Evaluation of Geometric and Operational Characteristics Affecting the Safety of Six-Lane Divided Roadways

Final Report

Project No. BD 543 RPWO 5

Theodore A. Petritsch, P.E.
Srikalyan Challa, E.I.
Herman F. Huang, Ph.D.
Sprinkle Consulting, Inc.
18115 U.S. Highway 41 North, Suite 600
Lutz, Florida 33549

Renatus Mussa, Ph.D., P.E.
Department of Civil Engineering
FAMU-FSU College of Engineering
2525 Pottsdamer Street, Room 129
Tallahassee, FL 32310

January 2007

DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

METRIC CONVERSION FACTORS

1 ft = 0.3048 m
1 mph = 1.609 km/h

TECHINICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Geometric and Operational Characteristics Affecting the Safety of Six-Lane Divided Roadways		5. Report Date January 2007
		6. Performing Organization Code
7. Author(s) Theodore Petritsch, Srikalyan Challa, Herman Huang, and Renatus Mussa		8. Performing Organization Report No.
9. Performing Organization Name and Address Sprinkle Consulting, Inc. 18115 U.S. Highway 41 North, Suite 600 Lutz, Florida 33549		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. BD-543
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee St. MS 30 Tallahassee, Florida 32399 (850)414-4615		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes Prepared in cooperation with the USDOT and FHWA		

16. Abstract

The overall objective of this project was to evaluate roadway and operational factors influencing the high injury and fatality rates on six-lane divided roadways in Florida. To accomplish this objective, data from the FDOT crash database, the Roadway Characteristics Inventory, FDOT videologs, and field studies were analyzed. Although four-lane roadways had more crashes than six-lane roadways in terms of percentages, six-lane roadways had higher crash, fatality, and injury rates based on many environmental and geometric factors. The Spearman and chi-square tests showed that, based on a number of geometric and traffic variables, the distribution of crashes on four-lane and six-lane highways were not significantly different. Zero-inflated negative binomial models were used to model crash rates according to three levels of severity: (1) fatal and severe injury, (2) non-incapacitating and possible injury, and (3) property damage only. Increases in the number of signals per miles and the number of driveways per mile increased the crash rate. Increases in inside shoulder width, horizontal degree of curvature, outside shoulder width, median width, and surface width all reduced the crash rate. Based on the results of this research, the researchers strongly endorse FDOT's efforts to enforce its standards, especially with regard to median width, shoulder width, and access management.

17. Key Word Safety analysis, crash modeling, highway safety.		18. Distribution Statement No restrictions	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8_72)

ACKNOWLEDGMENTS

The authors wish to acknowledge the support and assistance of project manager Patrick Brady of the FDOT Safety Office.

EXECUTIVE SUMMARY

Problem Statement

In an effort to determine those factors influencing the crash rates on Florida's roadways, the Florida Department of Transportation State Safety Office reviews and analyzes the crash trends on the state highway system. One such review revealed that six-or more lane, non-limited access roadways have the highest fatality rate (fatalities/million vehicle miles traveled) of all FDOT roadways. In 1998, six- or more lane divided highways had a 25% higher fatality rate than four-lane divided highways. By 2001, six-lane sections had 32% to 48% higher fatality rates than four-lane divided highways, depending on urban, suburban, or rural location. This difference in the crash rate is hypothesized to be caused by differences in geometrics and traffic characteristics between six- and four-lane highways.

Objectives

The main goal of this project was to improve the safety of six-lane divided roadways in the State of Florida by mitigating the high crash rates on these roadways as compared to four-lane divided roadways. To attain this goal, the overall objective of this project was to evaluate roadway and operational factors influencing the high injury and fatality rates on six-lane divided roadways. Detailed analysis of geometric and traffic data collected from various databases – the FDOT crash database, the Roadway Characteristics Inventory, and FDOT videologs – and in the field was undertaken to establish the correlation between these factors and injury and fatal crashes. The major outcome of this research project was expected to be the development of roadway safety models that can be used by planners, designers, and engineers to improve highway design and maintenance in order to promote safety of six-lane divided roadways. To achieve these objectives, the following tasks were performed:

1. Review of literature review (Chapter 2)
2. Collection of background data (Chapter 3)
3. Comparison of four-lane and six-lane crashes (Chapter 4)
4. Development of crash rate models for six-lane highways (Chapter 5)

Findings

A review of previous studies revealed that as the value of the following variables increases, the probability of a crash also increases: (1) Number of lanes, (2) AADT, (3) section length, (4) access density, and (5) standard deviation of speed. The presence of heavy vehicles and intersections at-grade also increased the probability of a crash. On the other hand, as the value of the following variables increases, the probability of a crash decreases: (1) Shoulder width, (2) median width, (3) pavement condition index, (4) lane width, (5) speed, and (6) roadway curvature.

Descriptive statistics showed that four-lane sections had more crashes than six-lane sections in terms of percentages. But six-lane sections had higher crash, fatality and injury rates compared to four-lane sections on many environmental, weather, and geometric factors. The findings revealed that differences in geometry brought about by increasing number of lanes resulted in different crash history between four-lane and six-lane roadways. The Spearman and Pearson chi-square tests found that, based on a number of roadway and traffic features, the distribution of crashes occurring on four-lane and six-lane roadways was not significantly different.

Zero-inflated negative binomial models were used to model crash rates according to three levels of severity: (1) fatal and severe injury, (2) non-incapacitating and possible injury, and (3) property damage only. The models showed that crash rates were affected by a variety of geometric and operational variables. Two variables—signals per mile and inside shoulder width—were present in all three models. In all three models, an increase in the number of signals per mile increased the crash rate. An increase in the inside shoulder width reduced the crash rate. Horizontal degree of curvature was present in both the non-incapacitating/possible injury and property damage only models; an increase in horizontal degree of curvature reduced the crash rate. The total number of driveways per mile was present in both the non-incapacitating/possible injury and property damage only models; an increase in the number of driveways per mile increased the crash rate. Outside shoulder width was present in these two models as well; an increase in the outside shoulder width reduced the crash rate. Median width and surface width were present in the property damage only model; increases in the median width or the surface width reduced the crash rate.

The implications of the models for FDOT include the following:

1. *Horizontal degree of curvature* – The observed effect of increased horizontal degree of curvature on reducing crash rates suggests that horizontal curves should not be automatically removed or flattened when reconstructing roadways. In some cases, the addition of gentle curves (approximately up to 4^0) in the design of arterial roadways may reduce the observed crash rates on six-lane highways. It should be noted that the trend of reducing crashes with respect to increasing degree of curvature was observed as significant for PDO and non-incapacitating injury crashes. With regard to incapacitating and fatal crashes a slight positive (increasing curvature results in increasing crash rates) relationship was found. While this correlation was not found to be significant, and the term could have been left out of the incapacitating and fatal injury crash model, it was included in the proposed model to make reviewers aware of a potential undesirable correlation. It could also be hypothesized that although a crash is less likely on a curved roadway, once a crash occurs it has a higher potential for being fatal.
2. *Median width* – The results strongly support FDOT's median width policy. The researchers strongly endorse FDOT's efforts to implement the median width requirements on all new roadways.
3. *Shoulder width and inside shoulder width* – The results support FDOT's shoulder width policy. The researchers strongly endorse FDOT's efforts to implement the shoulder width requirements on all new roadways.
4. *Surface width* – The results support FDOT's current lane width standards (instead of narrower widths).
5. *Signals per mile and driveways per mile* – The results support FDOT's access management standards. The researchers acknowledge that FDOT must balance safety with the access needs of residents and businesses. Nevertheless, the researchers strongly endorse FDOT's efforts to enforce its access management policies when considering applications for new driveway connections and signalized intersections.

Conclusions

The results of this research strongly support FDOT's standards, as stated in the Plans Preparation Manual and the State Highway Access Management Classification System and Standards. The information obtained by this research will help designers make decisions on what roadway treatments may be appropriate and under what conditions. Although FDOT has comprehensive design and operational standards, these standards provide some flexibility to individual designers / engineers. In some cases, this flexibility is required to address right-of-way or environmental constraints. At other times, the flexibility allows for the accommodation of local community preferences. Additionally, various designers / engineers may apply the standards differently from each other. However, the researchers strongly recommend that FDOT weigh the advantages of granting exceptions to the standards against the potential for reduced safety. By implementing the results of this research, FDOT will be able to continue to provide for the roadway capacity needs of Florida while maintaining or improving the safety of its roadways.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 Overview

Numerous researches on traffic crash occurrence and avoidance have been conducted. The research questions are targeted at issues such as designing a roadway which can totally eliminate traffic crashes, whether crashes are predictable, and if there is a relationship between a crash and geometrics or traffic operations. In answering these research questions, different researchers have tried to find a relationship between highway geometrics/traffic characteristics with highway crashes. These relationships are based on crash prediction models. A crash prediction model is a statistical approach which links crash frequency or rate as a response variable with highway geometrics and traffic data as independent variables.

In recent years, analysis has shown six-lane highways having higher crash rates when compared to four-lane sections in the State of Florida. This difference in the crash rate is hypothesized to be caused by differences in geometrics and traffic characteristics on six-lane highways compared to four-lane sections. The main goal of this study was therefore to improve the safety of six-lane divided roadways in the State of Florida by mitigating the high crash rates on the roadways. The goal was to be achieved by evaluating the roadway and operational factors influencing the crash frequency on six-lane divided roadways. The detailed analysis of geometric and traffic data from various databases and in the field was undertaken in order to establish correlation between these factors and crash frequency. These factors are used to build the crash prediction model, which can be used by planners, designers, and engineers to improve highway design and maintenance in order to promote the safety of six-lane divided roadways.

1.2 Scope and Methodology

In undertaking this study, a comprehensive review of literature was done to uncover previous research, both published and unpublished studies. Both the Florida State University (FSU) library and other external libraries were used to search for appropriate literature. More than seventy texts, reports and articles on crash prediction and modeling were found and most of them are summarized in the reference section. The external libraries utilized in this study were TRIS, NTIS, Elsevier Science, TRRL and other website search engines. Findings from the literature review are found in chapter two of this report.

Crash data and roadway geometrics were acquired from the Florida Department of Transportation (FDOT). Through the Virtual Private Network (VPN) and by using FDOT INFONET, we were able to access the Roadway Characteristic Inventory (RCI), crash data information, and video logs of six-lane divided roadways categorized as urban (456 miles) and suburban (66 miles). Additional collected data included pavement condition in terms of the international roughness index and rutting rate. Through straight line diagrams (SLD) and video logs, access points were counted and variables verified. The STATA program was used for combining crashes with RCI and also for section segmentations.

