	12.0	12.0	12.0	11.0
		Mean	8.4	8.5	6.6		7.7	8.2	9.1	7.0	4.4	7.2	7.7	7.5	7.1	9.1
		Std. Dev.	3.1	3.1	4.0		3.6	4.3	3.7	4.7	3.7	3.1	2.9	4.2	3.6	

Figure 5-7. Total Accidents per Segment under Different Lighting Conditions
After Construction

e - Roadway Departures and Overturn per Segment under Different Lighting Conditions Before and After Construction

Similar to the previous analysis, the roadway departures and overturn crashes were analyzed according to the lighting conditions. Figure 5-8 and 5-9 shows only the roadway departures and overturn crashes for the studied road segments. Each segment has information regarding five lighting conditions: Dawn, Daylight, Dusk, Dark-Lighten, and Dark-Un-Lighten. For each lighting condition, the following information is provided: Number of Months with roadway departures and overturn crashes are provided (N), minimum number of roadway departures and overturn crashes on any month with roadway departures and overturn crashes (Min), maximum number of roadway departures and overturn crashes (Max), mean number of roadway departures and overturn crashes for the months with roadway departures and overturn crashes (Mean) and standard deviation (Std. Dev.). It is evident in Figure 5-8 and 5-9 that as in the previous analysis, different lighting conditions have a definite impact on the number of roadway departures and overturn crashes both before and after construction.

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dawn	N		2.0			1.0	1.0	2.0	2.0	1.0		2.0		1.0	12.0
		Min		2.0			1.0	10.0	6.0	7.0	3.0		6.0		2.0	1.0
		Max		10.0			1.0	10.0	11.0	8.0	3.0		10.0		2.0	11.0
		Mean		6.0			1.0	10.0	8.5	7.5	3.0		8.0		2.0	
		Std. Dev.		5.7					3.5	0.7			2.8			
	Daylight	N	17.0	22.0	15.0		18.0	8.0	9.0	12.0	24.0	4.0	10.0		16.0	155.0
		Min	2.0	1.0	2.0		1.0	2.0	1.0	2.0	1.0	2.0	4.0		1.0	1.0
		Max	12.0	12.0	11.0		10.0	12.0	12.0	10.0	12.0	8.0	12.0		12.0	12.0
		Mean	6.4	6.7	6.3		5.2	7.8	7.1	7.0	5.5	5.5	7.7		6.6	
		Std. Dev.	2.5	3.7	3.2		2.6	3.6	3.6	2.3	3.5	3.0	2.9		4.0	
	Dusk	N														0.0
		Min														0.0
		Max														0.0
		Mean														
		Std. Dev.														
	Dark-Lit	N													1.0	1.0
		Min													1.0	1.0
		Max													1.0	1.0
		Mean													1.0	
		Std. Dev.														
	Dark-Unlit	N	3.0	14.0	5.0		12.0	11.0	3.0	8.0	9.0	5.0	3.0		6.0	79.0
		Min	4.0	3.0	3.0		1.0	1.0	3.0	2.0	3.0	2.0	4.0		1.0	1.0
		Max	11.0	12.0	12.0		12.0	11.0	9.0	10.0	11.0	7.0	12.0		9.0	12.0
		Mean	7.7	7.3	8.6		6.8	5.0	6.0	4.8	7.8	4.6	8.7		4.8	
		Std. Dev.	3.5	3.3	3.4		4.1	2.9	3.0	3.0	2.8	2.1	4.2		3.4	

Figure 5-8. Total Roadway Departures and Overturns per Segment under Different Lighting Conditions Before Construction

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
AFTER	Dawn	N								1.0				2.0		3.0
		Min								7.0				10.0		7.0
		Max								7.0				11.0		11.0
		Mean								7.0				10.5		
		Std. Dev.												0.7		
	Daylight	N	5.0	8.0	7.0		17.0	8.0	3.0	1.0	5.0	3.0	2.0	21.0	7.0	87.0
		Min	6.0	4.0	2.0		4.0	3.0	4.0	4.0	4.0	3.0	12.0	1.0	5.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	4.0	12.0	11.0	12.0	12.0	11.0	12.0
		Mean	8.6	8.1	8.4		8.3	7.4	7.7	4.0	9.4	7.7	12.0	6.6	7.1	
		Std. Dev.	2.2	3.4	3.4		2.7	3.2	4.0		3.7	4.2	0.0	3.3	2.1	
	Dusk	N														0.0
		Min														0.0
		Max														0.0
		Mean														
		Std. Dev.														
	Dark-Lit	N	1.0											2.0		3.0
		Min	6.0											9.0		6.0
		Max	6.0											12.0		12.0
		Mean	6.0											10.5		
		Std. Dev.												2.1		
	Dark-Unlit	N	2.0	7.0	3.0		14.0	1.0				4.0		5.0	5.0	41.0
		Min	10.0	2.0	10.0		3.0	9.0				9.0		1.0	6.0	1.0
		Max	12.0	12.0	12.0		12.0	9.0				11.0		12.0	11.0	12.0
		Mean	11.0	9.0	10.7		8.9	9.0				10.5		8.6	9.2	
		Std. Dev.	1.4	3.5	1.2		2.9					1.0		4.4	2.2	

Figure 5-9. Total Roadway Departures and Overturns per Segment under Different Lighting Conditions After Construction

<u>f - Total Crashes per Segment under Different Road Conditions Before and After Construction</u>

The data was also analyzed to understand the impact of different road conditions before and after construction. Figures 5-10 and 5-11 show the total crashes per segment under different road conditions before construction on the studied road segments. Each segment has information regarding three road conditions: Dry, Wet, and Snow. For each road condition, the following information is provided: Number of Months with crashes (N), minimum number of crashes reported in any month (Min), maximum number of crashes reported in any month (Max), mean number of crashes reported for the months (Mean) and standard deviation (Std. Dev.). It is evident in Figures 5-10 and 5-11 that different road conditions have a definite impact on the number of crashes. This occurs both before and after construction. It is also important to highlight that, while there are fewer crashes in wet and snow conditions, the number of hours per year of wet and snow on the studied road segments are significantly less. The specific analysis regarding the distribution of hours of dry, wet and snow conditions was beyond the scope of this project.

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dry	N	40	43	46		96	47	35	40	53	32	54		39	525
		Min	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	12.0	12.0		12.0	12.0
		Mean	5.9	6.4	6.6		5.9	6.3	6.4	6.1	5.6	6.1	7.1		5.6	
		Std. Dev.	3.3	3.6	4.0		3.1	3.4	3.7	3.1	3.3	3.6	3.2		3.8	
	Wet	N			1.0				3				2			6
		Min			3.0				2.0				2.0			2.0
		Max			3.0				8.0				6.0			8.0
		Mean			3.0				4.0				4.0			
		Std. Dev.							3.5				2.8			
	Snow	N	4	3	6						6	3				22
		Min	3.0	9.0	2.0						2.0	7.0				2.0
		Max	7.0	10.0	10.0						10.0	11.0				11.0
		Mean	6.0	9.7	7.0						6.0	8.7				
		Std. Dev.	2.0	0.6	3.9						3.5	3.6				

Figure 5-10. Total Crashes per Segment under

Different Road Conditions Before Construction

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
AFTER	Dry	N	33	34	78		130	54	54	27	47	50	30	107	62	706
		Min	1.0	2.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	11.0	12.0	12.0	12.0	12.0
		Mean	7.2	7.2	7.0		7.9	7.8	7.5	6.8	6.3	6.9	7.1	6.6	7.4	
		Std. Dev.	3.2	3.5	3.5		3.4	3.7	3.4	3.6	4.0	3.2	3.7	3.5	3.1	
	Wet	N	1	12	9		16	6	8	1	8	1	6		6	74
		Min	10.0	1.0	1.0		1.0	3.0	1.0	4.0	2.0	12.0	7.0		1.0	1.0
		Max	10.0	12.0	12.0		12.0	11.0	12.0	4.0	12.0	12.0	12.0		11.0	12.0
		Mean	10.0	8.6	5.2		5.6	6.7	6.5	4.0	7.1	12.0	8.8		7.3	
		Std. Dev.		3.1	3.7		4.2	3.4	5.6		5.2		1.9		4	
	Snow	N					3							1	1	
		Min					4.0							6.0	6.0	
		Max					11.0							6.0	6.0	
		Mean					7.0							6.0	6.0	
		Std. Dev.					3.6									

Figure 5-11. Total Crashes per Segment under
Different Road Conditions After Construction

<u>g - Roadway Departures and Overturn Crashes per Segment under Different Road Conditions Before and After Construction</u>

Similarly to the previous analysis, the roadway departures and overturn crashes data was also analyzed to understand the impact of different road conditions before and after construction. Figures 5-12 and 5-13 show the roadway departures and overturn crashes per segment under different road conditions before and after construction for the studied road segments. Each segment has information regarding three road conditions: Dry, Wet, and Snow. For each road condition, the following information is provided: Number of Months with roadway departures and overturn crashes (N), minimum number of roadway departures and overturn crashes reported in any month (Min), maximum number of roadway departures and overturn crashes (Max), mean number of roadway departures and overturn crashes reported for the months (Mean) and standard deviation (Std. Dev.). As previous analysis, it is evident in Figures 5-12 and 5-13 that different road conditions have a definite impact on the number of roadway departures and overturn crashes. This occurs both before and after construction.

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dry	N	15	35	14		31	20	14	21	30	7	15	29	24	255
		Min	2.0	1.0	3.0		1.0	1.0	1.0	2.0	1.0	2.0	4.0	1.0	1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	10.0	12.0	8.0	12.0	12.0	12.0	12.0
		Mean	6.7	6.6	6.8		5.7	6.4	7.1	6.2	5.8	4.4	7.9	7.5	5.7	
		Std. Dev.	2.9	3.6	3.3		3.4	3.4	3.3	2.7	3.4	2.4	2.9	3.6	3.9	
	Wet	N			1											1
		Min			3.0											3.0
		Max			3.0											3.0
		Mean			3.0											
		Std. Dev.														
	Snow	N	4	3	5						4	1				17
		Min	3.0	9.0	2.0						2.0	8.0				2.0
		Max	7.0	10.0	10.0						10.0	8.0				10.0
		Mean	6.0	9.7	8.0						7.3	8.0				
		Std. Dev.	2.0	0.6	3.4						3.8					

Figure 5-12. Total Roadway Departures and Overturns per Segment under
Different Road Conditions Before Construction

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
AFTER	Dry	N	8	12	6		25	13	2	2	3	7	2		10	
		Min	6.0	2.0	10.0		3.0	1.0	4.0	4.0	4.0	3.0	12.0		5.0	
		Max	12.0	12.0	12.0		12.0	12.0	7.0	7.0	12.0	11.0	12.0		11.0	
		Mean	8.9	7.8	10.8		8.6	7.6	5.5	5.5	7.7	9.3	12.0		8.1	
		Std. Dev.	2.4	3.3	1.0		2.7	4.0	2.1	2.1	4.0	2.9	0.0		2.4	
	Wet	N		3	3		2	1	1		2				1	
		Min		10.0	2.0		11.0	6.0	12.0		12.0				9.0	
		Max		12.0	7.0		12.0	6.0	12.0		12.0				9.0	
		Mean		11.3	5.3		11.5	6.0	12.0		12.0				9.0	
		Std. Dev.		1.2	2.9		0.7				0.0					
	Snow	N					3								1	
		Min					4.0								6.0	
		Max					11.0								6.0	
		Mean					7.0								6.0	
		Std. Dev.					3.6									

Figure 5-13. Total Roadway Departures and Overturns per Segment under Different Road Conditions After Construction

5.6. INFERENTIAL STATISTIC ANALYSIS

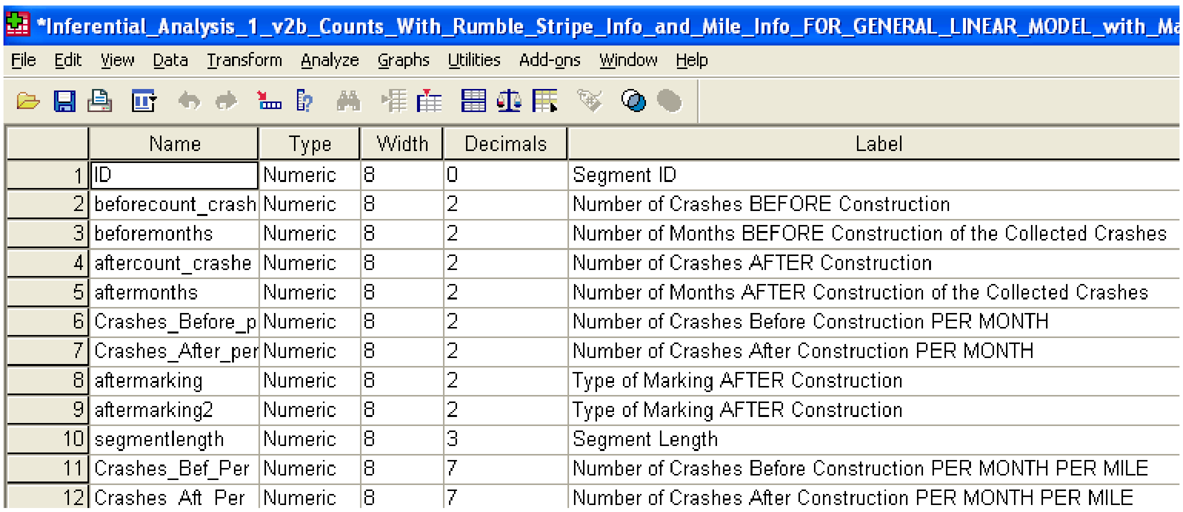
Based on the main objective of the project (evaluate the safety impact of the Rumble Stripes), the available data and the results from the descriptive statistics are provided in this section. Eight specific statistical analyses were established aiming to determine if there was any correlation between the studied variables. The eight analyses in the studied roadway segments are presented in Table 5-2.

Table 5-2. Statistical Analysis Performed

Analysis 1 –	Rumble Stripes on the Road (in place) Vs. Number of Overall Crashes
Analysis 2 –	Rumble Stripes on the Road (in place) Vs. Number of Road Way Departures
Analysis 3 –	Lighting Conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) Vs. Number of Overall Crashes.
Analysis 4 –	Lighting Conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) Vs. Number of Road Way Departure
Analysis 5 –	Road Conditions (Dry/Wet/Snow) Vs. Number of Overall Crashes.
Analysis 6 –	Road Conditions (Dry/Wet/Snow) Vs. Number of Road Way Departures.
Analysis 7 –	Rumble Stripe on the Road Vs. Overall Crash Severity (5: Property Damage, 4: Complain of Pain, 3: Moderate, 2: Life Threatening, 1: Fatal)
Analysis 8 –	Rumble Stripe on the Road Vs. Road Way Departure (5: Property Damage, 4: Complain of Pain, 3: Moderate, 2: Life Threatening, 1: Fatal)

5.6.1. Analysis 1 – Rumble Stripe Presence on the Roadway Vs. Number of Overall Crashes

This analysis focused on how much the presence of Rumble Stripes impacted the number of overall crashes in the studied roadway segments. This analysis was based on the data obtained from MDOT. In order to measure the impact of rumble stripes on the number of overall crashes, data before and after the placement of the rumble stripes was collected. Additionally, the data collected was grouped according to the placement of rumble stripes or reflective marking put in place during the roadway construction. The variables used in this analysis were as follows Number of Crashes Before Construction Per Month Per Mile, Number of Crashes After Construction Per Month Per Mile, and Type of Marking After Construction as shown in the Figure 5-14.



	Name	Type	Width	Decimals	Label
1	ID	Numeric	8	0	Segment ID
2	beforecount_crash	Numeric	8	2	Number of Crashes BEFORE Construction
3	beforemonths	Numeric	8	2	Number of Months BEFORE Construction of the Collected Crashes
4	aftercount_crashe	Numeric	8	2	Number of Crashes AFTER Construction
5	aftermonths	Numeric	8	2	Number of Months AFTER Construction of the Collected Crashes
6	Crashes_Before_p	Numeric	8	2	Number of Crashes Before Construction PER MONTH
7	Crashes_After_per	Numeric	8	2	Number of Crashes After Construction PER MONTH
8	aftermarking	Numeric	8	2	Type of Marking AFTER Construction
9	aftermarking2	Numeric	8	2	Type of Marking AFTER Construction
10	segmentlength	Numeric	8	3	Segment Length
11	Crashes_Bef_Per	Numeric	8	7	Number of Crashes Before Construction PER MONTH PER MILE
12	Crashes_Aft_Per	Numeric	8	7	Number of Crashes After Construction PER MONTH PER MILE

Figure 5-14. Variable used in the Analysis

Table 5-3 shows a summary of the data analyzed. The analysis of the data indicates that there was an overall average of 0.241 crashes per month per mile before construction and an overall average of 0.218 crashes per month per mile after construction. It is also important to highlight that this calculation was done with the very small sample of 10 data points and relative high standard deviation of 0.82 before construction and 0.89 after construction.

Table 5-3. Mean Number of Crashes Per Month Per Mile Before and After Construction

Descriptive Statistics

	Type of Marking	Mean	Std. Deviation	N
Number of Crashes Before Construction PER MONTH PER MILE	Marking/Rumble Strip	.231	.104	5
	Rumble Stripe	.250	.064	5
	Total	.241	.082	10
Number of Crashes After Construction PER MONTH PER MILE	Marking/Rumble Strip	.172	.049	5
	Rumble Stripe	.265	.100	5
	Total	.218	.089	10

To account for the two measures (before and after) done in each of the segments of the studied areas a General Linear Model with Repeated Measures was used. The General Linear Models with Repeated Measures procedure provides analysis of variance when the same measurement is made several times on each subject or case [SPSS 2008]. When between-subjects factors are specified, they divide the population into groups. Using this general linear model procedure, the null hypotheses can be tested to measure the effects of both the between-subjects factors and the within-subjects factors. Interactions between factors as well as the effects of individual factors can also be investigated. This was performed in SPSS using the sequences of steps shown in Figure 5.15.

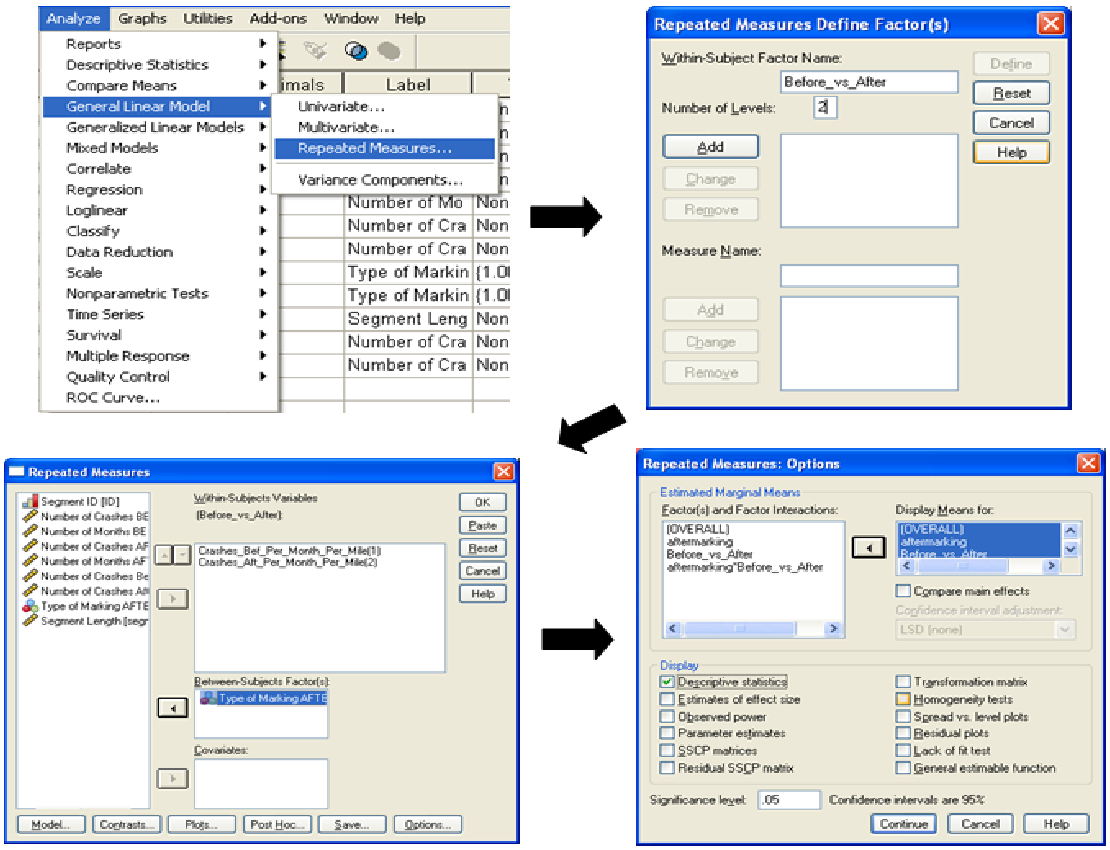


Figure 5-15. SPSS Screen Shots of Analysis Steps

The results of the General Linear Model in Table 5-4 showed that a difference significance of 0.264 which is above 0.05. As stated by Glenberg, relative frequency (Significance) of less than 5% is in the rejection region [Glenberg 1996]. The rejection region means that the null hypothesis (no difference between groups/conditions) can be rejected, thus there is a difference between groups/conditions. Therefore, with a significance level of more than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is not rejected. Since, the significance level of this analysis is more than 0.264 means it was concluded that there is no statistically significant difference in the number of crashes between the period before construction and the period after construction in the studied area.

Table 5-4. Statistical Analysis Comparing
Rumble Stripe on the Roadway Vs. Number of Overall Crashes

Multivariate Tests[b]

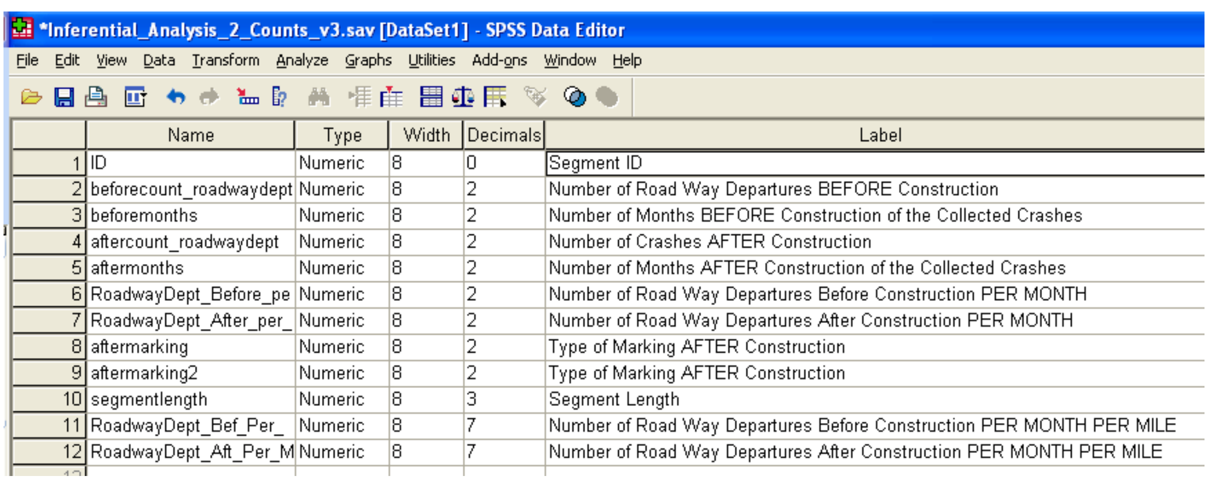
Effect		Value	F	Hypothesis df	Error df	Sig.
Before_Vs_After	Pillai's Trace	.153	1.441[a]	1.000	8.000	.264
	Wilks' Lambda	.847	1.441[a]	1.000	8.000	.264
	Hotelling's Trace	.180	1.441[a]	1.000	8.000	.264
	Roy's Largest Root	.180	1.441[a]	1.000	8.000	.264
Before_Vs_After * aftermarking	Pillai's Trace	.337	4.060[a]	1.000	8.000	.079
	Wilks' Lambda	.663	4.060[a]	1.000	8.000	.079
	Hotelling's Trace	.507	4.060[a]	1.000	8.000	.079
	Roy's Largest Root	.507	4.060[a]	1.000	8.000	.079

a. Exact statistic

b.
Design: Intercept+aftermarking
Within Subjects Design: Before_Vs_After

5.6.2. Analysis 2 – Rumble Stripes on the Roadway Vs. Number of Roadway Departures

This analysis focused on how much the presence of Rumble Stripes impacted the number of roadway departures in the studied segments. The difference between analysis 1 and analysis 2 is that analysis 1 focuses on the impact of rumble stripes on overall crashes while analysis 2 focuses only on the roadway departures. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, and Type of Marking After Construction as shown in the Figure 5-16. The analysis was performed in SPSS using a similar sequence of steps of the ones shown in Figure 5.15.



	Name	Type	Width	Decimals	Label
1	ID	Numeric	8	0	Segment ID
2	beforecount_roadwaydept	Numeric	8	2	Number of Road Way Departures BEFORE Construction
3	beforemonths	Numeric	8	2	Number of Months BEFORE Construction of the Collected Crashes
4	aftercount_roadwaydept	Numeric	8	2	Number of Crashes AFTER Construction
5	aftermonths	Numeric	8	2	Number of Months AFTER Construction of the Collected Crashes
6	RoadwayDept_Before_pe	Numeric	8	2	Number of Road Way Departures Before Construction PER MONTH
7	RoadwayDept_After_per_	Numeric	8	2	Number of Road Way Departures After Construction PER MONTH
8	aftermarking	Numeric	8	2	Type of Marking AFTER Construction
9	aftermarking2	Numeric	8	2	Type of Marking AFTER Construction
10	segmentlength	Numeric	8	3	Segment Length
11	RoadwayDept_Bef_Per_	Numeric	8	7	Number of Road Way Departures Before Construction PER MONTH PER MILE
12	RoadwayDept_Aft_Per_M	Numeric	8	7	Number of Road Way Departures After Construction PER MONTH PER MILE

Figure 5-16. Variable used in the Analysis

Table 5-5 shows a summary of the data analyzed regarding roadway departure only. The analysis of the data indicates that there was an overall average of 0.122 road way departures per month per mile before construction and an overall average of 0.39 crashes per month per mile after construction. It is also important to highlight that this calculation was done with a very small sample of 11 data points.

Table 5-5. Mean Number of Roadway Departures
Per Month Per Mile Before and After Construction

Descriptive Statistics

	Type of Marking	Mean	Std. Deviation	N
Number of Road Way Departures Before Construction PER MONTH PER MILE	Marking/Rumble Strip	.122	.068	5
	Rumble Stripe	.089	.008	6
	Total	.104	.047	11
Number of Road Way Departures After Construction PER MONTH PER MILE	Marking/Rumble Strip	.031	.008	5
	Rumble Stripe	.046	.028	6
	Total	.039	.022	11

The results of the General Linear Model in Table 5-6 showed a difference significance level of .002 which it is below 5%. As stated by Glenberg, values of test statistics that occur with a relative frequency (Sig.) of less than 5% are in the rejection region [Glenberg 1996]. The rejection region means that the null hypothesis (no difference between groups/conditions) can be rejected, thus there is a difference between groups/conditions. This 0.002 means that only in less than 2/10000 cases in which the true means (roadway departures) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .002 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction.

Table 5-6. Statistical Analysis Comparing
Rumble Stripe on the Roadway Vs. Number of Roadway Departures.

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Before_vs_After	Pillai's Trace	.664	17.746[a]	1.000	9.000	.002
	Wilks' Lambda	.336	17.746[a]	1.000	9.000	.002
	Hotelling's Trace	1.972	17.746[a]	1.000	9.000	.002
	Roy's Largest Root	1.972	17.746[a]	1.000	9.000	.002
Before_vs_After * aftermarking2	Pillai's Trace	.208	2.364[a]	1.000	9.000	.159
	Wilks' Lambda	.792	2.364[a]	1.000	9.000	.159
	Hotelling's Trace	.263	2.364[a]	1.000	9.000	.159
	Roy's Largest Root	.263	2.364[a]	1.000	9.000	.159

a. Exact statistic

b.
Design: Intercept+aftermarking2
Within Subjects Design: Before_vs_After

5.6.3. Analysis 3 – Lighting Conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) Vs. Number of Overall Crashes.

This analysis focused on identifying the impact of lighting conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) on number of crashes before and after construction. The variables used in this analysis were: Number of Overall Crashes Before Construction Per Month Per Mile, Number of Overall Crashes After Construction Per Month Per Mile, Type of Marking After Construction, and Lighting Conditions as shown in the Figure 5-17.