All variables used in this study are also discussed in detail. Discussion is based on the criteria used to select desired variables among the others. Furthermore, the frequencies of those variables with respect to the total number of sections present and with respect to crash frequency are discussed. The scatter plots of the variables with crashes were also done for each variable in order to show their distribution and trends.

A review of crashes occurring on four-lane roadways was conducted for the purpose of comparing various attributes of these crashes to those pertaining to six-lane roadway crashes. The main intention of comparative analysis was to find problematic factors of six-lane highways and compare their effects on four-lane sections. Through RCI and the crash database, a comparison of four-lane and six-lane crashes was conducted in terms of descriptive statistics without undertaking inferential statistics. By using roadway geometrics, pavement and environmental conditions, crash contributing factors and traffic characteristics, descriptive analysis was done in terms of the crash rate between four-lane and six-lane roadways.

The choice of appropriate distribution was selected based on statistical tests. This involved different statistical tests and observations before concluding appropriate distribution. Also completed in this study is the analysis of data which led to the relationship between roadway geometrics and operational features and crash frequencies of the sampled roadway segments. This includes determining the statistical significance between independent and response variables. Various statistical techniques were used to rank the significance of geometric and operational variables in influencing crashes. A number of hypotheses were tested and this led to the development of the final model. The main feature from this section is the "crash prediction model" developed through regression analysis. This crash prediction model will be able to make a quantitative estimate of crash frequency for given various independent geometric and traffic variables. At the end, the crash prediction model is developed. Also discussed are the different techniques which lead to dropping some variables from the model due to insignificancy or collinearity. Findings from the model and the effect of each variable are described. Lastly, the conclusion and recommendations are given in the final chapter of this report.

CHAPTER 2 LITERATURE REVIEW FINDINGS

2.1 Purpose and Scope

A comprehensive search of literature was undertaken to uncover both published and unpublished reports on previous efforts related to studying geometric factors affecting safety and operations on six-lane roadways. Resources at the Florida State University were used in the search. The resources included library holdings, databases, and gateway services. Through FSU libraries, external database services such as *TRIS*, *NTIS*, *Elsevier Science*, *TRRL*, and *OECD* were accessed. The collection of information related to the important modeling variables was achieved through review of past highway safety modeling results and the review of variables contained in the Roadway Characteristics Inventory (RCI) variables contained in the RCI database maintained by the Florida Department of Transportation. Since sufficient information related to the modeling variables was obtained through this process, survey of practices to the 50 states was not conducted as initially planned. The following sections describe the results of the review of the modeling variables.

2.2 Response Variables

The review of crash models reported in the literature revealed that the crash rate and crash frequency are commonly used as dependent (or response) variables. The crash rate is a measure of exposure as it is related to the vehicle miles of travel. Since the number of crashes is generally low on highway sections, the crash rate is calculated per million or 100 million vehicle miles of travel. The use of the crash rate as the response variable causes the volume of traffic and section length not to be treated as independent variables. If volume and section length have to be considered as independent variables, the crash frequency should then be considered as a response variable and not a crash rate. Furthermore, the literature review revealed that even when the crash frequency is used as a dependent variable, the crashes are disaggregated into injury category (*i.e.*, fatal crashes, injury crashes, and property damage only [PDO] crashes) and modeled separately. Generally, the disaggregation is done by researchers when building models designed to investigate the influence of operating speed and other traffic variables on safety. Another important issue in deciding on the response variable is the time frame of the analysis. To avoid regression-to-the-mean phenomenon, the use of multi-year crash data is suggested. However, the modeler has to be careful that most of the independent variables (discussed below) must have remained the same during those years; otherwise, the modeling should consider different years independently.

2.3 Independent Variables

2.3.1 Lane Width

The effect of lane width has been discussed in various studies. The link between lane width and safety stands on two principles. The first is that the wider the lanes, the larger the average separation will be between vehicles moving in adjacent lanes. The second strand in the link between safety and lane width is that a wider lane may provide more room for correction in near-crash circumstances. Hence, for a narrow lane, a moment's inattention may lead a vehicle off the edge-drop and onto a shoulder; however, if the lane is wider and the shoulder paved, the same inattention will still leave the vehicle on the paved surface. In these near-crash circumstances, it was difficult to distinguish the effects of lane width, shoulder width, shoulder paving, edge-drops etc. Different studies have drawn contradictory conclusions on the effect of lane width. Noland and Oh (2004) found that the increase in lane width had no statistically significant effect on the crash rate, but Abdel-Aty and Radwan (2000) found that narrow lane width, narrow shoulder width and reduced median width resulted in significant increases in the crash rate. On the other hand, Hadi *et al*. (1995) found that increasing the lane width to 12-13 ft depending on the highway type is estimated to reduce crash rates for urban freeways and undivided highways while Karlaftis *et al.* (2002) found that lane width, pavement condition, pavement type and pavement friction are the most important variables affecting crash rates on two-lane highways. In another study done by Harwood *et al* (2000), they developed base models and accident modification factors (AMF). One of the factors was on lane width in which a factor of 1.15 was used to project the crash rates on roadways with 11-ft lane widths compared to roadways with 12-ft lane widths. This meant that the crash rates on highways with 11-ft lanes were higher by 15% compared to highways with 12-ft lanes.

2.3.2 Number of Lanes

The number of lanes is another variable which has been discussed in detail by various researchers. Almost all studies do conclude that the higher the number of lanes, the higher the crash rate. In their research, Noland and Oh (2004) found that increasing the number of lanes was associated with increased traffic crashes. In another study, Abdel-Aty and Radwan (2000) found that more lanes in urban roadway sections are associated with higher crash rates. Garber (2000) considered flow per lane and found that there was an increase in the crash rate as the flow per lane increased. Evidence of the effect of the number of lanes can be seen when a study is done on the conversion of a two-lane, two-way roadway to four or six lanes. With such studies, most have shown an increase in the crash rate. A study by Hadi *et al.* (1995) developed negative binomial regression models to estimate the influence of cross-sectional elements on different highway types including freeways, two-lane highways, and multi-lane highways. Of interest in this review were the model result differences between four-lane urban divided roadways and six-lane urban divided roadways. The general comparison of the models indicated that higher AADT levels resulted in higher crash rates for urban divided highways. In addition, the models suggested that the safety benefits of increasing median width were more on six-lane urban highways than on four-lane urban highways. In addition, the models showed that the effect of intersection density on crash rates was more pronounced on four-lane divided highways than on six-lane divided highways.

2.3.3 Median Width and Type

The primary function of the median is to separate the opposing traffic streams. It also provides a recovery area for out-of-control vehicles, a place where vehicles can stop in emergencies, and it allows for the accommodation of left-turn lanes and of openings for left or U-turn maneuvers. A study by Hadi *et al*. (1995) evaluating median types found that the safety of the median type decreased in the following order: flush unpaved, raised curb, crossover resistance, and two way left turn lane (TWLTL). Wider medians also seem superior to narrow medians plus a physical barrier, since the latter can only be effective if vehicles actually collide with them. Another study (Sawalha and Sayed, 2001) found that type of median and nature of land use affect crash rate significantly. Harwood (1986) evaluated various design alternatives including the following: 2-lane undivided; 2-lane with continuous two way left turn lane; 4-lane undivided; 4-lane with raised median; 4-lane with continuous two way left turn lane; 4-lane with continuous alternating left turn lane; 6-lane with raised median; and 6-lane with continuous two way left turn lane. Harwood indicated that one advantage of the 6-lane with raised median design over the 4-lane design is that the additional roadway width provides a more generous turning radius for vehicles to make U-turns at signalized intersections to complete midblock left-turn maneuvers that are prevented by the median. Abdel-Aty and Radwan (2000) found that narrow lane width, narrow shoulder width, and reduced median width resulted in significant increases in crash frequency.

2.3.4 Shoulder Width and Type

There are several purposes for providing shoulders along the highway. These include accommodating stopped vehicles so that they do not encroach on the traveled lane, facilitating maintenance work, facilitating access by emergency vehicles and protection of the structural integrity of the pavement. In general, the main purpose of paving shoulders is to protect the road structure from being weakened by water, to protect the shoulder from erosion by stray vehicles and to enhance controllability of stray vehicles. The shoulder also provides a fairly even and obstacle- free surface where drivers of stray vehicles can regain control, recover from error, and resume normal travel. The effect of shoulder width and type has been pointed out by different studies as an important aspect in crash frequency. The effects of shoulder width and shoulder paving material go hand-in-hand with lane width, and road side events.

Researchers generally agree that the effect of shoulder width on safety is confounded with the effect of lane width and thus these two variables are generally modeled together. Zegeer *et al*. (1994) found that the presence of a shoulder is associated with a significant crash reduction for lane widths of 10 ft or wider while for 10-ft lanes, a shoulder of 5 ft or greater was found to affect the crash rate significantly. For 11- and 12-ft lanes, shoulders of 3 ft or greater were associated with significant crash reductions. Another significant result was reported by Ivan *et al.* (1999) in which the shoulder width model coefficient was negative for predicting single vehicle crashes but was positive for predicting multi-vehicle crashes. A positive coefficient signifies an increase in the number of crashes as the shoulder width increases, while a negative coefficient signifies a decrease in the number of crashes as the shoulder width increases. Abdel-Aty and Radwan (2000) study found that narrow shoulder width increases the fatality and injury rate compared to wider shoulder width. Harwood *et al*. (2000) introduced the accident modification factor, which is based on the shoulder width to predict the crash rate at roadways with different shoulder widths.

2.3.5 Access Density and Number of Signalized Intersections

Access density refers mainly to the number of driveways within a roadway segment. This term can also be linked with the number of signalization intersections within a specified roadway section. Consideration of intersection spacing is traditionally governed by considerations of delay, signal timing, and signal co-ordination. The safety impact of increased traffic signal spacing is obscured by the traffic volume on intersecting roadways and by vehicle miles of travel. Access density is one of the factors which has been pointed out as the determinant of crash rates on the highways. One study done in New Jersey (Mouskos *et al.*, 1999) on the impact of access driveways on crash rates for multilane highways found that approximately 30% of the reported crashes were in mid-block sections and were caused by the presence of access points.

Another finding in this study was that approximately 25% of the entering/exiting vehicles from/to access points have impact on mainline traffic. Karlaftis *et al.* (2002) found that for rural multilane roads, median width and access control were the most important factors followed by the influence of pavement conditions in the crash. Some empirical evidence suggests that the crash rate increases linearly with access density, but some found that the increase may be nonlinear. Mouskos *et al*. (1999) found that access density and intersection spacing had positive and significant coefficients. Positive coefficients signify increases in the crash rate as the access density or intersection spacing increases. In another study (Ivan *et al.*, 1999), it was found that for multi-vehicle crashes, the most important predictor variables were the class of roadway, number of signals and daily single-unit truck percentage. Collectively, these studies suggest that frequent access points, median openings, and closely spaced traffic signals are a recipe for congestion on major roadways with its attendant consequences on safety. Research results deviate from each other on the level of impact of the number of access points on crash rates. The model developed by Gluck *et al.* (1999) suggests that an increase from 10 access points to 20 access points per mile would increase crash rates by roughly 30 percent. Papayannoulis *et al.* (1999) related traffic safety to access point spacing, and presented results from eight states. They found that most studies show an increase in accidents as a result of the increase in number of driveways. The study suggested that a road with 60 access points per mile would have triple the crash rate compared to 10 access points per mile.