*Inferential_Analysis_5_v3_after_Davidsav_WITH_ONLY_2.sav [DataSet3] - SPSS Data Editor

File Edit View Data Transform Analyze Graphs Utilities Add-ons Window Help

	Name	Type	Width	Decimals	Label
1	ID	Numeric	11	0	Segment ID
2	SegmentLenght	Numeric	8	3	Segment Length
3	Before_Months	Numeric	8	2	Number of Months BEFORE Construction of Collected Crashes
4	After_Months	Numeric	8	2	Number of Months AFTER Construction of Collected Crashes
5	LightingConditionDescription	String	10	0	Lighting Conditions - DESCRIPTION
6	LightingConditions	Numeric	11	0	Lighting Conditions
7	BEFORE_NumberofOverallCrashe	Numeric	11	0	Number of Overall Crashes BEFORE Construction
8	AFTER_NumberofOverallCrashes	Numeric	11	0	Number of Overall Crashes AFTER Construction
9	Aftermarking	Numeric	11	0	Type of Marking AFTER Construction
10	Crashes_Before_per_Month	Numeric	8	3	Number of Overall Crashes BEFORE Construction PER MONTH
11	Crashes_After_per_Month	Numeric	8	3	Number of Overall Crashes AFTER Construction PER MONTH
12	Cashes_Before_per_Month_per_	Numeric	8	2	Numerb of Overal Crashes BEFORE Construction PER MONTH PER MILE
13	Crashes_After_per_Month_per_mi	Numeric	8	3	Number of Overall Crashes AFTER Construction PER MONTH PER MILE

Figure 5-17. Variable used in the Analysis

Table 5-7 shows a summary of the data analyzed regarding overall crashes under different lighting conditions before construction. The analysis of the data indicates that there was an overall average of 0.039 crashes per month per mile before construction on the segments that only had marking or rumble strips placed during the construction and an overall average of 0.44 crashes per month per mile before construction on the segments that had rumble stripes placed after construction.

Table 5-8 shows a summary of the data analyzed regarding overall crashes under different lighting conditions after construction. The analysis of the data indicates that there was an overall average of 0.032 crashes per month per mile after construction on the segments that only had marking or rumble stripes placed during construction and an overall average of 0.55 crashes per month per mile after construction on the segments that had rumble stripes placed after construction.

Table 5-7. Mean Number of Crashes Per Month Per Mile
Before Construction Discriminated Per Type of Marking After Construction and Lighting Conditions

Descriptive Statistics

	Type of Marking	Lighting Conditions	Mean	Std. Deviation	N
Numerb of Overal Crashes BEFORE Construction PER MONTH PER MILE	Nothing/Marking	Dawn	.015	.010	3
		Daylight	.097	.036	4
		Dusk	.000	.	1
		Dark-Lit	.003	.004	4
		Dark-Unlit	.045	.008	4
		Total	.039	.042	16
	Rumble Stripe	Dawn	.008	.006	7
		Daylight	.141	.041	7
		Dusk	.002	.002	6
		Dark-Lit	.006	.007	6
		Dark-Unlit	.052	.025	7
		Total	.044	.058	33
	Total	Dawn	.010	.008	10
		Daylight	.125	.043	11
		Dusk	.002	.002	7
		Dark-Lit	.005	.006	10
		Dark-Unlit	.049	.020	11
		Total	.042	.053	49

Table 5-8. Mean Number of Crashes Per Month Per Mile
After Construction Discriminated Per Type of Marking After Construction and Lighting Conditions

Descriptive Statistics

	Type of Marking	Lighting Conditions	Mean	Std. Deviation	N
Number of Overall Crashes AFTER Construction PER MONTH PER MILE	Nothing/Marking	Dawn	.003	.005	3
		Daylight	.091	.024	4
		Dusk	.005	.	1
		Dark-Lit	.007	.004	4
		Dark-Unlit	.027	.012	4
		Total	.032	.039	16
	Rumble Stripe	Dawn	.002	.002	7
		Daylight	.186	.100	7
		Dusk	.005	.004	6
		Dark-Lit	.010	.005	6
		Dark-Unlit	.061	.025	7
		Total	.055	.085	33
	Total	Dawn	.002	.003	10
		Daylight	.151	.092	11
		Dusk	.005	.003	7
		Dark-Lit	.009	.005	10
		Dark-Unlit	.048	.026	11
		Total	.048	.073	49

To account for the multiple variable measures (Before and After, type of marking, and lighting conditions), the General Linear Model with Repeated Measures was also used for this analysis. The analysis was performed in SPSS using the sequence of steps shown in Figure 5.18.

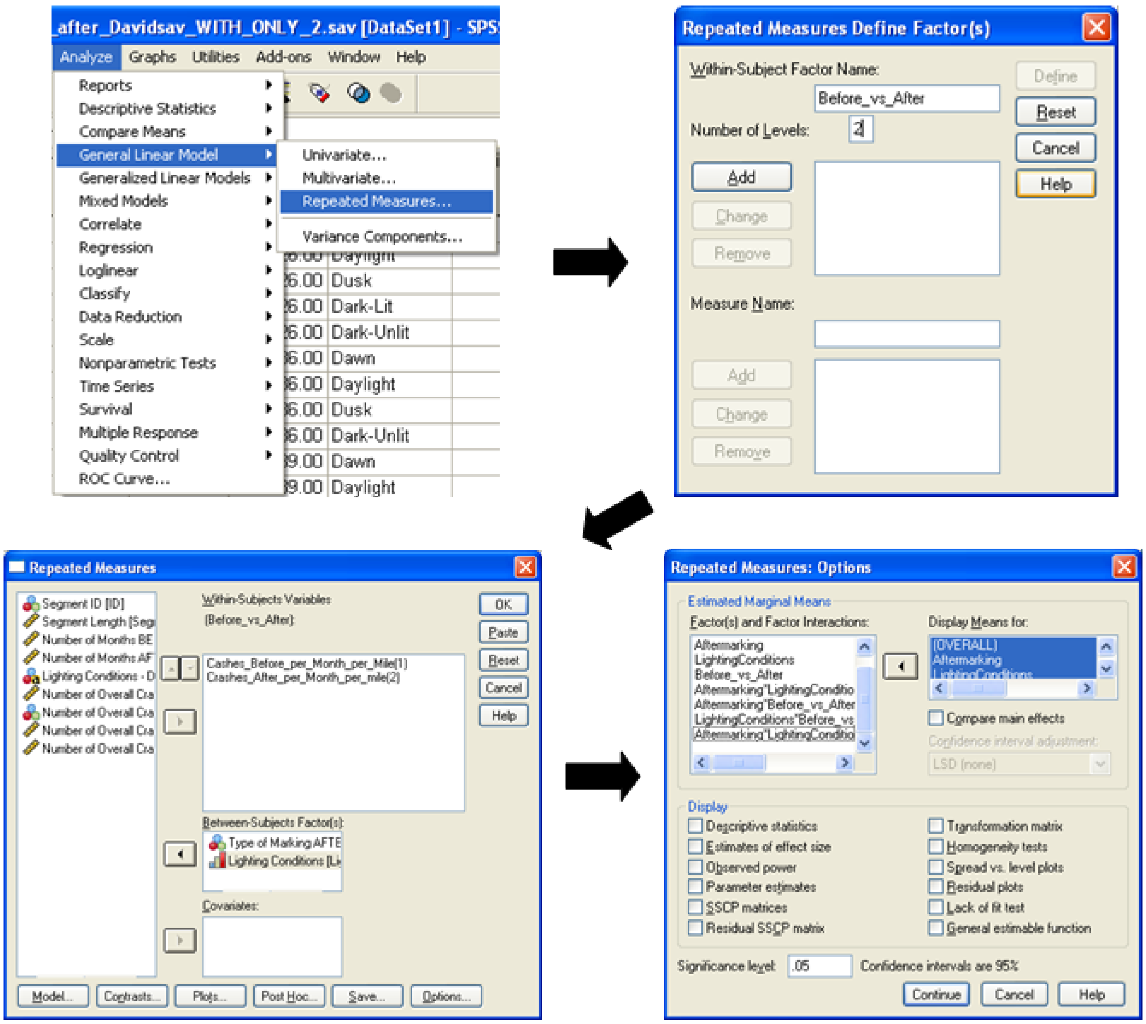


Figure 5-18. SPSS Screen Shots of Analysis Steps

The results of the General Linear Model in Table 5-9 showed: difference significance of 0.686 for the comparison of Before and After, of 0.248 for the comparison of Before and After considering after marking), of 0.605 for the comparison of Before and After considering lighting conditions and of 0.651 for the comparison of Before and After considering both after marking and lighting conditions. These differences significance are all above 0.05. Since, the significance levels of this analysis are more than 0.05, it was concluded that there is no statistically significant difference in the number of crashes between the period before construction and the period after construction in the studied roadway segments considering the lighting conditions.

Table 5-9. Statistical Analysis Comparing
Rumble Stripes on the Roadway Vs. Overall Crashes under Different Lighting Conditions

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
Before_vs_After	Pillai's Trace	.004	.166(a)	1.000	39.000	.686
	Wilks' Lambda	.996	.166(a)	1.000	39.000	.686
	Hotelling's Trace	.004	.166(a)	1.000	39.000	.686
	Roy's Largest Root	.004	.166(a)	1.000	39.000	.686
Before_vs_After * Aftermarking	Pillai's Trace	.034	1.374(a)	1.000	39.000	.248
	Wilks' Lambda	.966	1.374(a)	1.000	39.000	.248
	Hotelling's Trace	.035	1.374(a)	1.000	39.000	.248
	Roy's Largest Root	.035	1.374(a)	1.000	39.000	.248
Before_vs_After * LightingConditions	Pillai's Trace	.066	.687(a)	4.000	39.000	.605
	Wilks' Lambda	.934	.687(a)	4.000	39.000	.605
	Hotelling's Trace	.070	.687(a)	4.000	39.000	.605
	Roy's Largest Root	.070	.687(a)	4.000	39.000	.605
Before_vs_After * Aftermarking * LightingConditions	Pillai's Trace	.060	.620(a)	4.000	39.000	.651
	Wilks' Lambda	.940	.620(a)	4.000	39.000	.651
	Hotelling's Trace	.064	.620(a)	4.000	39.000	.651
	Roy's Largest Root	.064	.620(a)	4.000	39.000	.651

a Exact statistic
b Design: Intercept+Aftermarking+LightingConditions+Aftermarking * LightingConditions
Within Subjects Design: Before_vs_After

5.6.4. Analysis 4 – Lighting Conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) Vs. Number of Roadway Departures

This analysis focused on identifying the impact of lighting conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) on number of road way departures. The difference between analysis 3 and analysis 4 is that analysis 3 focuses on the impact of rumble stripes on the overall crashes under different lighting conditions while analysis 4 focuses only on the roadway departures under different lighting conditions. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, Type of Marking After Construction, and Lighting Conditions.

Table 5-10 shows a summary of the data analyzed regarding roadway departures under different lighting conditions before and after construction. The analysis of the data indicated that there was an average of 0.030 road way departures per month per mile before construction and an average of 0.014 road way departures per month per mile after construction. It is also important to highlight that this calculation was done with a very small sample size and the standard deviation is relatively high.

Table 5-10. Mean Number of Road Way Departures Per Month Per Mile Before and After Construction Discriminated Per Type of Marking After Construction and Lighting Conditions

Descriptive Statistics

	Type of Marking	Lighting Condition	Mean	Std. Deviation	N
Number of Roadway Departures Before Construction PER MONTH PER MILE	Nothing/Marking	Dawn	.008	.008	3
		Daylight	.068	.053	4
		Dark-Lit	.000	.	1
		Dark-Unlit	.042	.021	4
		Total	.039	.040	12
	Rumble Stripe	Dawn	.006	.004	6
		Daylight	.057	.026	8
		Dark-Lit	.001	.002	4
		Dark-Unlit	.023	.015	8
		Total	.026	.027	26
	Total	Dawn	.007	.005	9
		Daylight	.060	.035	12
		Dark-Lit	.001	.002	5
		Dark-Unlit	.029	.019	12
		Total	.030	.032	38
Number of Roadway Departures After Construction PER MONTH PER MILE	Nothing/Marking	Dawn	.003	.005	3
		Daylight	.017	.008	4
		Dark-Lit	.002	.	1
		Dark-Unlit	.009	.007	4
		Total	.009	.008	12
	Rumble Stripe	Dawn	.001	.002	6
		Daylight	.035	.021	8
		Dark-Lit	.003	.002	4
		Dark-Unlit	.013	.012	8
		Total	.015	.019	26
	Total	Dawn	.002	.003	9
		Daylight	.029	.019	12
		Dark-Lit	.003	.002	5
		Dark-Unlit	.012	.011	12
		Total	.014	.017	38

The results of the General Linear Model in Table 5-11 showed a difference significance level of .01 which it is below 5%. As stated by Glenberg, values of test statistics that occur with a relative frequency (Sig.) of less than 5% are in the rejection region [Glenberg 1996]. The rejection region means that the null hypothesis (no difference between groups/conditions) can be rejected, thus there is a difference between groups/conditions. This 0.01 means that only in less than 1/1000 cases in which the true means (number of citations) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .01 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction.

Table 5-11. Statistical Analysis Comparing
Rumble Stripe on the Road Vs. Roadway Departures under Different Lighting Conditions

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
Before_Vs_After	Pillai's Trace	.200	7.486(a)	1.000	30.000	.010
	Wilks' Lambda	.800	7.486(a)	1.000	30.000	.010
	Hotelling's Trace	.250	7.486(a)	1.000	30.000	.010
	Roy's Largest Root	.250	7.486(a)	1.000	30.000	.010
Before_Vs_After * AfterMarking	Pillai's Trace	.046	1.451(a)	1.000	30.000	.238
	Wilks' Lambda	.954	1.451(a)	1.000	30.000	.238
	Hotelling's Trace	.048	1.451(a)	1.000	30.000	.238
	Roy's Largest Root	.048	1.451(a)	1.000	30.000	.238
Before_Vs_After * Lighting_Conditions	Pillai's Trace	.209	2.644(a)	3.000	30.000	.067
	Wilks' Lambda	.791	2.644(a)	3.000	30.000	.067
	Hotelling's Trace	.264	2.644(a)	3.000	30.000	.067
	Roy's Largest Root	.264	2.644(a)	3.000	30.000	.067
Before_Vs_After * AfterMarking * Lighting_Conditions	Pillai's Trace	.053	.559(a)	3.000	30.000	.646
	Wilks' Lambda	.947	.559(a)	3.000	30.000	.646
	Hotelling's Trace	.056	.559(a)	3.000	30.000	.646
	Roy's Largest Root	.056	.559(a)	3.000	30.000	.646

a Exact statistic
b Design: Intercept+AfterMarking+Lighting_Conditions+AfterMarking * Lighting_Conditions
Within Subjects Design: Before_Vs_After

5.6.5. Analysis 5 – Roadway Conditions (Dry/Wet/Snow) Vs. Number of Overall Crashes.
This analysis focused on identifying the impact of Roadway Conditions (Dry/Wet/Snow) on the number of crashes before and after construction. The variables used in this analysis were: Number of Overall Crashes Before Construction Per Month Per Mile, Number of Overall Crashes After Construction Per Month Per Mile, Type of Marking After Construction, and Roadway Conditions.

Table 5-12 shows a summary of the data analyzed regarding overall crashes under different roadway conditions before and after construction. The analysis of the data indicates that there was an average of 0.069 overall crashes per month per mile before construction and an average of 0.088 overall crashes per month per mile after construction. It is also important to highlight that this calculation was done with a very small sample size and the standard deviation is relatively high. Also, this analysis did not account for the difference in the number of dry/wet/snow days because it was beyond the scope of this project.

Table 5-12. Mean Number of Crashes Per Month Per Mile Before and After Construction Discriminated Per Type of Marking After Construction and Road Conditions

Descriptive Statistics

	Type of Marking	Road Condition	Mean	Std. Deviation	N
Number of Crashes Before Construction PER MONTH PER MILE	Nothing/Marking	Dry	.217	.101	4
		Wet	.000	.000	4
		Snow	.010	.017	3
		Total	.081	.121	11
	Stripe	Dry	.175	.085	8
		Wet	.004	.006	8
		Snow	.004	.007	7
		Total	.063	.096	23
	Total	Dry	.189	.089	12
		Wet	.003	.005	12
		Snow	.006	.010	10
		Total	.069	.104	34
Number of Crashes After Constrution PER MONTH PER MILE	Nothing/Marking	Dry	.167	.047	4
		Wet	.014	.011	4
		Snow	.000	.000	3
		Total	.066	.085	11
	Stripe	Dry	.252	.137	8
		Wet	.031	.025	8
		Snow	.002	.003	7
		Total	.099	.139	23
	Total	Dry	.224	.119	12
		Wet	.025	.023	12
		Snow	.001	.003	10
		Total	.088	.124	34

The results of the General Linear Model in Table 5-13 showed a difference significance of 0.524 for the comparison of Before and After, of 0.101 for the comparison of Before and After considering after marking), of 0.763 for the comparison of Before and After considering road way conditions and of 0.174 for the comparison of Before and After considering both after marking and road conditions. These difference significances are all above 0.05. Since the significance levels of this analysis are more than 0.05, it was concluded that there is no statistically significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area considering the roadway conditions.

Table 5-13. Statistical Analysis Comparing
Rumble Stripes on the Road Vs. Overall Crash under Different Roadway Conditions

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
Before_vs_After	Pillai's Trace	.015	.417(a)	1.000	28.000	.524
	Wilks' Lambda	.985	.417(a)	1.000	28.000	.524
	Hotelling's Trace	.015	.417(a)	1.000	28.000	.524
	Roy's Largest Root	.015	.417(a)	1.000	28.000	.524
Before_vs_After * AfterMarking	Pillai's Trace	.093	2.877(a)	1.000	28.000	.101
	Wilks' Lambda	.907	2.877(a)	1.000	28.000	.101
	Hotelling's Trace	.103	2.877(a)	1.000	28.000	.101
	Roy's Largest Root	.103	2.877(a)	1.000	28.000	.101
Before_vs_After * ROAD_CONDITIONS	Pillai's Trace	.019	.273(a)	2.000	28.000	.763
	Wilks' Lambda	.981	.273(a)	2.000	28.000	.763
	Hotelling's Trace	.020	.273(a)	2.000	28.000	.763
	Roy's Largest Root	.020	.273(a)	2.000	28.000	.763
Before_vs_After * AfterMarking * ROAD_CONDITIONS	Pillai's Trace	.117	1.859(a)	2.000	28.000	.174
	Wilks' Lambda	.883	1.859(a)	2.000	28.000	.174
	Hotelling's Trace	.133	1.859(a)	2.000	28.000	.174
	Roy's Largest Root	.133	1.859(a)	2.000	28.000	.174

a Exact statistic
b Design: Intercept+AfterMarking+ROAD_CONDITIONS+AfterMarking * ROAD_CONDITIONS
Within Subjects Design: Before_vs_After

5.6.6. Analysis 6 – Road Conditions (Wet/Dry) Vs. Number of Road Way Departures.

This analysis focused on identifying the impact of Roadway Conditions (Dry/Wet/Snow) on a number of roadway departures. The difference between analysis 5 and analysis 6 is that analysis 5 focuses on the impact of rumble stripes on the overall crashes under different roadway conditions while analysis 6 focus only on the roadway departures under different roadway conditions. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, Type of Marking After Construction, and Roadway Conditions.

Table 5-14 shows a summary of the data analyzed regarding overall crashes under different roadway conditions before and after construction. The analysis of the data indicated that there was an average of 0.029 road way departures per month per mile before construction and an average of 0.012 roadway departures per month per mile after construction. It is also important to highlight that these calculations were done with a very small sample size and the standard deviation is relatively high. Also, this analysis did not account for the difference in the number of dry/wet/snow days because it was beyond the scope of this project.

Table 5-14. Mean Number of Roadway Departures Per Month Per Mile Before and After Construction Discriminated Per Type of Marking After Construction and Road Conditions

Descriptive Statistics

	Type of Marking	Road Conditions	Mean	Std. Deviation	N
Number of Roadway Departures Before Construction PER MONTH PER MILE	Nothing/Marking	Dry	.103	.071	4
		Wet	.000	.000	4
		Snow	.005	.010	4
		Total	.036	.062	12
	Stripe	Dry	.072	.035	8
		Wet	.001	.002	8
		Snow	.004	.006	8
		Total	.026	.039	24
	Total	Dry	.082	.049	12
		Wet	.000	.001	12
		Snow	.004	.007	12
		Total	.029	.047	36
Number of Roadway Departures After Construction PER MONTH PER MILE	Nothing/Marking	Dry	.020	.008	4
		Wet	.002	.003	4
		Snow	.000	.000	4
		Total	.007	.010	12
	Stripe	Dry	.036	.022	8
		Wet	.004	.004	8
		Snow	.003	.004	8
		Total	.014	.020	24
	Total	Dry	.030	.020	12
		Wet	.004	.004	12
		Snow	.002	.004	12
		Total	.012	.017	36

The results of the General Linear Model in Table 5-15 showed a difference significance level of .003 which it is below 5%. This 0.003 means that only in less than 3/1000 cases in which the true means (number of citations) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .003 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction. Similarly, the before vs. after accounting for the road condition has a difference significance level of less than 0.001 which indicate that there is a statistically significant differences on the number of roadway departures under different road conditions.

Table 5-15. Statistical Analysis Comparing
Rumble Stripe on the Road Vs. Road Way Departures under Different Road Conditions

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
Before_vs_After	Pillai's Trace	.263	10.730(a)	1.000	30.000	.003
	Wilks' Lambda	.737	10.730(a)	1.000	30.000	.003
	Hotelling's Trace	.358	10.730(a)	1.000	30.000	.003
	Roy's Largest Root	.358	10.730(a)	1.000	30.000	.003
Before_vs_After * AfterMarking	Pillai's Trace	.062	1.979(a)	1.000	30.000	.170
	Wilks' Lambda	.938	1.979(a)	1.000	30.000	.170
	Hotelling's Trace	.066	1.979(a)	1.000	30.000	.170
	Roy's Largest Root	.066	1.979(a)	1.000	30.000	.170
Before_vs_After * ROAD_CONDITIONS_DESC_2	Pillai's Trace	.419	10.804(a)	2.000	30.000	.000
	Wilks' Lambda	.581	10.804(a)	2.000	30.000	.000
	Hotelling's Trace	.720	10.804(a)	2.000	30.000	.000
	Roy's Largest Root	.720	10.804(a)	2.000	30.000	.000
Before_vs_After * AfterMarking * ROAD_CONDITIONS_DESC_2	Pillai's Trace	.089	1.468(a)	2.000	30.000	.247
	Wilks' Lambda	.911	1.468(a)	2.000	30.000	.247
	Hotelling's Trace	.098	1.468(a)	2.000	30.000	.247
	Roy's Largest Root	.098	1.468(a)	2.000	30.000	.247

a Exact statistic
b Design: Intercept+AfterMarking+ROAD_CONDITIONS_DESC_2+AfterMarking * ROAD_CONDITIONS_DESC_2
Within Subjects Design: Before_vs_After

5.6.7 Analysis 7 – Rumble Stripes on the Roadway Vs. Crash Severity [Property Damage (5), Complain of Pain (4), Moderate (3), Life Threatening (2), Fatal (1)]

This analysis focused on identifying the impact of Rumble Stripes on the severity of the crashes in the studied roadway segments. The severity levels considered were the following: Property Damage (5), Complain of Pain (4), Moderate (3), Life Threatening (2), Fatal (1). The variables used in this analysis were: Number of Overall Crashes Before Construction Per Month Per Mile, Number of Overall Crashes After Construction Per Month Per Mile, Type of Marking After Construction, and Crash Severity.

Table 5-16 shows a summary of the data analyzed regarding overall crashes with different injury severity before construction. The analysis of the data indicates that there was an overall average of 0.050 crashes per month per mile before construction on the segments that only had marking or rumble stripes placed during the construction and an overall average of 0.035 crashes per month per mile before construction on the segments that had rumble stripes placed after construction.

Table 5-16. Mean Number of Crashes Per Month Per Mile Before Construction Discriminated Per Type of Marking Before Construction and Injury Severity

Descriptive Statistics

	Type of Marking	Injury Severity	Mean	Std. Deviation	N
Number of Crashes Before Construction PER MONTH PER MILE	Nothing/Marking	Fatal	.002	.002	4
		Life Threatening	.019	.014	4
		Moderate	.022	.016	4
		Complain of Pain	.044	.033	5
		Property Damage	.140	.063	5
		Total	.050	.061	22
	Stripe	Fatal	.005	.005	8
		Life Threatening	.020	.016	8
		Moderate	.027	.018	8
		Complain of Pain	.036	.023	7
		Property Damage	.096	.063	7
		Total	.035	.042	38
	Total	Fatal	.004	.005	12
		Life Threatening	.020	.015	12
		Moderate	.025	.017	12
		Complain of Pain	.040	.027	12
		Property Damage	.114	.064	12
		Total	.041	.050	60

Table 5-17 shows a summary of the data analyzed regarding overall crashes with different injury severity after construction. The analysis of the data indicates that there was an overall average of 0.046 crashes per month per mile after construction on the segments that only had marking or rumble stripes placed during construction and an overall average of 0.050 crashes per month per mile after construction on the segments that had rumble stripes placed after construction.

Table 5-17. Mean Number of Crashes Per Month Per Mile Before Construction Discriminated Per Type of Marking After Construction and Injury Severity.

Descriptive Statistics

	Type of Marking	Injury Severity	Mean	Std. Deviation	N
Number of Crashes After Constrution PER MONTH PER MILE	Nothing/Marking	Fatal	.001	.002	4
		Life Threatening	.004	.005	4
		Moderate	.028	.016	4
		Complain of Pain	.050	.019	5
		Property Damage	.125	.058	5
		Total	.046	.055	22
	Stripe	Fatal	.005	.006	8
		Life Threatening	.013	.025	8
		Moderate	.035	.029	8
		Complain of Pain	.063	.053	7
		Property Damage	.164	.090	7
		Total	.053	.073	38
	Total	Fatal	.004	.006	12
		Life Threatening	.010	.021	12
		Moderate	.033	.025	12
		Complain of Pain	.057	.041	12
		Property Damage	.148	.078	12
		Total	.050	.066	60

The results of the General Linear Model in Table 5-18 showed a difference significance of 0.221 for the comparison of Before and After, of 0.069 for the comparison of Before and After considering after marking, of 0.365 for the comparison of Before and After considering injury severity and 0.192 for the comparison of Before and After considering both after marking and injury severity. These difference significances are all above 0.05. Since, the significance levels of this analysis are more than 0.05, it was concluded that there is no statistically significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area considering the injury severity.

Table 5-18. Statistical Analysis Comparing
Rumble Stripes on the Road Vs. Overall Crashes discriminated by Injury Severity

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
Before_Vs_After	Pillai's Trace	.030	1.533(a)	1.000	50.000	.221
	Wilks' Lambda	.970	1.533(a)	1.000	50.000	.221
	Hotelling's Trace	.031	1.533(a)	1.000	50.000	.221
	Roy's Largest Root	.031	1.533(a)	1.000	50.000	.221
Before_Vs_After * AfterMarking	Pillai's Trace	.065	3.447(a)	1.000	50.000	.069
	Wilks' Lambda	.935	3.447(a)	1.000	50.000	.069
	Hotelling's Trace	.069	3.447(a)	1.000	50.000	.069
	Roy's Largest Root	.069	3.447(a)	1.000	50.000	.069
Before_Vs_After * INJURY_SEVERITY_DESCRIPTION	Pillai's Trace	.081	1.105(a)	4.000	50.000	.365
	Wilks' Lambda	.919	1.105(a)	4.000	50.000	.365
	Hotelling's Trace	.088	1.105(a)	4.000	50.000	.365
	Roy's Largest Root	.088	1.105(a)	4.000	50.000	.365
Before_Vs_After * AfterMarking * INJURY_SEVERITY_DESCRIPTION	Pillai's Trace	.113	1.589(a)	4.000	50.000	.192
	Wilks' Lambda	.887	1.589(a)	4.000	50.000	.192
	Hotelling's Trace	.127	1.589(a)	4.000	50.000	.192
	Roy's Largest Root	.127	1.589(a)	4.000	50.000	.192

a Exact statistic
b Design: Intercept+AfterMarking+INJURY_SEVERITY_DESCRIPTION+AfterMarking * INJURY_SEVERITY_DESCRIPTION
Within Subjects Design: Before_Vs_After

5.6.8. Analysis 8 – Rumble Stripes on the Roadway Vs. Crash Severity of Roadway of Roadway Departures [Property Damage (5), Complaint of Pain (4), Moderate (3), Life threatening (2), Fatal (1)].

This analysis focused on identifying the impact of Rumble Stripes on the severity of the roadway departures in the studied roadway segments. The severity levels considered were the following: Property Damage (5), Complain of Pain (4), Moderate (3), Life Threatening (2), Fatal (1). The difference between analysis 7 and analysis 8 is that analysis 7 focuses on the impact of rumble stripes on the overall crash's injury severity while analysis 8 focuses only on road way departure injury severity. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, Type of Marking After Construction, and Injury Severity.

Table 5-19 shows a summary of the data analyzed regarding roadway departures with different types of injury severity before construction. The analysis of the data indicated that there was an overall average of 0.023 roadway departures per month per mile before construction on the segments that only had marking or rumble strips placed during the construction and an overall average of 0.016 roadway departures per month per mile before construction on the segments that had rumble stripes placed after construction.