2.3.6 Speed and Standard Deviation of Speed

Previous studies have taken account of the speed variable in crash modeling in various forms including posted speed limit, design speed, speed variance, 85th percentile speed, average speed, and actual involvement speed. In analyzing crashes in Virginia, Garber and Gadiraju (1999) reported that crash rates increased with increasing speed variance on all types of roadways and that speeds were higher on roads with higher design speeds, irrespective of the posted speed limits. The authors reported minimal variance when the posted speed limit was less than 10 mph below the design speed of the road. The limitation of the study is that the researchers combined data from different road types – *e.g.,* rural two-lane, urban freeway, and rural freeway – the results of which might not necessarily be replicated when considering six-lane urban roadways only. Furthermore, Garber (2000) found that the crash rate increases as the mean speed deviates from the posted speed limit. The crash rates were higher when the mean speed was less than the posted speed. The crash rates decreased to a minimum when the means were approximately equal to the posted speed limit; crash rates then continued to increase significantly as the speed increases above the posted speed limit. For a given standard deviation of speed, the crash rate decreased as the flow per lane increased to approximately 1,200 vehicles per hour after which the crash rate began to increase with the flow rate.

2.3.7 Section Length

The importance of section length in a crash prediction model is generally revealed when the crash rate or crash frequency per mile is calculated. Shorter section lengths can sometimes result in higher crash rates that might affect the validity of crash prediction models. On the other hand, longer section lengths can lead to unrealistic prediction of crashes especially if the uniformity of the sections in geometrics and other variables is not controlled. The literature review revealed some suggestions of reasonable section lengths for use in modeling. Tarso & Benekohal (1997), for example, suggested section lengths of at least 0.5 miles in modeling crash rates on rural interstate highways and two-lane rural highways. Furthermore, some researchers argue that if standardization of section lengths cannot be achieved, then separate models should be built in groups of similar section lengths. Qin *et al.* (2004) found a positive coefficient to section length when they modeled single-vehicle and multi-vehicle crashes. The positive coefficient signifies an increase in the number of crashes as the section length increases. Milton and Mannering (1998) found the coefficient of length as a variable to be positive which suggested shorter sections would be less likely to experience crashes than longer sections because of decreased exposure in terms of vehicle miles of travel (VMT).

2.3.8 Traffic Volume

Several studies have attempted to determine the variation in crash rates as they relate to hourly traffic volumes and traffic congestion. Traffic congestion occurs when the number of vehicles exceeds the capacity of a highway or road. In some literature, the effect of volume is associated with other aspects of traffic flow like speed, density, and flow. The literature indicates a direct relationship between traffic volume and the occurrence of traffic crashes. As the number of vehicles on a highway increases, the potential for conflicts within a traffic stream also increases. In addition, previous research has tended to quantify the influence of volume on multi-vehicle crashes and on severity of crashes. Qin *et al.* (2004) found that for single-vehicle crashes the marginal crash rate is high at low traffic volumes and low at high traffic volumes, probably because crashes are more likely to involve multiple vehicles at high traffic volumes. Zegeer *et al*. (1994) found that low-volume road crashes are affected primarily by roadway width, roadside hazard, terrain, and driveways per mile.

Martin (2002) found that incidence rates involving property damage only crashes and injury crashes in France are highest when traffic is lightest (under 400 vph) and the incidence rates are at their lowest when traffic flows at a rate of 1,000 to 1,500 vph. Hadi *et al.* (1995) found that sections with higher AADT levels are associated with higher crash frequencies for all highway types. Garber (2000) found that there is an increase in the crash rate as the flow per lane increased. Mouskos *et al.* (1999) found that as AADT increases the crash rate also increases. Milton and Mannering (1998) found positive coefficients of AADT in their model indicating that as the number of vehicles through a section increases, so does the number of crashes. They explained that as the number of vehicles increases through a section, the exposure to potential crashes and number of conflicts increases. The same finding about the effect of AADT on crash rates was also found by Aruldhas (1998), Sawalha (2003) and Poch and Mannering (1996).

2.3.9 Percentage Trucks and Traffic Mix

Apart from general independent variables, traffic mix has been studied in terms of percentage of heavy vehicles on the roadway and their effect on the crash rate. Hiselius (2004) estimated the relationship between crash frequency and the traffic flow by empirically treating the hourly traffic flow in two different ways: consisting of homogeneous vehicles and consisting of cars and trucks. He studied rural roads in Sweden using Poisson and negative binominal regression models. He found that important information is lost if no consideration is taken to differentiate between vehicle types when estimating the marginal effect of the traffic flow. The crash rate decreases when the traffic flow is treated as if it were homogeneous. However, when cars are studied separately the result suggests that the crash rate is constant or increases. The result with respect to trucks is reversed, indicating a decreasing number of accidents as the number of trucks increases. Miaou (1993) evaluated the performance of Poisson and negative binomial (NB) regression models in establishing the relationship between truck accidents and geometric design of road sections. He used the percentage of trucks as an independent variable in building the models. In all models, the trucks' percentage had a negative coefficient, meaning that as the percentage of trucks increased, there was a reduction in the number of crashes. Milton and Mannering (1998) used the percentage of single-unit trucks and the percentage of trucks as the variables in the crash prediction model. They found that an increase in the percentage of single-unit trucks tends to decrease crash frequency in Western Washington. Concerning the percentage of trucks, they found that it tends to decrease crash frequency in Eastern Washington.

2.3.10 Land Use

Location of the roadway has been considered separately in different studies. Various studies considered suburban, urban or rural areas separately and few of them investigated the three situations in the same model. Retting *et al.* (2001) studied a simple method for identifying and correcting crash problems on urban arterial streets in Washington, D.C. They found that urban crashes are often concentrated at specific locations and occur in patterns that can be mitigated through appropriate engineering countermeasures. In another study, Ossenbruggen *et al.* (2001) considered safety in rural and small urbanized areas. Comparative risk assessment showed village sites to be less hazardous than residential and shopping sites. Karlaftis and Golias (2002) investigated effects of road geometry and traffic volumes on rural roadway crash rates. They developed a methodology which allows for the explicit prediction of crash rates for given highway sections, as soon as a profile of a road is given. Greibe (2001) created crash prediction models for urban roads in which he found shopping streets and city center roads having significantly higher crash risk than, for example, residential roads in less densely built-up areas. He concluded that the lower the building density, the lower the crash risk.

2.4 Other Variables

Other variables which are found in different literature include sidewalks, grades, horizontal curvature, superelevation, pavement condition, and parking type. Miaou (1993) used horizontal degree of curvature, length of horizontal curvature and vertical grade as independent variables in truck crash prediction. He found that both horizontal curvature and percentage grade have positive coefficients, signifying that crashes increases as horizontal curvature or percentage grade increase. Greibe (2001) found that roads linked with parked motor vehicles along the roadside (at the curb) or in marked parking bays have the highest crash risk, particularly for crashes involving pedestrians, motor vehicles from driveways or minor side roads, and for parked vehicles. He also found that the road environment (type and function of buildings along the road) has a considerable influence on the crash risk, with shopping streets and city center roads having significantly higher crash risk than residential roads in less densely built-up areas. Milton and Mannering (1998) found that large horizontal curves tend to decrease crash frequency.

2.5 Facilities Modeled

It is clear that roadways of different functional classes will have different crash experiences with the experiences also being different between rural and urban areas for the same functional class. Similarly, it is evident that crashes occurring at intersections are influenced by independent variables which are mostly different from variables influencing crashes in sections or midblock. Some researchers developed separate models for highways of different functional classes and for intersections and sections. Some studies combine all roadways in a single model. As explained before, some studies use a dummy variable to indicate whether the section was in a rural or urban environment or whether the crash occurred at an intersection or midblock. Poch and Mannering (1996) used a negative binomial to model only intersection-related crashes in which the independent variables were left-turn and right-turn volumes, phase signals and intersection approach speeds. Mouskos *et al.* (1999) separated 4-lane and 2-lane roads into different models; they also separated models at the sections with and without shoulders. Greibe (2001) modeled only urban crashes. Harwood *et al.* (2000) did research on the safety performance of rural two-lane highways in which they developed base models and accident modification factors to account for different roadway geometrics. Persaud *et al*. (1997) studied the effect on crash reduction of traffic signal removal in Philadelphia.

2.6 Intersection-Related Crashes

Intersection-related crashes have been modeled separately or with particular attention compared to those which are non-intersection related. Greibe (2001) evaluated the influence of signal control on the total number of observed crashes. He found that the signal control variable was not significant in the model, which indicates that the expected total number of crashes is very similar for signalized and non-signalized junctions with the same flow function. With respect to different crash types, Greibe found that rear-end crashes are significantly higher at signalized junctions than at non-signalized junctions. Turner and Nicholson (1998) studied the role of intersection location and non-collision flows on intersection crash estimation. They found that intersection location affects the number of different crash types and that it is important to consider the interactions between turning flows. Retting *et al.* (2001) developed a countermeasure for individual intersection-based collisions. They proposed the implementation of safety-related operational and design changes along entire stretches of urban arterials, which include roadway widening, installation of two-way left-turn lanes, driveway elimination, street lightning improvements, installation of raised medians, and improved traffic signal coordination.

2.7 Choice of Crash Models

The literature suggests that there are two conditions that should be satisfied when developing crash prediction models [Miaou and Lump (1993); Cameroon and Trivedi (1998)]. The first condition is that the model must yield logical results, which means it must not lead to the prediction of a negative number of crashes and it must ensure a prediction of zero crash frequency for zero values. The second condition is that there must exist a known link function that can linearize this form for the purpose of coefficient estimation. The literature review revealed that Poisson and negative binomial distributions are often more appropriate for modeling discrete counts of events such as crashes which are likely to be zero or a small integer during a given time period. However, the Poisson distribution is more appropriate for modeling cross-sectional crash data that has equality between mean and variance – a phenomenon called equidispersion. In many crash modeling situations the data generally exhibits extra variation, resulting in variance being greater than the mean – a phenomenon known as overdispersion. A negative binomial model is well suited for this case.