Table 5-19. Mean Number of Road Way Departures Per Month Per Mile Before Construction Discriminated Per Type of Marking After Construction and Injury Severity

Descriptive Statistics

	Type of Marking	Injury Severity	Mean	Std. Deviation	N
Number of Roadway Departures Before Construction PER MONTH PER MILE	Nothing/Marking	Fatal	.002	.002	4
		Life Threatening	.011	.009	4
		Moderate	.016	.013	4
		Complain of Pain	.021	.014	5
		Property Damage	.056	.040	5
		Total	.023	.028	22
	Stripe	Fatal	.003	.003	8
		Life Threatening	.011	.009	8
		Moderate	.015	.011	8
		Complain of Pain	.016	.011	7
		Property Damage	.037	.026	7
		Total	.016	.017	38
	Total	Fatal	.002	.003	12
		Life Threatening	.011	.009	12
		Moderate	.015	.011	12
		Complain of Pain	.018	.012	12
		Property Damage	.045	.033	12
		Total	.018	.022	60

Table 5-20 shows a summary of the data analyzed regarding roadway departures with different types of injury severity after construction. The analysis of the data indicated that there was an overall average of 0.008 roadway departures per month per mile before construction on the segments that only had marking or rumble strips place during the construction and an overall average of 0.009 road way departures per month per mile before construction on the segments that had rumble stripes placed after construction

Table 5-20. Mean Number of Roadway Departures Per Month Per Mile After Construction Discriminated Per Type of Marking After Construction and Injury Severity

Descriptive Statistics

	Type of Marking	Injury Severity	Mean	Std. Deviation	N
Number of Roadway Departures After Construction PER MONTH PER MILE	Nothing/Marking	Fatal	.001	.001	4
		Life Threatening	.004	.005	4
		Moderate	.006	.004	4
		Complain of Pain	.010	.008	5
		Property Damage	.017	.019	5
		Total	.008	.011	22
	Stripe	Fatal	.002	.003	8
		Life Threatening	.004	.008	8
		Moderate	.008	.010	8
		Complain of Pain	.013	.009	7
		Property Damage	.018	.006	7
		Total	.009	.009	38
	Total	Fatal	.001	.003	12
		Life Threatening	.004	.007	12
		Moderate	.007	.008	12
		Complain of Pain	.012	.009	12
		Property Damage	.017	.012	12
		Total	.008	.010	60

The results of the General Linear Model in Table 5-21 shows a difference significance level of less than .001, which is below 5%. This 0.001 means that only in less than 1/1000 cases in which the true means (number of roadway departures) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .001 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction.

Table 5-21. Statistical Analysis Comparing
Rumble Stripes on the Road Vs. Roadway Departure Discriminated by Injury Severity

Multivariate Tests(b)

Effect		Value	F	Hypothesis df	Error df	Sig.
Before_vs_After	Pillai's Trace	.234	15.250(a)	1.000	50.000	.000
	Wilks' Lambda	.766	15.250(a)	1.000	50.000	.000
	Hotelling's Trace	.305	15.250(a)	1.000	50.000	.000
	Roy's Largest Root	.305	15.250(a)	1.000	50.000	.000
Before_vs_After * AfterMarking	Pillai's Trace	.027	1.410(a)	1.000	50.000	.241
	Wilks' Lambda	.973	1.410(a)	1.000	50.000	.241
	Hotelling's Trace	.028	1.410(a)	1.000	50.000	.241
	Roy's Largest Root	.028	1.410(a)	1.000	50.000	.241
Before_vs_After * INJURY_SEVERITY_DESCRIPTION	Pillai's Trace	.213	3.381(a)	4.000	50.000	.016
	Wilks' Lambda	.787	3.381(a)	4.000	50.000	.016
	Hotelling's Trace	.270	3.381(a)	4.000	50.000	.016
	Roy's Largest Root	.270	3.381(a)	4.000	50.000	.016
Before_vs_After * AfterMarking * INJURY_SEVERITY_DESCRIPTION	Pillai's Trace	.040	.527(a)	4.000	50.000	.716
	Wilks' Lambda	.960	.527(a)	4.000	50.000	.716
	Hotelling's Trace	.042	.527(a)	4.000	50.000	.716
	Roy's Largest Root	.042	.527(a)	4.000	50.000	.716

a Exact statistic
b Design: Intercept+AfterMarking+INJURY_SEVERITY_DESCRIPTION+AfterMarking * INJURY_SEVERITY_DESCRIPTION
Within Subjects Design: Before_vs_After

5.7. Lessons Learned

It is worth noting that this first project from the MDOT to quantitatively document the effectiveness of rumble stripes on highway safety was a success. It provided quantitative evidences of the program effectiveness. It also helps develop a sample process to evaluate other programs in the future and identify the data required for those evaluations. It was also evident (based on the statistical analysis) that the most useful inferential statistical analysis for the intended analysis were the t-test and bivariate correlation. Furthermore, histograms, line charts, and scatter plots seems to be the most practical type of chart to present the gathered data.

5.8. Summary

One of the special measures implemented by numerous departments of transportation around the United States, to reduce the number and severity of crashes and roadway departures is the placement of rumble stripes during the construction. This chapter focused on the descriptive and inferential statistical analysis to quantify the impact of the placement of rumble stripes during the construction.

The results presented in this chapter indicate that the placement of rumble stripes during construction of the roadway segments in the studied area significantly improved safety in terms of the number and severity of crashes and roadway departures.

It is also expected that the results and process presented in this paper could be used by other research teams to perform similar analysis of the placement of rumble stripes during construction or others methods implemented around the U.S. to reduce the deaths and injuries on roadways.

CHAPTER 6:
SUMMARY EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY

6.1. INTRODUCTION TO THE PROJECT OBJECTIVE AND APPROACH

The objective of this project is to evaluate the safety impact of the Rumble Stripes program. This objective will be achieved by (1) collecting historical and field data from selected Mississippi roadways, before and after the construction of Rumble Stripes; (2) reviewing nationwide literature on Rumble Stripes effectiveness; and (3) analyzing the compiled Mississippi data and the nationwide literature findings.

The collection of historical and field data in Mississippi will begin by consolidating MDOT and other governmental entities' historical data. The data consolidation will include: (a) characteristics of the road (such as locations, conditions before, and after the construction), (b) traffic parameters (such as volume before and after construction), and (c) accident information (such as location, time, severity, and cause of the crash). The historical data collection will be followed by gathering current and accurate field data. This field data will include: (a) characteristics of the road (such as field inspection of the Rumble Stripes), (b) traffic parameters in the road (such as volume and speed), and (c) crash information in the road (such as location, time, and cause).

Another important component of this study will be a literature review on Rumble Stripes effectiveness. This review will focus on identifying the impact of Rumble Stripes in other states. Additionally, nationwide effectiveness criterion disseminated by U.S. Department of Transportation's Federal Highway Administration [FHWA 2003], the American Association of State Highway and Transportation Officials [AASHTO 2003], American Traffic Safety Services Association [ATSSA 2003] and the National Highway Traffic Safety Administration [NHTSA 2006] will be considered. All this information will be evaluated for its possible implications on the Mississippi Rumble Stripes program.

Finally, the data analysis will begin by establishing correlations between traffic parameters (such as volume and speed) and crashes in the road prior to the construction of Rumble Stripes. A second correlation between the traffic parameters and crashes in roads after the construction of Rumble Stripes will be established. Using these two correlations (traffic parameters->crashes prior to the Rumble Stripes and after the Rumble Stripes) the impact of Rumble Stripes on crash reduction will be identified.

The collection of the historical and field data followed a descriptive research methodology to systematically collect data from the several agencies involved in construction projects. The first step in the data collection was for MDOT to contact the agency and provide brief information about the project and research. Then the researchers met with the agency to discuss the overall purpose of the project and request the required data. Then the agency was responsible for assembling the collected data and sending it to the researchers.

The analysis of the collected data followed a quasi-experimental methodology because the groups were not randomly selected. More specifically, the nonequivalent groups design was implemented because it allowed the comparison of pretest (no law enforcement-) and posttest (law enforcement) for a treated group [Trochim, W. 2006].

The following is a summary of findings and lessons learned regarding the evaluation of rumble stripes on highway safety.

6.2. NATIONWIDE IMPACT LITERATURE OF RUMBLE STRIPES

It can be summarized that, as documented in the literature, fatalities due to roadway departure are at staggering levels. Therefore, it is critical to expedite the assessment of safety countermeasures (such as Rumble Strips and Stripes), especially in Mississippi which has one of the worst safety records in the nation.

In this paper the characteristics of Rumble Stripes and Rumble Strips supported by the Federal Highway Administration studies were presented. Then, based on a systematic literature review of the nationwide implementation and studies on Rumble Strips and Stripes, a synthesis of the current state-of-the-art knowledge regarding the safety impacts of these countermeasures was provided.

The results presented in this paper are very important for the scholarly community, because they can be used as the foundation for similar studies in other states and it has the potential to directly benefit construction education by serving as an example of good practice in engineering education

For a number of years, the Federal Highway Administration (FHWA) has actively endorsed the use of rumble strips as a way to reduce roadway departure crashes [Public Roads 2005]. There have been a number of Rumble Strip and Rumble Stripe projects implemented across the U.S. A FHWA report indicates that the following states have implemented extensive rumble strip programs: Kansas, Michigan, Minnesota, Mississippi, Oklahoma, and Pennsylvania, among others [Public Roads 2005]. Some studies have been performed documenting the roadway safety improvements due to the Rumble Strip and Rumble Stripes installation.

Even though a comprehensive study of the rumble stripe impact on highway safety, there have been a number of documented studies. Studies:

The Michigan Department of Transportation reports that milled rumble strips installed on Michigan roadways have reduced drift-off-the-road crashes by 40 percent [Morena 2003]

The Nevada Department of Transportation indicates that the installation of milled rumble strips, adjacent to the travel way, is a surefire way to warn drivers that their vehicles are about to leave the travel lane so they can take corrective action [ATSSA 2002]. Nevada found that with a cost benefit ratio ranging from more than 30:1 to more than 60:1. Rumble strips are more cost effective than many other safety features, including guardrails, culvert-end treatments, and slope flattening [FHWA 2007a].

The Kentucky Department of Transportation has installed several miles of Rumble Strips and as reported in the Growing Traffic in Rural America [The Road Information Program 2005] Rumble Strips have been found to reduce run off the road crashes by between 25 to 43 percent [Agent et al 2003].

The New York Department of Transportation has been installing rumble strips for many years. A New York study showed a significant change in the number of roadway departure crashes, injuries, and fatalities after rumble strips were installed on the New York State Thruway. Roadway departure crashes were reduced 88 percent, from a high of 588 crashes in 1993 to 71 in 1997. Total injuries were reduced 87 percent, from a 1992 high of 407 to 54 in 1997. Fatalities were reduced 95 percent, from 17 in 1991 and 1992 to 1 fatality in 1997 [FHWA 2007a].

6.3. MDOT DIVISIONS AND THEIR DATA TO ASSESS EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY.

Collecting, processing, archiving and retrieving data/information is a costly, demanding and necessary activity of all organizations. Each organization's division manages data/information in a different way for a variety of purposes to fulfill their primary responsibility. This primary responsibility is important to understand in requesting the appropriate data from the different divisions. The following is a brief description of the responsibilities of the MDOT Divisions involved in collecting data to be used to assess the effectiveness of rumble stripes on highway safety.

Four offices within MDOT actively participated in this project: 1- District 6 Office, 2- District 5 Office, 3- Planning Division and 4- Traffic Engineering Division.

> 1 - District 6 Office is responsible for coordinating, planning, design, construction and maintenance of the intermodal transportation network within fourteen counties. These counties include: Hancock, Harrison, Jackson, Pearl River, Stone, George, Lamar, Forrest, Perry, Greene, Jones, Wayne, Jasper, and Clarke. Figure 3-1 shows a map of the MDOT Districts. District 6 is located in the south east portion of the state
>
> 2 - District 5 Office is responsible for coordinating, planning, design, construction and maintenance of the intermodal transportation network within ten counties. The counties include: Hinds, Madison, Rankin, Leake, Scott, Neshoba, Newton, Noxubee, Kemper, and Lauderdale. Figure 3-1 shows a map of the MDOT Districts. District 5 is located in the central portion of the state
>
> 3 - Planning Division provides the Legislature, MDOT and the Federal Highway Administration with information to support program planning and decisions. Table 3-2

shows the planning division fundamental functions to provide support for planning and decisions [MDOT Planning Division, 2006].

4 - Traffic Engineering Division ensures that safe, efficient traffic control measures are standardized throughout the State Maintained Highway System. It is responsible for the development of programs to add, upgrade or revise existing traffic control devices. This task compels studies to determine and recommend appropriate speed zones as well as the development and distribution of policies for the application of traffic control devices in accordance with established guidelines. The Traffic Engineering Division also directs the in-house manufacture and distribution of MDOT erected signs. Personnel travel statewide to install and maintain signs and signals on assigned sections of state maintained highways [MDOT Traffic Engineering Division, 2006].

Planning Division - Mississippi Department of Transportation

One of the first pieces of information received by the research team was a series of maps showing geographical information of gathered data. Maps that were provided to the research team illustrated the location of each the studied segments. From this map, recording devices in the studied area were selected to retrieve traffic volume counts that corresponded with the segments part of the study. Several computers files with data from the stations from several years were received by the research team. The information provided by the Planning Division represented a wide range of timeframe in different locations. The Planning Division also provided hourly counts information for some locations.

District 6 Office - Mississippi Department of Transportation

One of the first pieces of information received by the research team was a list of construction projects suitable to assess the effectiveness of the rumble stripes on highway safety. Figure 3-9 shows the list of project segments as chosen by District 6. This list was then used as the foundation to collect all relevant traffic flow and crash information relevant to the project. The district office also provided detailed information regarding the construction projects.

District 5 Office - Mississippi Department of Transportation

The first piece of information provided by this district was the list of construction projects most suitable for the assessment. In addition to the list of construction projects this district also provided detailed information on each project.

Traffic Engineering Division - Mississippi Department of Transportation

The main data provided by this division was crash information for each of the segments provided by the district offices.

It was found that all agencies that were interviewed as part of this study considered of paramount importance the safety of drivers and workers in construction zones. It was also found that all agencies were very willing to collaborate in the data consolidation process. However, collecting, archiving and retrieving information was not a main priority for any of these agencies. Additionally, no general guidelines for data structuring was communicated among the agencies. Therefore, it was evident that input into the data gathering process before the data is collected rather than after the fact, could greatly improve the process of accessing the impact of law enforcement surveillance in construction zones or assessing the impact of any other program. By defining the data to be collected, the method for collecting the data, the formatting of the data, the timeframes for collecting the data (before, during and after construction) all the participating agencies would be able to share information and to demonstrate the impact of their performance to the stakeholders. Furthermore, it is suggested that the creation of a data structure that allow these agencies to share common data for common purposes and reduce the cost of the data collection efforts would be very beneficial.