2.7.1 Poisson and Negative Binomial

Miaou and Lump (1993) suggested the use of Poisson regression as an initial step in the modeling effort, with the negative binomial model then being applied where appropriate. For the Poisson regression model, the probability of section i having y_i crashes per year (where y_i is a non-negative integer) takes the following form (Cameroon and Trivedi, 1998), Washington *et al*., 2002):

$$P(y_i) = \frac{e^{-\mu_i} {\mu_i}^{y_i}}{y_i!} \qquad y_i = 0, 1, 2\ldots$$

The mean parameter is
$E[y_i / x_i] = \mu = \exp(x_i \beta)$, Variance =$\mu$,

where
y_i= a random variable representing number of crashes or crash rate
x_i= parameter which is related to the occurrence of a crash (vector of explanatory variables)
β= the coefficient of the corresponding factor (vector of estimable parameters)

The negative binomial (NB) regression takes the following form (Cameroon and Trivedi, 1998):

$$f(y/\mu,\alpha) = \frac{\Gamma(y+\alpha^{-1})}{\Gamma(y+1)\Gamma(\alpha^{-1})}\left[\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right]^{\alpha^{-1}}\left[\frac{\mu}{\alpha^{-1}+\mu}\right]^{y}, \text{ y= 0, 1, 2}$$

If α=0 means the mean is concentrated in the point, then it reduces to a Poisson distribution.
The mean parameter is
$\mu = E(Y_i) = \left[e^{x'_i \beta}\right]$

The variance of y_i is

$Var(y_i) = \mu_i + \alpha\mu_i^2$

where
α= overdispersion parameter

The appropriateness of the negative binomial relative to the Poisson model is determined by the statistical significance of the estimated coefficient, α. If α is not significantly different from zero, the negative binomial model simply reduces to the Poisson model. If α is significantly different from zero, the negative binomial is the correct choice and Poisson becomes inappropriate (Poch and Mannering, 1996).

Apart from the parameter α, the decision of whether to use a Poisson or negative binomial is also based on the dispersion parameter, σ_d by the Poisson error structure (Sawalha, 2003), $\sigma_d = \frac{Pearson\chi^2}{n-p}$,where n is the number of observations, p is the number of model parameters, and $Pearson\chi^2$ is defined as $Pearson\chi^2 = \sum_{i=1}^{n} \frac{\lfloor y_i - \hat{E}(y_i) \rfloor^2}{Var(y_i)}$, where y_i is the observed number of crashes on section i, $E(Y_i)$ is the predicted crash frequency for section i, and $Var(y_i)$ is the variance of crash frequency for section i. If σ_d turns out to be significantly greater than 1.0, then the data has greater dispersion than is explained by the Poisson distribution, and the negative binomial regression model is fitted to the data (Sawalha, 2003).

2.7.2 Zero Inflated Poisson and Negative Binomial Regression Models

This is a kind of distribution which is used to model excessive zero count models. The zero count may refer to the situations where the likelihood of an event occurring is extremely rare in comparison to the normal count (Cameroon and Trivedi , 1998; Washington *et al.*, 2002; Lee and Mannering, 2000). The phenomenon of zero-inflated counting has been addressed as Zero Inflated Poisson (ZIP) and Zero Inflated Negative Binomial (ZINB) regression models.

For the ZIP model, it assumes that the events y_I = (y_1, y_2…..y_N) are independent and the model is $\Pr[y_i = 0] = \varphi_i + (1-\varphi_i)e^{-\mu_i}$

$\Pr[y_i = r] = (1-\varphi)\frac{e^{-\mu_i}\mu_i^r}{r!}$, r=1, 2… n

where
φ=proportion of zeroes.
Maximum likelihood estimates are used to estimate the parameters of the ZIP regression model and confidence intervals are constructed by likelihood ratio tests.

The ZINB regression model follows a similar formulation:

$$P(y_i=0) = \varphi_i + (1-\varphi_i)\left[\frac{\frac{1}{\alpha}}{(\frac{1}{\alpha}) + \mu_i}\right]^{\frac{1}{\alpha}}$$

$$P(y_i=r) = (1-\varphi_i)\left[\frac{\Gamma((\frac{1}{\alpha})+r)\lambda_i^{\frac{1}{\alpha}}(1-\lambda_i)^r}{\Gamma(\frac{1}{\alpha})r!}\right], \; r=1, 2, 3\ldots, n$$

where $\lambda_i = \frac{(1/\alpha)}{[(1/\alpha)+\mu_i]}$.

Maximum likelihood methods are again used to estimate the parameters of ZINB regression model. Furthermore we can test the appropriateness of using the zero inflated model rather than the traditional model, Poisson or negative binomial.

The test statistic is calculated as follows.

$$m_i = \ln\left\{\frac{f_1(y_i / X_i)}{f_2(y_i / X_i)}\right\}$$, where "ln" is a natural logarithm

where

$f_1(yi/Xi)$ is the probability density function for model1, say Zero-Inflated Negative Binomial, ZINB

$f_2(y_i/X\mathrm{i})$ is the probability density for model2, say standard negative binomial, NB

$$V = \frac{\sqrt{n}\left(\overline{m}\right)}{S_m}$$

Where

$$\overline{m} = Mean = \left[(1/n)\sum_{i=1}^{n} m_i\right]$$

S_m= standard deviation

n = sample size

V= Vuong's Value

If Absolute(V)<$V_{critical}$(1.96 for 95% confidence interval), the test does not support the selection of one model over the other. Large positive values of V greater than $V_{critical,}$ e.g. V> $V_{critical}$ favor model1 over model2 whereas large negative values support model2.

2.8 Model Validation

Researchers generally build crash prediction models using dataset that is different from data used to validate the model prediction capabilities. Several tests are generally used to gauge the validity of the fitted model (Greibe, 2001). The first test involves checking the validity of the assumed distribution of the response variable. At this stage, normality is tested on the deviance residuals, using the Shapiro-Wilk test. The second test involves using a graphical technique that plots the absolute residuals verses the fitted values. The third type of validation is by plotting both observed and predicted responses on the same graph, then checking the variations in the trends and values of the two responses.

2.9 Significance of Variables

Apart from the effect of lane width, which different studies have given contradictory conclusions in terms of its effect on the crash rate, all other variables have been found to either increase or decrease the crash rate. The magnitude of the effect of individual variables depends on the response variable in the target. The significance of the variable in the model is determined in several ways. First, it is determined by looking to the sign of the coefficient of the variable in the model. If the coefficient is positive, this means that an increase in the measure of this variable will increase the response variable in the target. If the coefficient variable is negative, then an increase in the measure of the variable is associated with a reduction in response variable. The value of the coefficient also can be used to determine if it increases or reduces the crash rate by calculating the incident rate ratio (IRR): if the IRR is significantly less than 1.0, then an increase in the value of that variable is associated with a reduction in the total number of crashes. Similarly, if the IRR is significantly greater than 1.0, then this variable increases the crash rate or frequency. If the IRR is not significantly different than 1.0, then the variable is insignificant or has no effect on the crash rate. Another way of identifying the effect of the variable on the model is by looking at the *p*-value. The default of most modeling software tests the effect of the variable based on a 95% significance level, meaning that any variable with a *p*-value less than or equal to 0.05(5%) is said to be significant. The *p*-value answers the hypothesis that the coefficient of the variable is zero (has no effect on the response variable). If the *p*-value is less than 5%, then we are confident for more than 95% that the variable has an effect on the response variable.

2.10 Summary

The results of literature discussed above revealed that some variables tend to be positively correlated with occurrence of crashes while other variables tend to be negatively correlated with crash occurrences. The results suggest that the number of lanes, AADT, section length, access density and the standard deviation of the speed seem to be the variables that frequently have positive coefficients in crash prediction models. When an independent variable in a crash prediction model has a positive coefficient, the probability of crashes increase with the increase in value of the variable. The variables that seem to be negatively correlated with crash occurrences include shoulder width, median width, pavement conditions, lane width and operating speed. The results revealed by the literature search will be used in analyzing the difference in crash occurrences on four-lane and six-lane roadways as well as building of crash prediction models for six-lane roadways.

CHAPTER 3 COLLECTING BACKGROUND DATA

3.1 Introduction

The following sections describe in detail the methodology used to capture crash and geometric data from Florida Department of Transportation (FDOT) for this study. The study used databases which have been created and maintained by the Safety Office within FDOT to capture crash, traffic and roadway geometric data. The data for all of the counties was obtained and entered into a unified database. To limit preliminary data needs, we originally planned to use data from eight counties (Alachua, Duval, Broward, Leon, Miami Dade, Seminole, Walton and Volusia) to build the preliminary base model, and to use data for other counties for model modification and validation. Since data were obtained more quickly than expected, we used a randomly selected 80% of statewide data for the model development portion of effort; 20% of the dataset was used to validate the models developed in this effort.

3.2 Databases Used

The crash and roadway geometrics were acquired from FDOT databases on the FDOT's mainframe computer. The databases were accessed through the server called Virtual Private Network (VPN), which is a private network system allowing remote access to state-maintained information like the Florida DOT database. FDOT has a database called Crash Analysis Reporting (CAR) which has different components including crash data stored in different categories and attributes, roadway characteristics inventory (RCI), skid resistance information and other administrative information. As our interest was crash and RCI information, our access was mainly limited to those two categories of the database. Within the CAR database, the crash information is divided into subsections depending on the description in which one is interested. This includes crash data reports for state maintained roadways, crash reports for all roads or non-state roads, a high crash reference location, a criteria-based subset of crash databases and the combination of the high crash reference location with the criteria-based crash data.

Video logs were used for verification of the data and for counting the number of access points. This database provides a visual record of each highway as well as its immediate environment. Both directions of the highway are filmed separately, and the view displayed is what "drivers" would typically see as they proceed along the road.

3.3 Downloading Crash Data and Segmentation

The process of data downloading and segmentation was in various stages and is described in the following sections.

3.3.1 Statewide Augmented Crashes

Crashes which occurred on state-maintained roads were downloaded for all four and six-lane urban, suburban and rural highways. For state-maintained roads, there are various options one has to choose depending on the description of crash he needs. Our interest was augmented crash information which gives the crash location, time of crash and all contributing factors associated with that crash. This information was downloaded. Crashes that occurred from January 1997 to December 2001 on state-maintained roadways were downloaded. However, in the augmented crash information, data about the exact number of lanes where a crash had occurred is missing. The database only indicates the lane group where crashes had occurred – for example 4-5 lanes or 6+ lanes. In addition, this database lacks information of segment which could explain the variability of the roadway geometrics with crash. This necessitated the use of the RCI database in combination with the augmented crash database in order to relate crashes with roadway geometrics.