6.4. Data Structuring For Statistical Analysis Of: Effectiveness of Rumble Stripes on Highway Safety

The first step in consolidating the data was to identify the divisions and district offices with needed data, and their responsibility/roles in collecting data. Figure 6-1 shows the information needed for this project and the particular MDOT division and/or district responsible for the data.

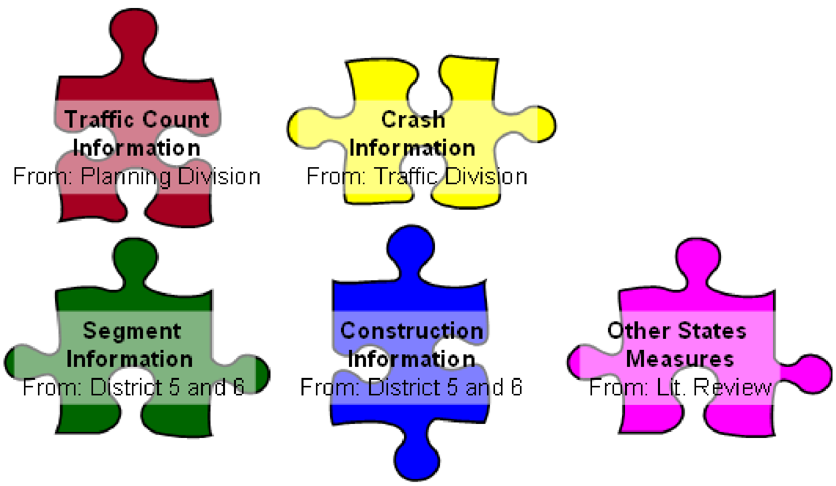


Figure 6-1. Data Needed for the Study and Sources

Then, the MDOT leader of this project contacted the divisions and district offices and provided a brief description of the project and the research team. The research team followed-up this initial contact by requesting a meeting with the representatives of the divisions and district offices to provide an overview of the project and initiate the turn-over of the data that had been collected by the divisions and district offices.

6.4.1. Districts 5 and 6 Data - Mississippi Department of Transportation (MDOT)

One of the most valuable pieces of information provided by the district offices to the research team was the segments that could be used for this project as shown Table 6-1.

Table 6-1. Road Segments Included in the Study

ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)
1	US 98 in George County from the Greene County line to SR 63/Dist 6	US 98	Greene County line	SR 63
2	US 98 in Greene County from east of SR 198 in McLain to the George County line/Dist 6	US 98	Greene County from east of SR 198 in McLain	George County line
3	US 98 in Perry County from the Forrest County line east 7.5 miles/Dist 6	US 98	Forrest County line	East 7.5 miles into Perry County
4	US 98 in Forrest County from Interstate 59 to the Perry County line/Dist 6	US 98	Forrest County from Interstate 59	Perry County line
5	SR 589 in Lamar County from Haden Road north to US 98/Dist 6	SR 589	in Lamar County from US 98 north	to US 98
6	SR 589 in Lamar County from US 98 north to the Covington County line/Dist 6	SR 589	in Lamar County from US 98 north	to the Covington County line
7	SR 43 in Hancock County from SR 603 to Dummyline Road/Dist 6	SR 43	in Hancock County from SR 603	to Dummyline Road
8	SR 43 in Hancock County from Dummyline Road to Salem Road/Dist 6	SR 43	in Hancock County from Dummyline Road	to Salem Road
9	SR 43 in Pearl River County from Pinetucky Road to SR 26/Dist 6	SR 43	in Pearl River County from Pinetucky Road	to SR 26
10	US 11 in Pearl River County from Minkler Road to Charwood Drive/Dist 6	US 11	in Pearl River County from Minkler Road	to Charwood Drive
11	11 in Pearl River County from Charwood Drive to the north corporate limits of Poplarville/Dist 6	US 11	in Pearl River County from Charwood Drive	to the north corporate limits of Poplarville
12	Scooba-Noxubee County Line (7 ½ Miles of 4 lane) in Kemper County /Dist 5	US45	Scooba 0.644 North of	Noxubee County Line
13	Porterville-Scooba (9 ¾ Miles of 4 lane)/Dist 5	US45	Porterville	Scooba
14	Lauderdale to Porterville (10 Miles of 4 lane)/Dist 5	US45	Lauderdale	Porterville

6.4.2. Planning Division Data - Mississippi Department of Transportation (MDOT)

One of the most valuable pieces of information provided by the Planning Division to the research team was traffic volume in the studied area. Figures 6-2 to 6-5 show examples of traffic volume data furnished by the Planning Division.

	A	B	C	D	E	F	G	H
3	ID	Location	Date1	Date2	Time	Westbound	Eastbound	Total
4	1	1	Monday 1/30/06	Wednesday 2/1/06	0	44	30	74
5	1	1	Monday 1/30/06	Wednesday 2/1/06	100	41	25	66
6	1	1	Monday 1/30/06	Wednesday 2/1/06	200	33	23	56
7	1	1	Monday 1/30/06	Wednesday 2/1/06	300	53	24	77
8	1	1	Monday 1/30/06	Wednesday 2/1/06	400	84	68	152
9	1	1	Monday 1/30/06	Wednesday 2/1/06	500	123	83	206
10	1	1	Monday 1/30/06	Wednesday 2/1/06	600	138	142	279
11	1	1	Monday 1/30/06	Wednesday 2/1/06	700	177	212	388
12	1	1	Monday 1/30/06	Wednesday 2/1/06	800	195	232	427
13	1	1	Monday 1/30/06	Wednesday 2/1/06	900	207	263	470
14	1	1	Monday 1/30/06	Wednesday 2/1/06	1000	229	235	463
15	1	1	Monday 1/30/06	Wednesday 2/1/06	AM Peak 1100	245	233	478
16	1	1	Monday 1/30/06	Wednesday 2/1/06	1200	240	244	484
17	1	1	Monday 1/30/06	Wednesday 2/1/06	1300	258	273	531
18	1	1	Monday 1/30/06	Wednesday 2/1/06	1400	281	278	558
19	1	1	Monday 1/30/06	Wednesday 2/1/06	1500	278	272	550
20	1	1	Monday 1/30/06	Wednesday 2/1/06	PM Peak 1600	283	287	570
21	1	1	Monday 1/30/06	Wednesday 2/1/06	1700	252	271	523
22	1	1	Monday 1/30/06	Wednesday 2/1/06	1800	195	228	423
23	1	1	Monday 1/30/06	Wednesday 2/1/06	1900	153	153	306
24	1	1	Monday 1/30/06	Wednesday 2/1/06	2000	120	120	240
25	1	1	Monday 1/30/06	Wednesday 2/1/06	2100	105	95	200
26	1	1	Monday 1/30/06	Wednesday 2/1/06	2200	80	85	164
27	1	1	Monday 1/30/06	Wednesday 2/1/06	2300	62	50	112
28	1	2	Tuesday 2/11/03	Thursday 2/13/03	0	34	39	73
29	1	2	Tuesday 2/11/03	Thursday 2/13/03	100	39	57	95
30	1	2	Tuesday 2/11/03	Thursday 2/13/03	200	91	91	182
31	1	2	Tuesday 2/11/03	Thursday 2/13/03	300	149	109	258
32	1	2	Tuesday 2/11/03	Thursday 2/13/03	400	144	161	305
33	1	2	Tuesday 2/11/03	Thursday 2/13/03	500	167	195	362

Figure 6-2. A Sample of the Hourly Traffic Volume Data Received from Planning

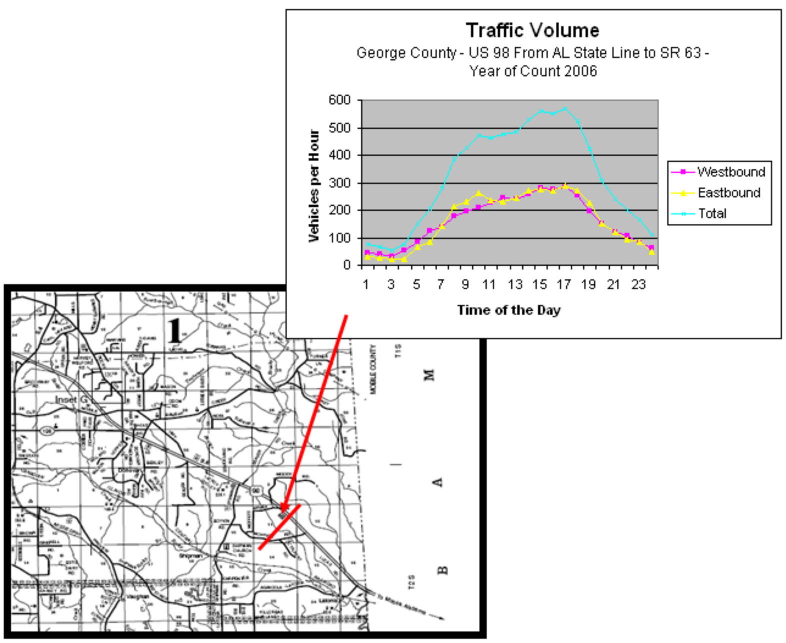


Figure 6-3. A Sample of the Hourly Traffic Volume Data Received from Planning

ID	Location #	Location Description	Route	County	AADT 1 Year	AADT 1 Volume	AADT 2 Year	AADT 2 Volume
1	1	From SR 63 to Greene CL	US 98	George	2002	6500	2005	7200
2	1	From Perry CL to Old Hwy 24	US 98	Greene	2001	8500	2004	8900
2	2	From Perry CL to Old Hwy 24	US 98	Greene	2003	10000	2006	8000
2	3	From SR 57 to Vernal River Rd	US 98	Greene	2003	7300	2006	6500
2	4	From Vernal River Rd to George CL	US 98	Greene	2003	7700	2006	7500
3	1	From Mahned Rd to SR 29	US 98	Perry	2003	10000	2006	9700
3	2	From SR 29 to SR 198	US 98	Perry	2001	8700	2004	10000
3	3	From SR 198 (W) to Eight Mile Rd	US 98	Perry	2003	8400	2006	8700
4	1	From I-59 to US 49	US 98	Forrest	2003	13000	2006	23000
5	1	From WPA to Old Hwy 24	SR 589	Lamar	2001	2000	2004	2000
6	1	From US 98 to Epley Rd	SR 589	Lamar	2000	4300	2004	5000
6	2	From Epley Rd to SR 42	SR 589	Lamar	2000	4200	2004	4300
6	3	From SR 42 to Covington CL	SR 589	Lamar	2000	1800	2004	2200
8	1	From Dummyline Rd to Pearl River CL	SR 43	Hancock	2003	4000	2006	6400
8	2	From Pearl River CL to Salem Rd	SR 43	Pearl River	2003	4000	2006	6400
9	1	From Pinetucky Rd to SR 26	SR 43	Pearl River	2003	1600	2006	1900
10	1	From Derby Whitesand Rd to SR 26	US 11	Pearl River	2004	1900	2006	3300
11	1	From Derby Whitesand Rd to SR 26	US 11	Pearl River	2003	1900	2006	3300
11	2	From SR 26 to North St	US 11	Pearl River	2003	6200	2006	6300
11	3	From North St to Lamar St	US 11	Pearl River	2003	4800	2006	5200
11	4	From Lamar St to Springhill Rd	US 11	Pearl River	2003	1500	2006	1700
14	1	From Old Lauderdale Rd to Kemper CL	US 45	Lauderdale	2003	3600	2006	3700
14	2	From Lauderdale CL to Dekalb-Porterville Rd	US 45	Kemper	2003	3600	2006	3700

Figure 6-4. Annual Average Daily Traffic over Time Received from Planning

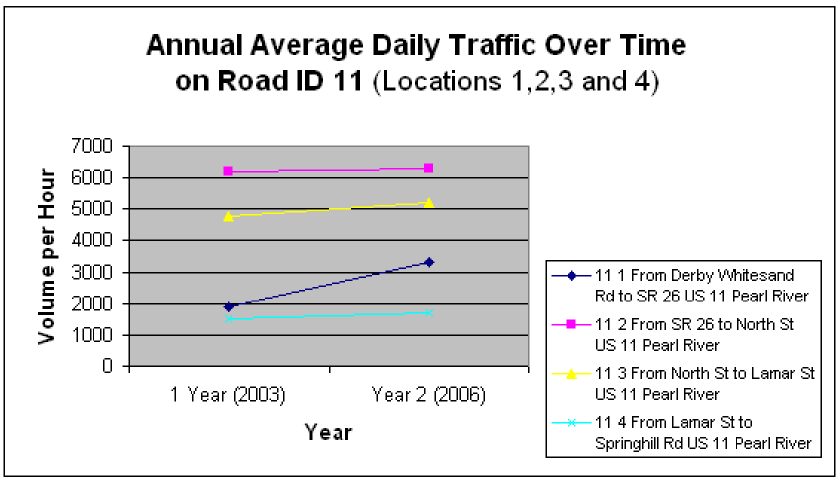


Figure 6-5. A Sample of the Annual Average Daily Traffic Over Time
Receive from Planning

6.4.3. Traffic Engineering Division Data – Mississippi Department of Transportation (MDOT)

The most valuable pieces of information provided by the Traffic Engineering Division to the research team were the crash data. Figures 6-1 to 6.6 show examples of traffic volume data furnished by the Traffic Engineering Division.

	B	C	D	E	F	G	H	I
1	ROUTE I	SAMS ROUTE NAM	STREET NAME	INTERSECTING ROUTE	INTERSECTING STREET NAME	SAMS INT ROUTE N	COUNTYNAM	SAMS CITYNA
4	198	MS 198	LONDON ST	198	RATLIFF ST	MS 198	George [20]	LUCEDALE
5	063		SOUTH				George [20]	
6			WEST CAMELLIA ROAD		TWIN CREEK ROAD		George [20]	
7	26	MS 26	WINTER ST.	63	COWART STREET	MS 63	George [20]	LUCEDALE
8			026 WEST		HENERY COCHRAN		George [20]	
9			063		VENTURA DR.		George [20]	
10			063 SOUTH		WALMART PL.		George [20]	
11			063 WALMART		063	MS 63	George [20]	
12			063 WINTER ST.		AUTO ZONE		George [20]	
13			08 SUNSET DR		FAIRGROUNDS		George [20]	
14			098		HWY 63		George [20]	
15			1205 MILL ST EAST		FOUNTAIN LAKE RD		George [20]	
16			13185 HWY 613		HWY 613	MS 613	George [20]	
17			132 NATHANS LANE		TUT RD		George [20]	
18			13TH ST		GRAND AVE		George [20]	
19	163		163	163	WALMART PARKING LOT		George [20]	LUCEDALE
20			163 SOUTH		WALMART PARKING LOT		George [20]	LUCEDALE
21	163		163 SOUTH	26	WINTER ST	MS 26	George [20]	LUCEDALE

Figure 6-6. Sample Crash Information with Components and their Elements

	H	I	J	K	L	M	N	O	P	Q
1	COUNTYNAM	SAMS CITYNA	INTERSECTION DIS	INTERSECTION DIST U	INTERSECTION DIST DI	REPORTED DA	REPORTED TI	SAMS CRASH I	VEHICLE COU	SAMS INJURY
4	George [20]	LUCEDALE	0.15	F	W	02/21/2006	12:05	1876478	2	
5	George [20]		0			09/03/2002	12:31	3970484	3	
6	George [20]					09/08/2005	05:40	1812614	1	
7	George [20]	LUCEDALE	200	F	S	10/08/2006	15:10	3470592	2	
8	George [20]		0			11/16/2002	12:41	4011012	2	
9	George [20]		0			09/10/2002	17:32	4027514	2	
10	George [20]		0			12/30/2003	13:04	4108442	2	
11	George [20]		0			03/04/2003	13:25	4032498	2	
12	George [20]		0			10/21/2002	11:48	3998293	3	
13	George [20]		500	F		01/13/2003	08:49	4013364	1	
14	George [20]		0			12/26/2002	03:45	4058866	1	
15	George [20]		0.08	M	S	10/27/2002	18:05	4021189	2	
16	George [20]		0.5	F	W	05/06/2005	14:20	3446778	2	
17	George [20]		300	F	N	10/06/2005	16:07	1812613	2	
18	George [20]					06/27/2005	19:17	3444162	2	
19	George [20]	LUCEDALE				05/04/2004	14:57	1768515	2	
20	George [20]	LUCEDALE				11/15/2004	11:25	1819635	2	
21	George [20]	LUCEDALE				08/22/2005	17:15	1819487	2	

Figure 6-7. Sample Crash Information with Components and their Elements

	Q	R	S	T	U	V	W	X
1	SAMS INJURY C	SAMS FATAL C	SAMS STAT INJURY SEVER	SAMS STAT DUI I	LIGHT CONDITION DE	ROAD CONDITION DESC	SAMS CRASH TYPE DESC	SAMS INTR
4			5		Daylight	Dry	Parked vehicle	
5	0	0	5		Daylight	Dry	Angle	
6	1		4		Dark-Unlit	Dry	Fixed Object	
7			5	0	Daylight	Dry	Hit and Run	
8	0	0	5		Dawn	Dry	Rear end slow or stop	
9	0	0	5		Daylight	Dry	Rear end slow or stop	
10	0	0	5		Daylight	Dry	Angle	
11	0	0	5		Daylight	Dry	Parked vehicle	
12	0	0	5		Daylight	Dry	Rear end slow or stop	
13	0	0			Daylight	Dry	Parked vehicle	
14	0	0	5		Dark-Unlit	Dry	Run off Road - Straight	
15	1	0	4		Dark-Unlit	Dry	Parked vehicle	
16			5	0	Daylight	Dry	Parked vehicle	
17			5		Daylight	Dry	Parked vehicle	
18			5	0	Daylight	Dry	Angle	
19			5		Daylight	Dry	Left turn same roadway	
20			5		Daylight	Dry	Rear end slow or stop	
21			5		Daylight	Dry	Rear end slow or stop	

Figure 6-8. Sample Crash Information with Components and their Elements

6.5. THE RESTRUCTURING AND CONSOLIDATION OF THE AVAILABLE DATA FOR THE ANALYSIS

To achieve this main objective, eleven specific statistical analyses were established aiming to determine if there was any correlation between the studied variables. The eleven analyses were as follows:

Analysis 1 – Rumble Stripe on the Road Vs. Number of Overall Crash
Analysis 2 – Rumble Stripe on the Road Vs. Number of Roadway Departure
Analysis 3 – Rumble Stripe Overtime Vs. Number of Overall Crash
Analysis 4 – Rumble Stripe Overtime Vs. Number of Roadway Departure

Analysis 5 – Lighting Conditions (Day/Night) Vs. Number of Overall Crash.
Analysis 6 – Lighting Conditions (Day/Night) Vs. Number of Roadway Departure
Analysis 7 – Road Conditions (Wet/Dry) Vs. Number of Overall Crash.
Analysis 8 – Road Conditions (Wet/Dry) Vs. Number of Road Way Departures.
Analysis 9 – Rumble Stripe on Road Vs -Crash Severity of Overall Crashes
Analysis 10 – Rumble Stripe on Road Vs Crash Severity of Road Way Departure
Analysis 11 – Rutting Condition Vs. Number of Overall Crash.
Analysis 12 – Rutting Condition Vs. Number of Road Way Departures.

Based on the eleven analyses, the following data was required:

- Construction starting and ending data of each studied segment
- Crashes in each of the studied segments
- Crash types/descriptions (Roadway departures, Overturn, etc)
- Crash dates
- Lighting conditions (Dark / Lighten)
- Road condition (Dry / Wet / Snow)
- Crash Injury Severity (Property Damage Only, Complain of Pain, Moderate, Life Threatening, Fatal)
- Rutting Condition
- Upon comparing the required statistical analysis and the data available from the MDOT division and/or district, it was recognized that there were four distinctive data sets (as shown in Figure 6-9): 1- Segments Information, 2- Crash Information 3- Traffic Volume Information, and 4- Pavement Analysis.

Segments Information Data Set
Segment ID
Project Name
Route
Starting Point
Ending Point
Intersecting Roads
Construction Start Date
Construction Ending Date

Crash Information Data Set
Segment ID
Date
Crash type/description
Lighting conditions
Road conditions
Crash Injury Severity

Traffic Volume Data Set
Segment ID
Date
Traffic Count

Pavement Analysis Data Set
Segment ID
Date
Rutting Conditions

Figure 6-9. Data Sets for Analyses

6.5.1. Restructuring Districts 5 and 6 Data - Mississippi Department of Transportation (MDOT) Data

The segment information received from Districts 5 and 6 was modified to include all the elements of the “Segment Information” data set. Figure 6-10 shows a portion of the enhanced segment information with all the needed elements

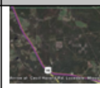
ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)	Desc	Map	Intersecting Roads	Project Dates (Start)	Project Dates (Ending)	BEFORE Data Traffic Flow and Incidents (Years)	AFTER Data Traffic Flow and Incidents (Years)
1	US 98 in George County from the Greene County line to SR 63/Dist 6	US 98	Greene County line	SR 63	has rumble stripe.		McInnis Ln - Billy Knight Rd Ben Eubanks Rd. Cutoff Rd. Merril Rd. Unknown Rd. Nicholson Ln N Bexley Rd. S Bexley Rd. Darlenes Ln Unknown Rd. Main St. – CF Eubanks Rd. Ernest Pipkins Rd.	04/08/2004	09/31/2004	From 01/01/2002 To 03/31/2004	From 10/01/2004 To 12/31/2006
2	US 98 in Greene County from east of SR 198 in McLain to the George County line/Dist 6	US 98	Greene County from east of SR 198 in McLain	George County line	has a rumble strip		Old MS 24 Unknown Rd. Hwy 57 Dewey McInnis Rd. – Jim Powell Rd. Midway Church Rd. Merritt Rd. Gatlin Creek Rd. Harry Eubanks Rd. Miller Loop Tom Miller Rd. Merritt Rd. Miller Loop Oscar Howard Rd. – Vernay Rd.	04/10/2003	11/28/2003	From 01/01/2001 To 03/31/2003	From 12/01/2003 To 12/31/2006

Figure 6-10. Enhanced Segment Information

The Segment Id, Project Name, District, Route, Starting and Ending Points were used as received without re-structuring. Intersecting roads were found and added to the information to facilitate the collection of the crash and traffic volume information. The project start and ending date were used to identify the before and after periods to collect and perform comparative analysis.

6.5.2. Restructuring Planning Division Data - Mississippi Department of Transportation (MDOT)

The traffic volume information received from the MDOT Planning Division was re-structured to two variables: Time of the Day and Volume. The variable Time of the Day was defined as “Ordinal” and since the “Volume” variable represented magnitude it was defined as “Scale”.

The Time of the Day variable was assigned a number between 0 and 23 representing a 24 hours clock which begins at midnight (which is 0000 hours). The Volume variable was organized by direction (bound) of the traffic and contained the number of vehicles per hour that passed each studied segment each hour. Figure 6-11 shows a sample a 24 hour count.

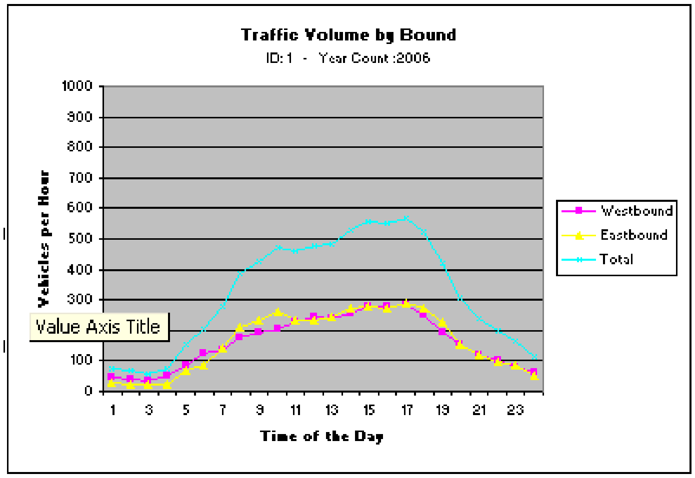


Figure 6-11. Sample 24 hour Traffic Count

6.5.3. Restructuring Traffic Engineering Division Data - Mississippi Department of Transportation (MDOT)

The crash information received from the Traffic Engineering Division was restructured to six variables: Segment ID, Date, Crash Type/Description
Lighting Conditions, Road Conditions and Crash Injury Severity.

6.5.4. Consolidation of all the Data

After restructuring the information received from each divisions and districts, the next step was to consolidate (or integrate) all of the data sets into one master data file. The variables "Segment ID" and "Date" were identified as the common fields among all the data sets. The dashed arrows pointing in two directions, in Figure 6-12, show these two variables are common among all the data sets. Therefore, "Segment ID" and "Date" were used as key fields and the data from all the data sets was copied into one master data set. As a result of this consolidation, a total of 1564 records were integrated into the master data set.

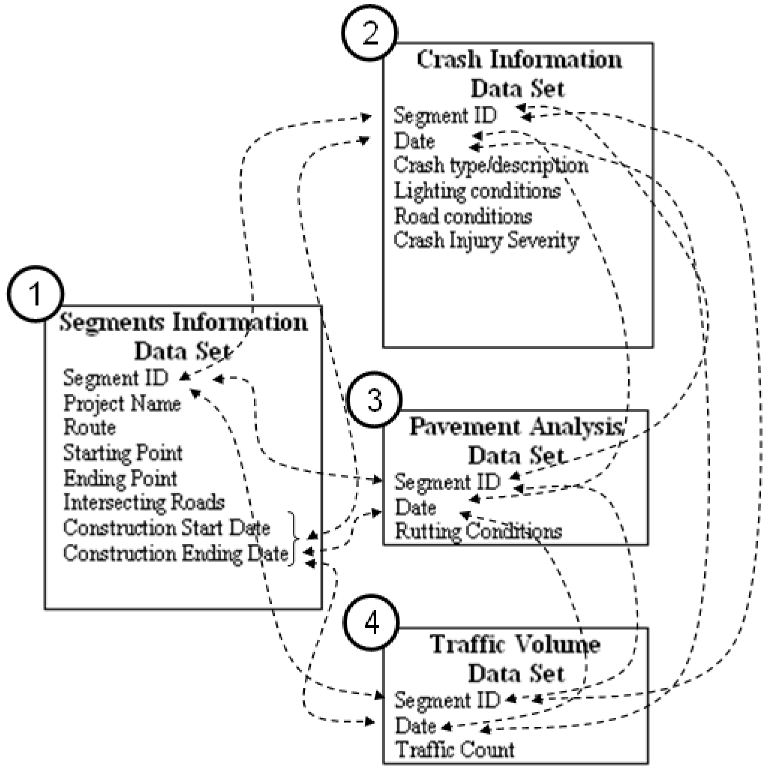


Figure 6-12. Data Set Consolidation

6.6. STATISTICAL ANALYSIS TO ASSESS EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY

The results of the statistical analysis were as follows:

The results of the statistical analysis indicate the following:

- Analysis 1 - This analysis focused on how much the presence of Rumble Stripes impacted the number of overall crashes in the studied roadway segments. In order to measure the impact of rumble stripes on the number of overall crashes, data before and after the placement of the rumble stripes was collected. Additionally, the data collected was grouped according to the placement of rumble stripes or reflective marking put in place during the roadway construction. The variables used in this analysis were: Number of Crashes Before Construction Per Month Per Mile, Number of Crashes After Construction Per Month Per Mile, and Type of Marking After Construction.

  Results: There is no statistically significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area.

- Analysis 2 - This analysis focused on how much the presence of Rumble Stripes impacted the number of roadway departures in the studied segments. The difference between analysis 1 and analysis 2 is that analysis 1 focuses on the impact of rumble stripes on overall crashes while analysis 2 focuses only on the roadway departures. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, and Type of Marking After Construction.

Results: There is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction. The results of the General Linear Model showed a difference significance level of .002 which it is below 5%. The rejection region means that the null hypothesis (no difference between groups/conditions) can be rejected, thus there is a difference between groups/conditions. This 0.002 means that only in less than 2/10000 cases in which the true means (roadway departures) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .002 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is statistically significant difference in the number of roadway departures between the period before construction and the period after construction.

- Analysis 3 - This analysis focused on identifying the impact of lighting conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) on number of crashes before and after construction. The variables used in this analysis were: Number of Overall Crashes Before Construction Per Month Per Mile, Number of Overall Crashes After Construction Per Month Per Mile, Type of Marking After Construction, and Lighting Conditions.

  Results: There is no statistically significant difference in the number of crashes between the period before construction and the period after construction in the studied roadway segments considering the lighting conditions.

- Analysis 4 - This analysis focused on identifying the impact of lighting conditions (Dawn, Daylight, Dusk, Dark-Lit, & Dark-Unlit) on number of road way departures. The difference between analysis 3 and analysis 4 is that analysis 3 focuses on the impact of rumble stripes on the overall crashes under different lighting conditions while analysis 4 focuses only on the roadway departures under different lighting conditions. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, Type of Marking After Construction, and Lighting Conditions.

  Results: There is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction. The results of the General Linear Model showed a difference significance level of .01 which it is below 5%. As stated by Glenberg, values of test statistics that occur with a relative frequency (Sig.) of less than 5% are in the rejection region [Glenberg 1996]. The rejection region means that the null hypothesis (no difference between groups/conditions) can be rejected, thus there is a difference between groups/conditions. This 0.01 means that only in less than 1/1000 cases in which the true means (number of citations) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .01 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction.