3.3.2 High Crash Reference Location Segments

This database contains the roadway identity, the beginning of the section, end of the section, total number of fatal, injury and property damage crashes. The beginning and end of the section gives out the segment length of that section. The high crash location was a very basic source of information in which roadways are distinguished as exactly 6 lanes or not. While downloading the crash data by using this database, the confidence level of any location with a minimum of zero crashes was specified in order to obtain all sections, even those with zero crashes. This enabled filtration of all six-lane divided roadways. In order to capture all crash information, the number of crashes in the high crash reference field was specified as zero. The default minimum number of crashes specified in this database is eight crashes. A confidence level of 0% was also specified for the same reasons; the default is 99.50% for urban, 99.00% for suburban, and 95.00% for rural. The next step was to screen for 6-lane divided roadways. All crashes which occurred on undivided and interstate highways were eliminated from further analysis.

3.3.3 Roadway Characteristic Inventory (RCI)

The Roadway Characteristics Inventory (RCI) database was the source of geometric and traffic variables in this study. As described above, high crash reference locations were used to find 6-lane divided highways. RCI information was downloaded for the 6-lane divided roadways obtained from previous procedures. The procedure of downloading RCI data from the CAR database was almost the same as that of crash. The common link between augmented crashes, high crash location and the RCI database is roadway identification (ID). The roadway ID is an eight digit number with the first two digits representing a department’s county designation, the next three numbers representing section number and the last three numbers representing the sub-section number. By specifying the year 2001, roadway ID and the beginning and end mileposts, the RCI for all specified roadways was downloaded. All the information from the CAR database comes out as a text file and the variables cannot be read directly, so a customized computer program was written which converted the text file format into a spreadsheet format and then systematically arranged the variables in columns.

3.3.4 Merging Augmented Crashes with RCI

The challenging procedure was how to combine crashes with corresponding segments in RCI in a simple and quick way. The challenge was based on the fact that crashes were in a different file from RCI, which meant the counting of crashes which fell in a certain segment would have involved too much manual work. This problem was solved by writing a program using STATA software to merge the augmented crashes (which shows the exact crash location) with the corresponding segments in RCI. The program had the capability of finding the roadway ID and segment length attributes in the RCI by looking for the beginning and end of the section, then matching and tallying the corresponding crashes in the augmented crash data file which falls within that segment; the two sets of data were then merged into a single dataset which includes the roadway ID, number of crashes, segments and all corresponding independent variables (as will be shown in the next sections).

One important consideration which was taken into account is the direction of the roadway. Crashes were matched with RCI based on the direction of the road in which the crash occurred, for example, eastbound, westbound, southbound or northbound. Though the RCI was common for a certain roadway at that particular segment for both directions, the number of crashes differed from one direction to another.

3.3.5 Characteristics of RCI Segments

It was found that some of the RCI segments were very short; for instance, SR-582, which begins from Milepost 2.036 to Milepost 7.242, had 240 segments. This on average leads to a segment length of 0.022 miles which is a very short segment for roadway geometrics to change. This necessitated the use of another way of segmenting the sections in order to get a reasonable segment length, compared to the one obtained directly from the RCI. This was taken with a grain of salt because literature has pointed out the need to delineate extremely short and long selections in the modeling of crashes.

Though the RCI segments were very short, the major variables for our interest were not changing much with those short lengths; they changed instead with a reasonable length of the road. As our interest was major geometric variables, and these were not changing with those short sections specified in RCI, we decided to segment our sections based on how the major variables of our interest changes and neglect other variables. Four variables—land use, spiral angle, superelevation, and percentage grade had values of "0" throughout all sections, so they were dropped. The variables of interest that were used are elaborated below:

LENGTH = Section Length
Number of Access points
AVGDFACT = Average D Factor
AVGKFACT = Average K Factor
AVGTFACT = Average Truck Factor
MAXSPEED = Maximum Posted Speed limit
MEDWIDTH = Median Width
SLDWIDTH = Shoulder Width
ISLDWDTH = Inside Shoulder Width
SURWIDTH = Pavement Surface Width
PAVECOND = Pavement Condition
SECTADT = Section AADT
SIDEWALK = Sidewalk Width

HRZDGCRV =	Horizontal Degree of Curve
IRI =	International Roughness Index
URSUBRUR =	Urban, Suburban, Rural
DIVUNDIV =	Divided Undivided Median
ACMANCLS =	Access Management Class
TYPEPARK =	Type of Parking
SURRNUM =	Surface Number
SHLDTYPE =	Shoulder Type
ISLDTYPE =	Inside Shoulder Type
RDMEDIAN =	Roadway Median Type

Section length is not a variable in the original RCI, but it was created in terms of segmenting the sections. The variables, number of access points and international roughness index are not in the RCI for the time being and we used different methodology, as will be further explained at a later point, to incorporate them into the segments. The access management class is present for all other counties except for Miami-Dade; external data apart from RCI was to be used to fill the variable for Miami-Dade.

3.3.6 Segmentation of the Sections

As mentioned before, the RCI segments were very short due to inclusion of some variables which were not of interest to us and we had to re-segment them based on how the major variables changed. The STATA program was developed again to segment the sections in order to increase the section lengths. This program had the capability of passing from the beginning of the first segment in short RCI, reading the measure of that variable, then advancing it to the next segment and recording the corresponding values. When this program recognizes that there is a variable which has changed in value or character or any measure of it, the program was able to combine all above segments together as a single segment. The program further read the start and end of that created segment, counted all crashes which fell within that segment and produced which variable had changed before advancing to the next group. The outcome of this program was roadway ID, start and end of the new segment, total number of crashes, and all variables; additionally, it noted the changed variable which led to that segmentation. At the end of this segmentation, there were 3200 sections from eighty different roadway ID sections from eight counties, as mentioned earlier.

3.3.7 Manual Segmentation

Even after segmenting the sections by using the computer program, there were still some sections with very short lengths like 0.001 miles. These short sections resulted from some minor changes which were not of much significance. For instance, the shoulder width changed from 2 ft to 1.5 ft or the raised curb changed from 4 inches to 6 inches. With these small differences, manual re-segmentation was done in order to combine those short length sections without deleting any variables and also without losing any segments. In this process, the segments were reduced to 2039 with a total length of 521 miles for both directions. The minimum section length was 0.021 mile and this was just for one section; the average section length was 0.256

mile, with a maximum of 1.925 miles. Figure 3.1 gives a summary of all procedures used for combining crashes with roadway segments.

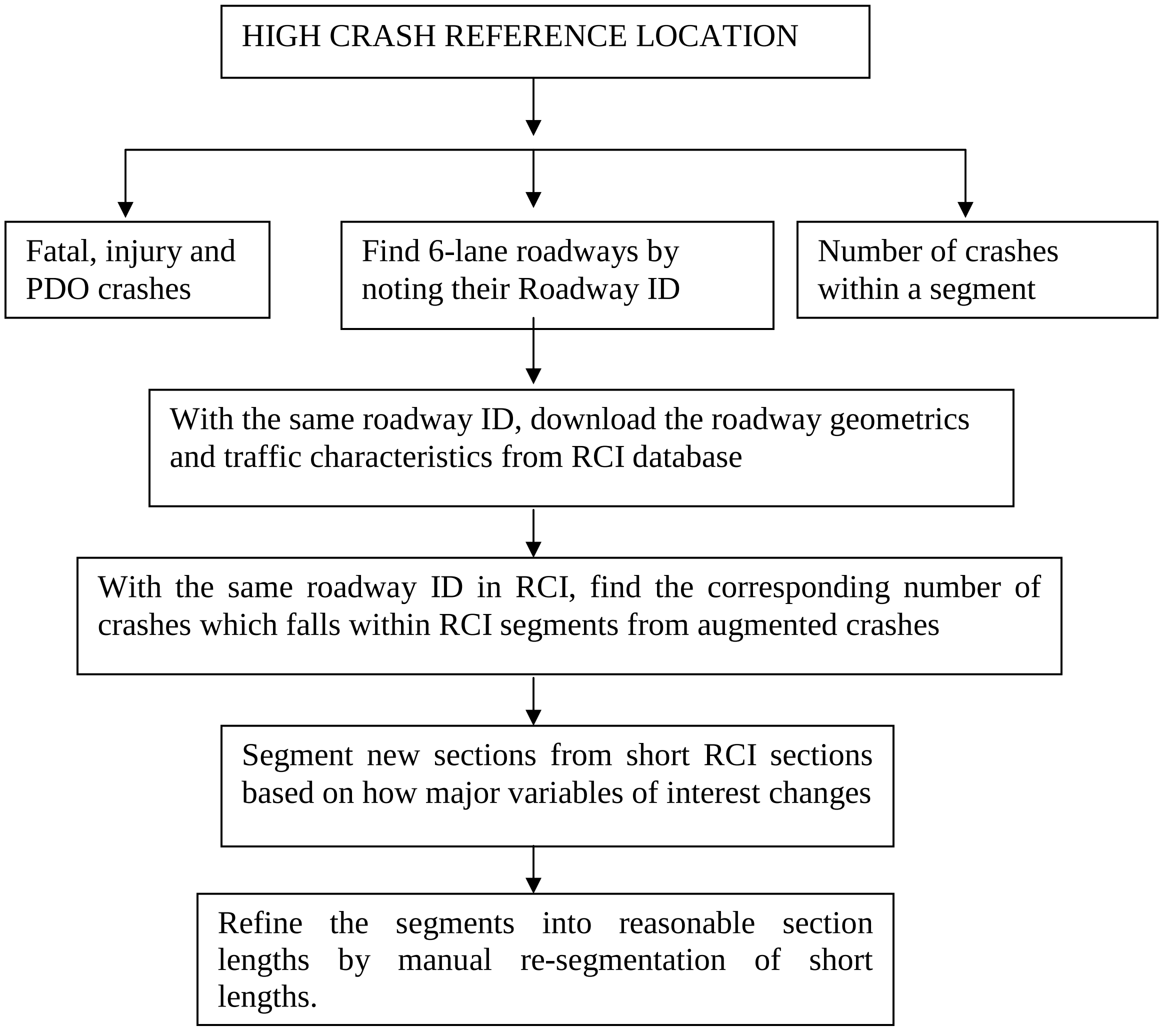


Figure 3.1 Procedures Used from Downloading Crash Data up to Final Segments

3.4 Inclusion of Number of Access Points

Inclusion of the number of access points was necessary since it is one of the factors which affects crashes on roadways. Detailed discussion of the effect of access density on the frequency of crashes is given by Gluck *et al.* (1999), Papayannoulis *et al.* (1999) and Karlaftis *et al.* (2002). As summarized earlier, this variable was obtained by using the video log, where the number of access points corresponding to every segment was counted. The number of access points with corresponding frequency and total length are shown in Table 3.1.

Table 3.1 Access Points Frequency

Access Points	Frequency	Total Length		Access Points	Frequency	Total Length
0	382	59.27		15	6	6.31
1	484	70.20		16	6	6.28
2	366	64.83		17	6	6.29
3	227	51.73		18	3	2.31
4	151	41.31		19	8	6.82
5	95	33.55		20	6	6.07
6	75	32.35		21	3	3.78
7	59	25.50		22	5	6.74
8	36	15.55		23	2	1.88
9	31	16.08		24	2	1.56
10	26	16.66		25	5	5.69
11	15	9.98		26	1	1.58
12	12	7.22		27	3	4.34
13	14	9.34		33	1	1.93
14	8	6.16				

3.5 International Roughness Index (IRI)

This variable is not currently in the RCI; however, it was found in the pavement condition index data which was obtained from FDOT. Among the variables present under pavement index data are the crack rate, IRI, pavement condition, ride rate number and rut rate number. International roughness index was chosen because the RCI already contained pavement condition as a variable. Moreover it was suggested that IRI explains the roadway pavement condition better than the other variables in this category. For all segments, the value of IRI corresponding to it was entered. All variables chosen for this study are explained in the next chapter where detailed descriptions about each variable will be given.

CHAPTER 4 COMPARATIVE ANALYSIS OF FOUR-LANE AND SIX-LANE CRASHES

4.1 Introduction

As part of the research objectives, safety characteristics of four-lane roadways were to be compared to the safety characteristics of six-lane roadways. The comparative analysis involved determining the impacts of various roadway elements, environmental conditions, weather and vehicular activities with the intention of highlighting variables that could have significantly contributed to crash occurrences. The comparison was based on the frequency of crashes, the number of fatalities, and the number of injuries on both six-lane and four-lane roadways. The percentage of crashes in a particular category with respect to others was also taken into account to find out which element within that category was higher in number of crashes or fatalities or injuries compared to others and compare its effect with six-lane or four lanes. A crash rate which is expressed as crashes per million vehicle miles of travel was also computed for each element and category and comparisons were made. Crash rate seems to be a good comparison value since it takes into account the length of the section and traffic volume. Spearman correlation and Pearson chi-square tests were used to test the hypotheses. Roadway geometrics considered include median width, median type (paved, raised and undivided), shoulder width, shoulder type, surface width, skid resistance number and traffic way (level and curve). Road condition variables considered include surface condition, surface type, weather condition and lightning condition. Traffic characteristics considered are posted speed limit and type of side road parking. Contributing causes, vehicle movement prior to crash occurrence, traffic control, land use, roadway functional class, and harmful event are also considered in this comparison. This comparison comprises of both divided and undivided sections.

Apart from comparing frequencies and crash rates, hypothesis testing was also performed comparing distributions of crashes on four and six-lane sections. The null hypothesis was that the distributions of crashes on four and six-lane sections were independently affected by roadway geometrics. In order to find if the distributions were the same or not, hypothesis testing was performed to test independency and distribution equality. Two statistical tests are used in this analysis to test crash distributions on four- and six-lane sections. The first one is the Spearman Rank Correlation Test. The Spearman Test produces a Spearman Correlation Coefficient, rho. This coefficient can take values between -1 and +1. When rho = -1, we have two distributions that have a perfect negative correlation. That is, without exception, as the value of one distribution in our sample becomes larger, the value of the second distribution gets smaller. Similarly, rho = +1 indicates a perfect positive correlation. A value of rho = 0 means that there is no correlation between the two distributions, that is, they are completely independent of one another. In short, the Spearman Test displays the Spearman rank correlation coefficient between four-lane and six-lane sections along with a test showing whether four-lane sections and six-lane sections are independent.

To carry out the Spearman Rank Correlation Test, we first rank the values of each distribution (six- and four-lane crashes) from smallest to largest. Then we find the difference between ranks for each pair of numbers. After that we square these differences and sum them to obtain difference, D. Then we use the following equation to calculate Spearman's rho.

$$rho = 1 - \frac{6\sum D_i^2}{n(n^2 - 1)}$$

Where n = number of pairs of values.

Thereafter, we compare the calculated rho with already-tabulated ones. If the calculated rho is equal to or greater than the tabulated rho, we reject the null hypothesis at the 5% level of confidence. If the calculated rho is less than the tabulated rho, we fail to reject the null hypothesis at the 5% level of confidence.

The second test used in this comparison is Pearson chi-square which creates a contingency table (cross tabulation). Five steps are taken when calculating Pearson Chi-square: (1) First, the null hypothesis is stated which is “Crashes on six-lane and four-lane sections are independently distributed.” (2) Then frequencies of the events expected under the null hypothesis are computed. These provide expected counts or frequencies based on some “statistical model,” which may be a theoretical distribution, an empirical distribution, an independent model, etc. (3) The observed counts of data falling in the different cells are noted. (4) The difference between the observed and the expected counts are computed and summed. The difference leads to a computed value of Chi-Square (χ^2) test statistic. The test statistic is given by

$$\chi_{cal}{}^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where $\mathbf{O}_i$ is observed counts and E_i is expected counts. (5) The test statistic is compared to the critical points of the χ^2 distribution ($\chi^2_{\alpha,k-p-1}$) and a decision on the null hypothesis is made. We reject the null hypothesis if $\chi^2_{cal} > \chi^2_{\alpha,k-p-1}$ and conclude that the two distributions are dependent; otherwise the two distributions are independent. The translation of a “dependent” result in four-lane to six-lane comparison would be that there is no significant difference in the way crashes are occurring on both roadways based on the roadway or traffic category of interest.

4.2 Comparison Based on the Total Number of Crashes, Fatalities, and Injuries

A total of 45,136 and 51,583 crashes occurred on six-lane and four-lane sections respectively. The combined number of crashes occurring on both roadway types is approximately 70% for all crashes that occurred on state-maintained roads in year 2001. The vehicle miles of travel on six-lane roadway sections in 2001 was 17,641,315,676 while on four-lane sections it was 32,295,189,655. Further results are shown in Table 4.1 and Figure 4.1(a).

Table 4.1 and Figure 4.1(a) show that six-lane sections had higher crash and injury rates compared to four-lane sections. The fatality rates are nearly the same though six-lane sections are higher by 0.004 (25%) fatalities per million vehicle mile of travel (VMT) while injury rates on six-lane sections are higher by 61% compared to four-lane sections. For all crashes, six-lane sections had a crash rate of 2.559 crashes per million VMT while four-lane sections had a crash rate of 1.597 crashes per million VMT, a 60% difference.

Table 4.1 Comparison of Crash, Fatality and Injury Rates

	Six Lanes			**Four Lanes**		
	Total Crash	VMT	Crash Rate	Total Crash	VMT	Crash Rate
Crashes	45,136	17,641,315,676	2.559	51,583	32,295,189,655	1.597
Fatalities	350	17,641,315,676	0.020	531	32,295,189,655	0.016
Injuries	40,611	17,641,315,676	2.302	46,048	32,295,189,655	1.426

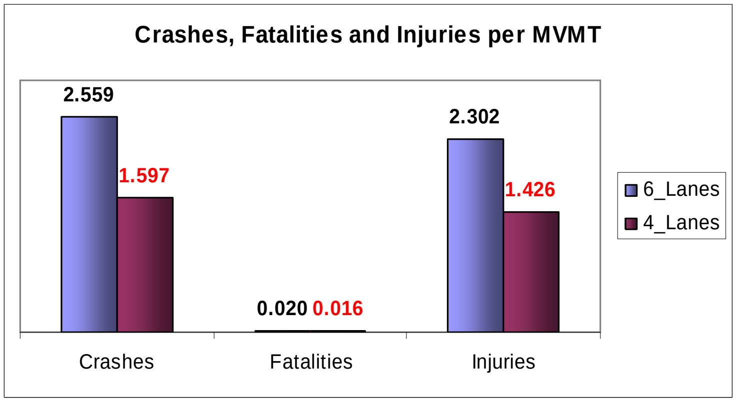


Figure 4.1(a) Rates per million VMT for Crashes, Fatalities and Injuries

4.3 Urban, Suburban, Rural and Median Type

4.3.1 Total Number of Crashes

Figure 4.2(a) shows that on six-lane roadways about 83% of crashes occurred in urban areas, 16% in suburban areas, and less than 2% occurred in rural areas. On four-lane sections, the percentages were 60, 30, and 10, respectively. Figure 4.2(b) shows that six-lane sections generally had higher crash rates except for urban undivided sections where four-lane sections had higher crash rates. A clear difference in crash rates is observed on raised median sections where crash rates on six-lane roadway sections are much higher compared to four-lane roadway sections. Undivided sections had higher crash rates on four-lane than six-lane sections. This difference is probably explained by the fact that there were few undivided six-lane sections compared to four-lane sections and that there were few crashes on undivided six-lane sections.

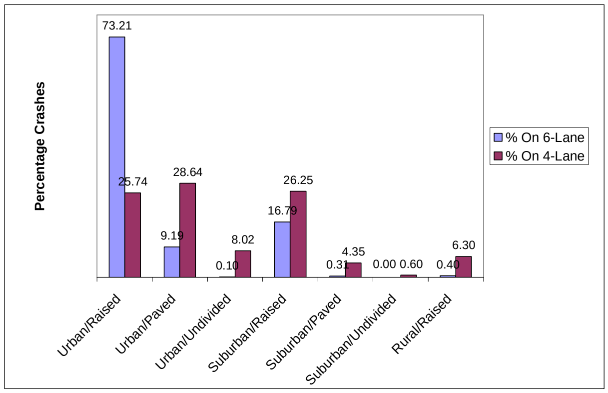


Figure 4.2(a) Percentage Comparison of the Number of Crashes

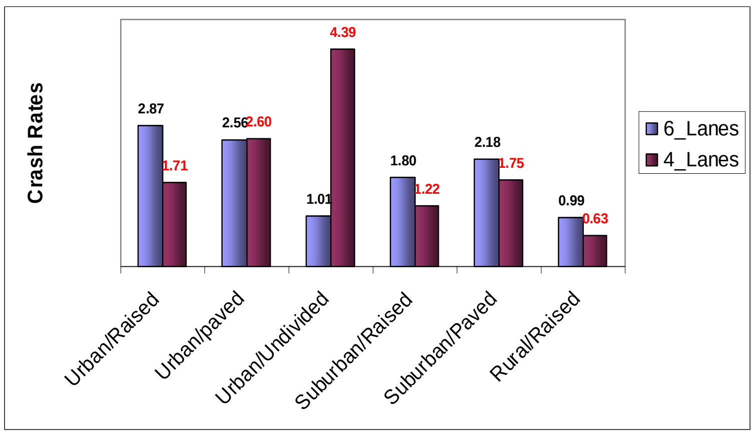


Figure 4.2(b) Comparison of Urban, Suburban and Rural Combined with Median Type

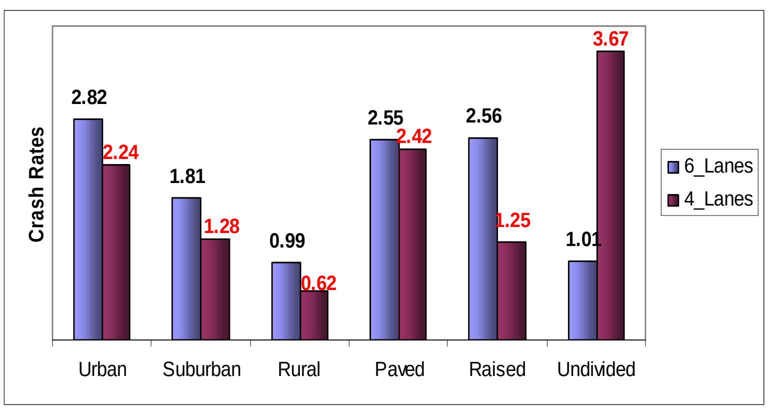


Figure 4.2(c) Comparison of Urban, Suburban and Rural areas and Median Type

4.3.2 Injuries and Fatalities

Figure 4.3 shows that six-lane sections had higher fatality rates on divided and raised sections compared to four-lane sections except for rural divided raised sections. There seems to be a difference between fatality rates occurring on six-lane roadways with raised medians compared to those without raised medians. Injury rates were high on six-lane sections for all categories except on undivided sections. In suburban areas, six-lane sections with raised medians had high injury and fatality rates.