- Analysis 5 - This analysis focused on identifying the impact of Roadway Conditions (Dry/Wet/Snow) on the number of crashes before and after construction. The variables used in this analysis were: Number of Overall Crashes Before Construction Per Month Per Mile, Number of Overall Crashes After Construction Per Month Per Mile, Type of Marking After Construction, and Roadway Conditions.

  Results: There is no statistically significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area considering the roadway conditions.

- Analysis 6 - This analysis focused on identifying the impact of Roadway Conditions (Dry/Wet/Snow) on number of roadway departures. The difference between analysis 5 and analysis 6 is that analysis 5 focuses on the impact of rumble stripes on the overall crashes under different roadway conditions while analysis 6 focus only on the roadway departures under different roadway conditions. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, Type of Marking After Construction, and Roadway Conditions.

  Results: There is a statistically significant differences on the number of roadway departures under different road conditions. The results of the General Linear Model showed a difference significance level of .003 which it is below 5%. This 0.003 means that only in less than 3/1000 cases in which the true means (number of citations) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .003 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction. Similarly, the before vs. after accounting for the road condition has a difference significance level of less than 0.001 which indicate that there is statistically significant differences on the number of roadway departures under different road conditions.

- Analysis 7 - This analysis focused on identifying the impact of Rumble Stripes on the severity of the crashes in the studied roadway segments. The severity levels considered were the following: Property Damage (5), Complain of Pain (4), Moderate (3), Life Threatening (2), Fatal (1). The variables used in this analysis were: Number of Overall Crashes Before Construction Per Month Per Mile, Number of Overall Crashes After Construction Per Month Per Mile, Type of Marking After Construction, and Crash Severity.

Results: there is no statistically significant difference in the number of overall crashes between the period before construction and the period after construction in the studied area considering the injury severity.

- Analysis 8 - This analysis focused on identifying the impact of Rumble Stripes on the severity of the roadway departures in the studied roadway segments. The severity levels considered were the following: Property Damage (5), Complain of Pain (4), Moderate (3), Life Threatening (2), Fatal (1). The difference between analysis 7 and analysis 8 is that analysis 7 focuses on the impact of rumble stripes on the overall crashes injury severity while analysis 8 focuses only on road way departures injury severity. The variables used in this analysis were: Number of Roadway Departures Before Construction Per Month Per Mile, Number of Roadway Departures After Construction Per Month Per Mile, Type of Marking After Construction, and Injury Severity.

  Results: There is a statistically significant difference in the number of roadway departures between the period before construction and the period after construction. The results of the General Linear Model shows a difference significance level of less than .001, which it is below 5%. This 0.001 means that only in less than 1/1000 cases in which the true means (number of roadway departures) were the same; the sample will show results as extreme as the one observed here. Therefore, with a significance level of .001 which is less than 0.05, the null hypothesis (which is that there is no difference between the groups/conditions) is rejected. Thus, it was concluded that there is statistically significant difference in the number of roadway departures between the period before construction and the period after construction.

6.7. Economic and Societal Impact of Rumble Stripes

The results of recent studies clearly indicate that the annual economic and societal costs of traffic crash are staggering even under the most conservative accident cost-measurement criteria. [Peck, R., Healey, E. 2009] . The cost-measurement criteria of a traffic crash is proportional to the severity. The severity classification include: Property Damage, Complain of Pain, Moderate, Life Threatening, and Fatal. The two most common approaches to quantifying traffic fatality consequence are human capital/production loss models, and willingness to pay (WTP)/comprehensive models [Peck, R., Healey, E. 2009]. Under the former, fatality costs include all direct economic losses associated with an injury or fatality. By far the largest component of this cost is lost future earnings of fatally injured victims. Under the latter (WTP/comprehensive model), estimates reflect the direct and indirect costs incurred by the involved individuals as well as those of the larger society. In WTP models, injury and fatal accident costs are ultimately defined in terms of what society and individuals are willing to pay to reduce, by given magnitudes, the probability of serious injuries or fatalities.

The American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Traffic Engineering publishes a crash cost comparison of all the states in the US [AASHTO Subcommittee on Traffic Engineering, 2009]. The crash cost for Mississippi in 2006 based on the severity classification is presented in Table 6.2.

Table 6.2. Crash Cost for Mississippi base on the Severity Classification
[AASHTO Subcommittee on Traffic Engineering, 2009]

Crash Severity	**Cost**
Fatal Crash	$3,391,176
Life Threatening Injury (Injury A)	$234,774
Moderate Injury (Injury B)	$46,955
Complaint of Pain (Injury C)	$24,782
Property Damage Only (PDO)	$2,609

An analysis evaluating the cost impact of Rumble Stripes was conducted. While there are many way of calculating this impact. The analysis of the research team focused on the cost of roadway departures based on the crash cost information provided by AASHTO for Mississippi based on the Severity Classification shown in the Table 6.2. More specifically, the research team compared cost before and after the construction project based on the number of roadway departures per month per mile and the crash cost from AASHTO.

Table 6.3 presents the cost in dollars per month per mile driven before and after construction. The first column shows the marking type after construction. The type of marking for before construction is not presented because all of the segments had the same type of marking with none having ruble strips or stripes. The second column of Table 6.2 shows the crash severity classification, the third and four columns shows the cost in dollar of each one of the crash type considering number of crashes and the cost per crashes. The fifth and sixth columns show the difference in dollars and percentage per month per mile driven. It is worth noting that the savings of the projects on crash cost was 79.0% for projects with only marking and 86.2% for projects with rumble strips/stripes. This means that providing markings on roadways provides a 79% savings based on crash severity. The use of rumble stripes provides an additional 7.2% savings over markings only.

Table 6.3 Cost in $ per Month per Mile Before and After Construction Discriminated by Crash Severity

Marking Type After Construction	Crash Severity	Cost in $ Before Construction	Cost in $ After Construction	$ Difference Before & After	% Difference Before & After
Nothing/Marking	Fatal	$2.70	$0.44	-$2.25	-83.5%
	Life Threatening	$0.83	$0.17	-$0.66	-79.4%
	Moderate	$0.17	$0.06	-$0.11	-64.2%
	Complain of Pain	$0.17	$0.11	-$0.06	-35.3%
	Property Damage	$0.05	$0.02	-$0.03	-62.7%
	Total	**$0.72**	**$0.15**	**-$0.57**	**-79.0%**
Strip and Stripe	Fatal	$1.35	$0.00	-$1.35	-100.0%
	Life Threatening	$0.47	$0.16	-$0.30	-65.2%
	Moderate	$0.16	$0.09	-$0.06	-41.5%
	Complain of Pain	$0.09	$0.03	-$0.06	-65.7%
	Property Damage	$0.02	$0.01	-$0.01	-66.2%
	Total	**$0.45**	**$0.06**	**-$0.39**	**-86.2%**
Total	Fatal	$1.95	$0.20	-$1.75	-89.9%
	Life Threatening	$0.63	$0.17	-$0.46	-73.6%
	Moderate	$0.16	$0.08	-$0.08	-51.9%
	Complain of Pain	$0.13	$0.07	-$0.06	-44.4%
	Property Damage	$0.04	$0.01	-$0.02	-63.5%
	Total	$0.58	$0.11	-$0.48	-81.8%

REFERENCES

AASHTO (2003) "American Association of State Highway and Transportation Officials", http://www.aashto.org, Last Visited: June 2003

AASHTO Subcommittee on Traffic Engineering (2009) "Crash Cost Comparison" http://www.transportation.org/sites/scote/docs/Crash%20Cost%20Poll%201-07.xls Last visited: January 2009

Agent, K; O'Connel, L; Green, E; Kreis, d; Pigman, J; Tollner, N; (2003) "Development of Procedures for Identifying High-Crash Locations and Prioritizing Safety Improvements" Research Report KTC-03-15/SPR250-02-IF, Kentucky Department of Transportation, June 2003, http://safety.transportation.org/htmlguides/implement/ProcAppFF.pdf, Last visited: January 2007

Amparano, G; Morena, D., (2006) "Senior Mobility Series: Article 4 Marking the Way To Greater Safety", Public Roads, FHWA, http://www.tfhrc.gov/pubrds/06jul/08.htm, Last visited: January 2007

ATSSA (2002), "Driving Down Fatalities: Nevada's Safer Roads", Press Release, ATSSA, (Sept. 26, 2002), Fredericksburg, VA 22406.

ATSSA (2003) "American Traffic Safety Services Association", http://www.atssa.com, Last Visited: June 2003

ATSSA (2006), "Low Cost Local Road Safety Solutions: Pavement Markings Over Rumble Strips (Rumble Stripes)Improve Pavement Marking Visibility" Volume 1 No. 11, ATSSA, (March 2006), Fredericksburg, VA 22406

Carlson, P.J., J.D. Miles, M.P. Pratt, and A.M. Pike (2005) "Evaluation of Wet-Weather Pavement Markings: First Year Report". Report 0-5008-1. Texas Transportation Institute, College Station, Texas, 2005. http://tti.tamu.edu/documents/0-5008-1.pdf. Last visited: January 2007

CHP (2005), "Definitions: Cochrane Health Promotion and Public Health Field", http://www.vichealth.vic.gov.au/cochrane/overview/definitions.htm. Last visited: October 2005

DOT (2007a); United States Department of Transportation Bureau of Transportation Statistics, Table 1-32: U.S. Vehicle-Miles, http://www.bts.gov/publications/national_transportation_statistics/2005/html/table_01_32.html, Last visited: January 2007

DOT (2007b) United States Department of Transportation Bureau of Transportation Statistics, Table 2-1: Transportation Fatalities by Mode, http://www.bts.gov/publications/national_transportation_statistics/2005/html/table_01_32.html, Last visited: January 2007

Filcek, M.J., V. Oulevski, J.G. Morena, D.C. Long, and T.L. Maleck (2004) "Development of a Profiled Pavement Marking System: Investigation of the Dry/Wet-Night Retroreflectivity and Durability of Pavement Markings Placed in Milled Rumble Strip" Paper presented at the Transportation Research Board 83rd Annual Meeting, January 2004.

FHWA (2003) "Federal Highway Administration", http://www.fhwa.dot.gov/ Last Visited: June 2003

FHWA Resource Center (2006) "Rumble Strips", http://www.fhwa.dot.gov/resourcecenter/teams/safety/safe_8rum.cfm, Last visited: January 2007

FHWA (2007a), "Rumble Strips", Federal Highway Administration, Safety & Design Team, http://www.fhwa.dot.gov/resourcecenter/teams/safety/safe_8rum.cfm, Last visited: January 2007

FHWA (2007b), "Safety , Rumble Strips" http://safety.fhwa.dot.gov/roadway_dept/rumble/index.htm, Last visited: January 2007

FHWA (2007c) Safety "Rumble Strip Policy", http://safety.fhwa.dot.gov/roadway_dept/rumble/rumble53001.htm, Last visited: January 2007

Glemberg, A., Andrzejewskim M., (1996) "Learning from Data- An Introduction to Statistical Reasoning", Taulor & Francis Group, New York, NY, 1996

MDOT, (2006) "Mississippi Department of Transportation Mission", MDOT, Retrieved February 2006, from: http://www.mdot.state.ms.us/facts/mission.htm

MDOT Planning Division, (2006) "Planning Division", MDOT, Retrieved February 2006, from: http://www.mdot.state.ms.us/facts/divisions/planning.htm

MDOT Traffic Engineering Division, (2006) "Traffic Engineering Division", MDOT, Retrieved February 2006, from: http://www.mdot.state.ms.us/facts/divisions/traffic_engineering.htm

NHTSA (2006) "National Highway Traffic Safety Administration", http://www.nhtsa.dot.gov/ Last Visited: June 2006.

Mohan, S.B., & Gautam, P., (2002) "Cost of Highway Work Zone Injuries", Practice Periodical on Structural Design and Construction, Volume 7, Issue 2, pp 68-73. May 2002.

Morena, D. (2003), "Rumbling Toward Safety", Public Roads, FHWA, http://www.tfhrc.gov/pubrds/03sep/06.htm, Last visited: January 2007

NCHRP (2005), "Syntheis 339 - Centerline Rumble Strips", National Cooperative Highway Research Program, Washington, D.C, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_339.pdf, Last visited: January 2007

Peck, R., Healey, E. (2009), "Accident Costs and Benefit Cost Analysis" , http://www.dmv.ca.gov/about/profile/rd/resnotes/accident.htm . Last visited: January 2009.

Public Roads (2004) "Building Safe Roads" , John R. Baxter, http://www.tfhrc.gov/pubrds/04may/04.htm, Last visited: January 2007.

Public Roads (2005) "Preventing Roadway Departures", Harry W. Taylor, http://www.tfhrc.gov/pubrds/05jul/03.htm, Last visited: January 2007

Safe Roads (2003) "Safe Roads for Road Workers", http://www.saferoadsforworkers.org, Last visited: June 2003

SPSS, "Descriptive and Inferential Statistics, (2006) http://www.utexas.edu/its/rc/tutorials/stat/spss/spss2/#Inferential, Last visited: September 2006

SPSS, 2008 " The Predictive Analytics Company" http://www.spss.com/ ", Last visited: July 2008

State of Missouri (2007), "Highway Safety Plan & Performance Plan", MODOT Highway Safety Division, Jefferson City, MO

StatSoft, (2006) "Basic Statistics", http://www.statsoft.com/textbook/stbasic.html#Descriptive%20statisticsb, Last visited: September 2006

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

TRB-RiP 2007a, "Application and Evaluation of Centerline Rumble Strips in Nevada", Transportation Research Board – Research in Progress, http://rip.trb.org/browse/dproject.asp?n=8802, Last visited: January 2007

TRB-RiP 2007b, "Guidelines for Center-of-Lane and Shoulder Rumble Strips on Two-Lane Rural Highways", Transportation Research Board – Research in Progress, http://rip.trb.org/browse/dproject.asp?n=4529, Last visited: January 2007

TRB-RiP 2007c, "Evaluation of the Effectiveness of Pavement Rumble Strips", Transportation Research Board – Research in Progress, http://rip.trb.org/browse/dproject.asp?n=12384, Last visited: January 2007.

Trochim W, Cornell University, Research Methods Knowledge Base. http://www.socialresearchmethods.net/kb/statdesc.htm. Last visited: September 2006.

Wikipedia 2006. "Statistics" http://en.wikipedia.org/wiki/Statistic. Last Visited: Dec 2006.

Willis, J. and W. Dean. (2004) Mississippi's Rumble Stripe Experience. Presentation at the Transportation Research Board 83rd Annual Meeting, January 2004. http://tcd.tamu.edu/documents/rumble/rumble1.htm, Last visited: January 2007