4.3.3 Hypothesis Testing on Distribution of Crashes with Respect to Road Class

To determine if there was a significant difference in the distribution of crashes, fatalities and injuries on six-lane and four-lane sections in relation to the class of the roadway, a Chi-square tests were performed the results of which are displayed in Table 4.2. Table 4.2 shows that all tests show that the distributions of crashes, fatalities and injuries on four-lane and six-lane sections based on roadway class were not significantly different. This result suggests that, despite the reported differences, one can not conclude that roadway class influences crashes differently on four-lane and six-lane roadways.

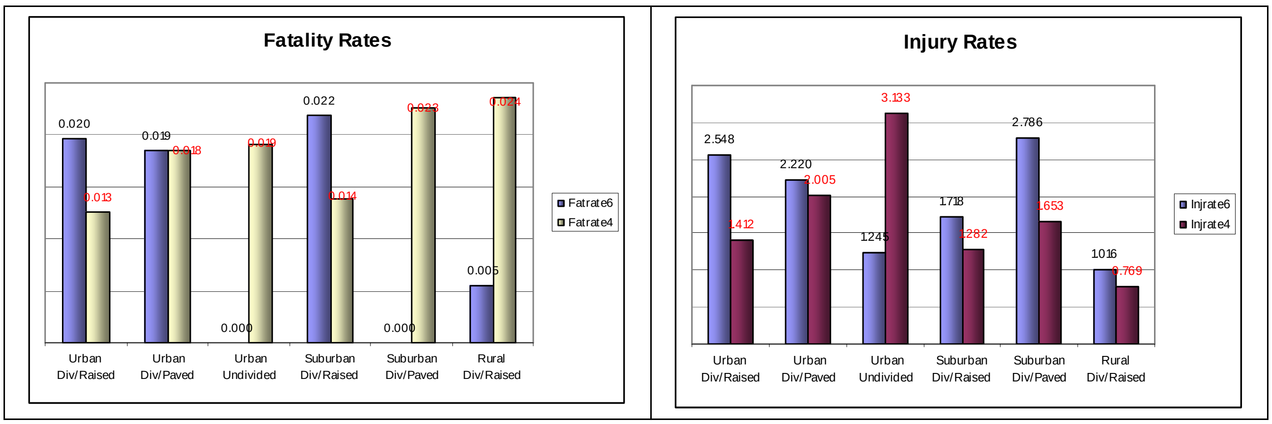


Figure 4.3 Injury and Fatality Rates Based on Roadway Classification

Table 4.2 Hypothesis Testing Based on Roadway Class

Chi-Square Test		**Calculated Chi-Square χ^2_{cal}**	**Observed Chi-Square(α=0.05) $\chi^2_{\alpha,n-p-1} = \chi^2_{Obs}$**	**Conclusion: Relation between Four- and Six-Lane Crashes**
	Total crashes	24407.8	11.07048	No difference
	Fatalities	249.2279	11.07048	No difference
	Injuries	22438.62	11.07048	No difference

4.4 Traffic Way

4.4.1 Total Number of Crashes

Figure 4.4(a) shows that most crashes on both four-lane and six-lane sections were on straight-level followed by straight at grade sections In both categories of traffic way (Straight-Level, Straight-Grade, Curve-Level and Curve-Grade), six-lane sections had higher crash rates as shown in Figure 4.4(b).

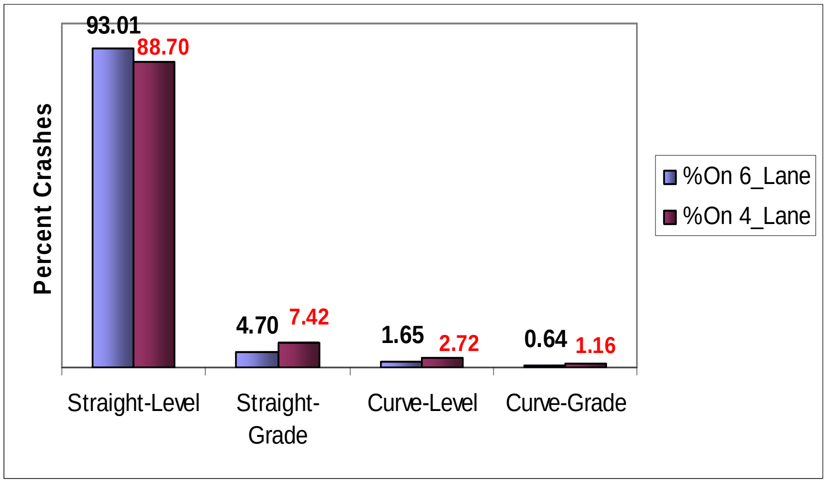


Figure 4.4(a) Percentage of Crashes Based on Traffic Way

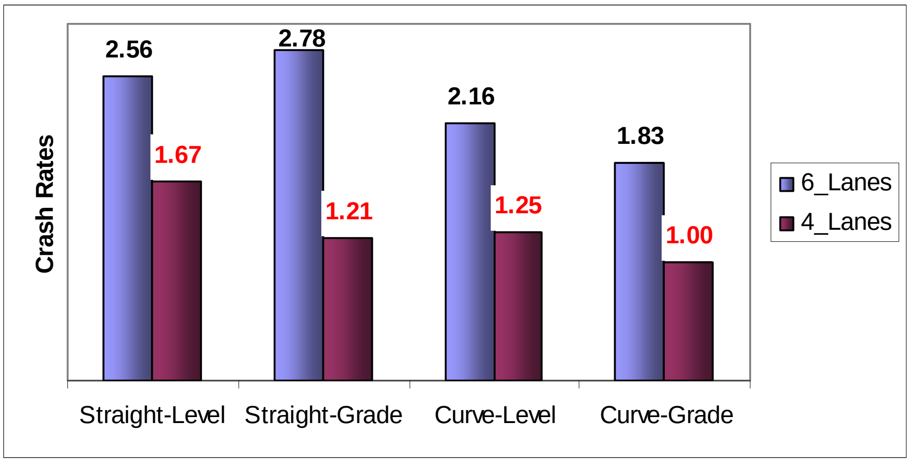


Figure 4.4(b) Comparison of Crash Rates Based on Traffic Way

4.4.2 Injuries and Fatalities

Figure 4.4(c) shows that six-lane sections had high fatality and injury rates for all categories of traffic way. The fatality rate was high on curved level sections while the injury rate on six-lane sections was high on straight with grade sections while on four-lane sections it was high on straight level sections. Figure 4.4(c) shows fatality and injury rates for both four-lane and six-lane roadway sections.

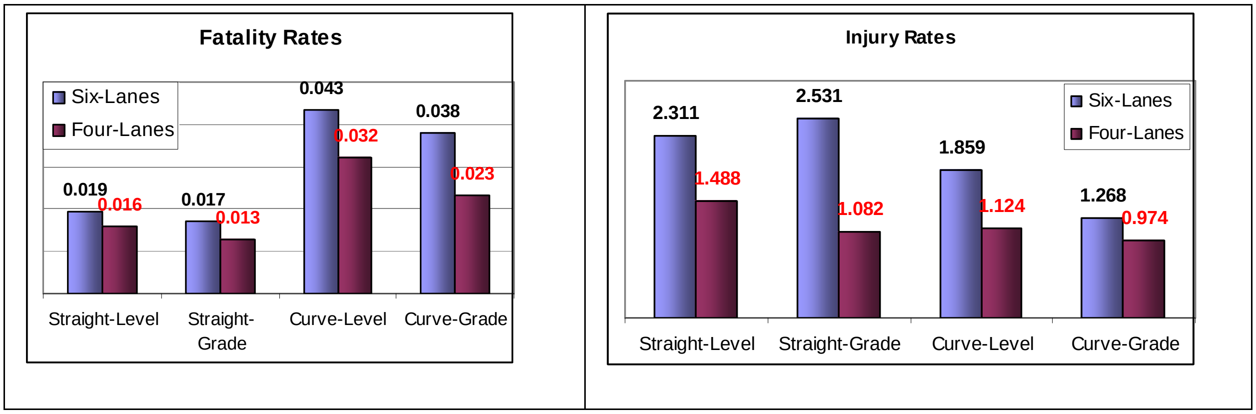


Figure 4.4(c) Fatality and Injury Rates with Respect to Traffic Way

4.4.3 Hypothesis Testing on Distribution of Crashes with Respect to Traffic Way

The Spearman rank correlation coefficient, rho, in Table 4.3 showed a high correlation between the distribution of crashes according to traffic way for four-lane and six-lane roadway sections. The results from the Spearman test showed that the crash and injury frequency distributions were not significantly different while fatality frequency distributions were significantly different. Overall, the Chi-square test found a similar result as shown in Table 4.3.

Table 4.3 Hypothesis Testing Based on Traffic Way

Test	**Value**	**Null Hypothesis**	**P-Value**	**Conclusion**
Spearman	Rho=1.000	Crash Frequencies are independent	Prob>|t|=0.000	Crash frequencies on six and four lanes are not different
	Rho=0.8	Fatal Frequencies are independent	Prob>|t|=0.200	Fatality frequencies on six and four lanes are different
	Rho=1.00	Injury Frequencies are independent	Prob>|t|=0.00	Injury frequencies on six and four lanes are not different
Chi-Square Test		**Calculated Chi-Square χ^2_{cal}**	**Observed Chi-Square (α=0.05) $\chi^2_{\alpha,n-p-1} = \chi^2_{Obs}$**	**Conclusion: Relation between Four- and Six-Lane Crashes**
	Total crashes	534.5411	7.814725	Not Different

4.5 Road Functional Class

4.5.1 Number of Crashes

Figure 4.5(a) shows that most crashes on both four-lane and six-lane roadways occurred on urban principal arterials. The six-lane sections had high crash rates for all categories of road functional class except for urban collectors where four-lane sections had higher crash rates as shown in Figure 4.5(b). Though four-lane sections had high crash rates in urban collectors, one can argue that there were very few six-lane urban collector sections. There were only 9 crashes which occurred on six-lane urban collector roads compared to 516 crashes on four-lane urban collector roadway sections. On both four-lane and six-lane sections, urban minor arterials had high crash rates.

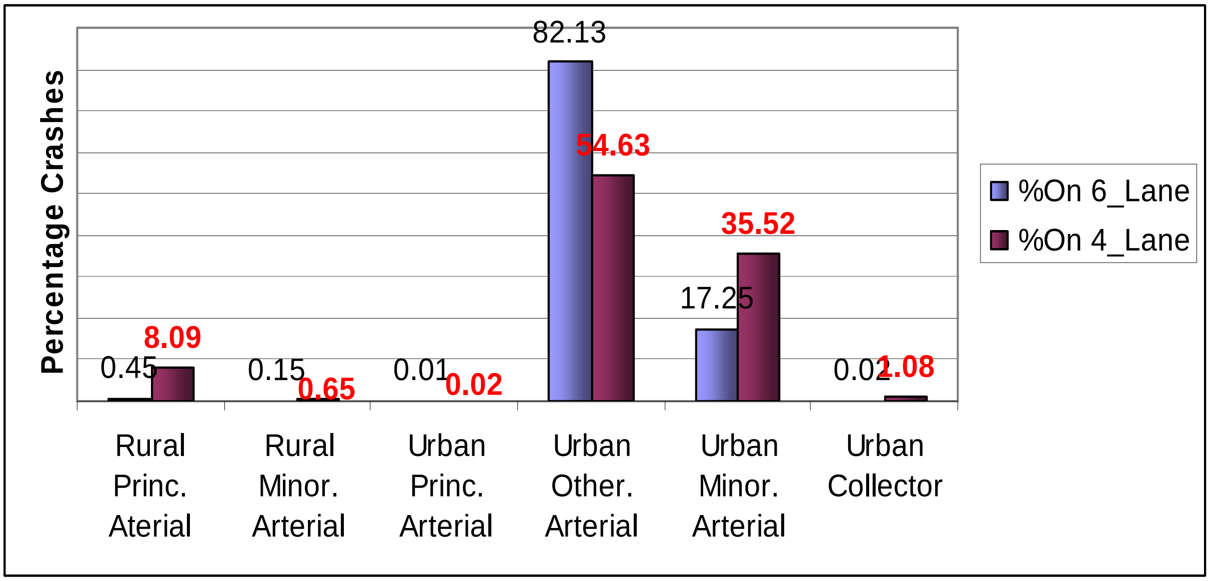


Figure 4.5(a) Percentage of Crashes Based on Road Functional Class

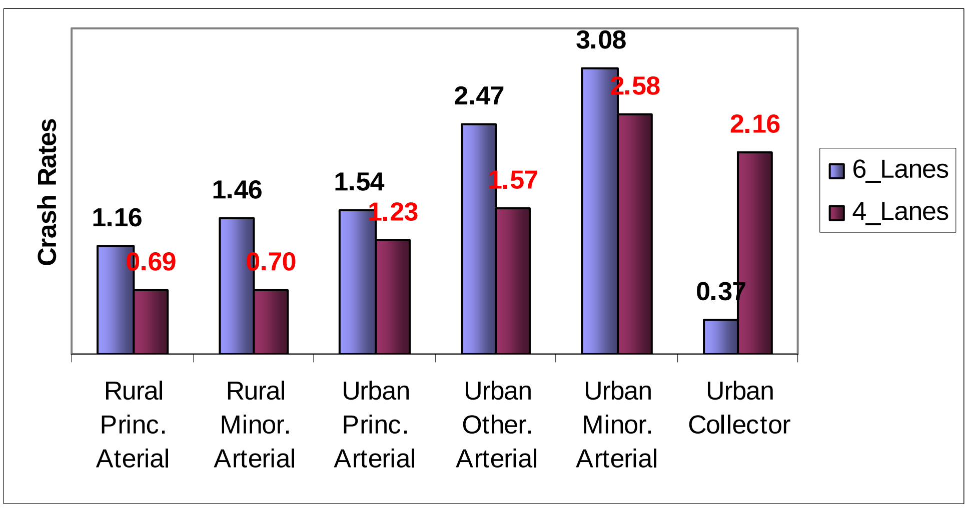


Figure 4.5(b) Comparison of Crash Rates Based on Road Functional Class

4.5.2 Injury Rates

Except for urban major principal arterials, six-lane sections had high in injury rates for other road functional class categories. Injury rates on urban major arterials were much higher on four-lane compared to six-lane sections. In urban minor arterial category, injury rates were not different between four-lane and six lane sections. Figure 4.5(c) gives details of injury rates based on road functional classes.

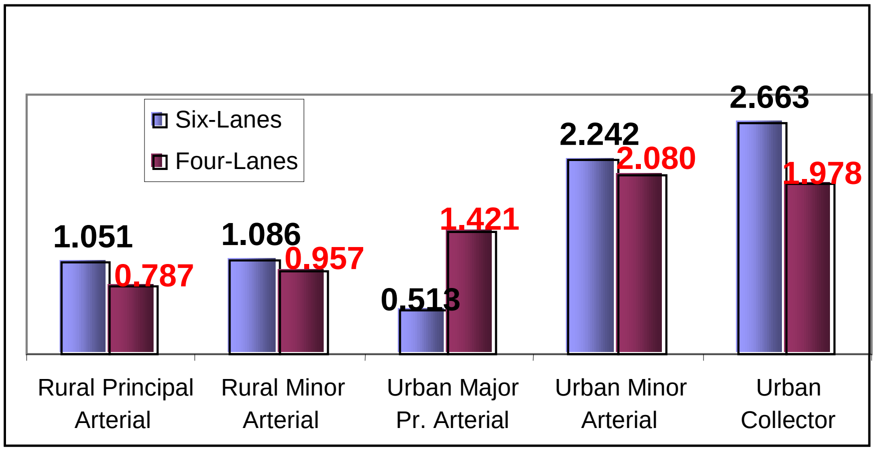


Figure 4.5(c) Injury Rates with Respect to Road Functional Class

4.5.3 Hypothesis Testing on Road Function

The Spearman test showed four-lane and six-lane sections had almost similar distribution of crash frequencies based on functional class as shown by rho of 0.9 in Table 4.4. The Chi-square test also shows similar result.

Table 4.4 Hypothesis Testing Based on Road Functional Class

Test	Value	Null Hypothesis	P-Value	Conclusion
Spearman	Rho=0.9	Crash Frequencies are independent	Prob>|t|=0.0374	Crash frequencies on six and four lanes are **dependent**
Chi-Square Test		**Calculated Chi-Square** χ^2_{cal}	**Observed Chi-Square (α=0.05)** $\chi^2_{\alpha,n-p-1}=\chi^2_{Obs}$	**Conclusion: Relation between Four- and Six-Lane Crashes**
	Total crashes	8678.626	11.07048	Not Different
	Injuries	39361.51	11.07048	Not Different

4.6 Parking Type

4.6.1 Number of Crashes

Analysis of parking related crashes showed that 98% of crashes on six-lane sections were not parking-related. On four-lane sections, 88% were not parking-related. For those crashes which were parking-related on four-lane sections, most occurred in areas with curbs on one or both sides of the roadway as shown in Figure 4.6(a). Four-lane sections had higher crash rates than six-lane sections when parking was available on both sides of the road as shown in Figure 4.6(b). Six-lane sections had higher crash rates for the other categories of parking type.

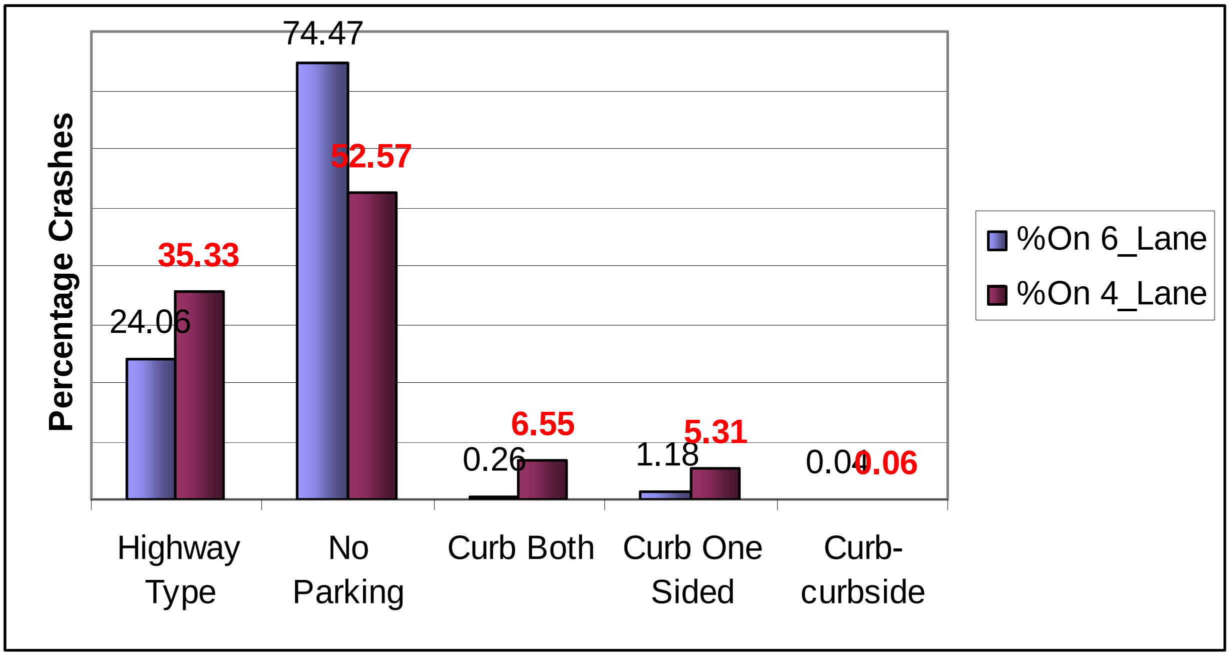


Figure 4.6(a) Percentage of Crashes Based on Roadside Parking Type

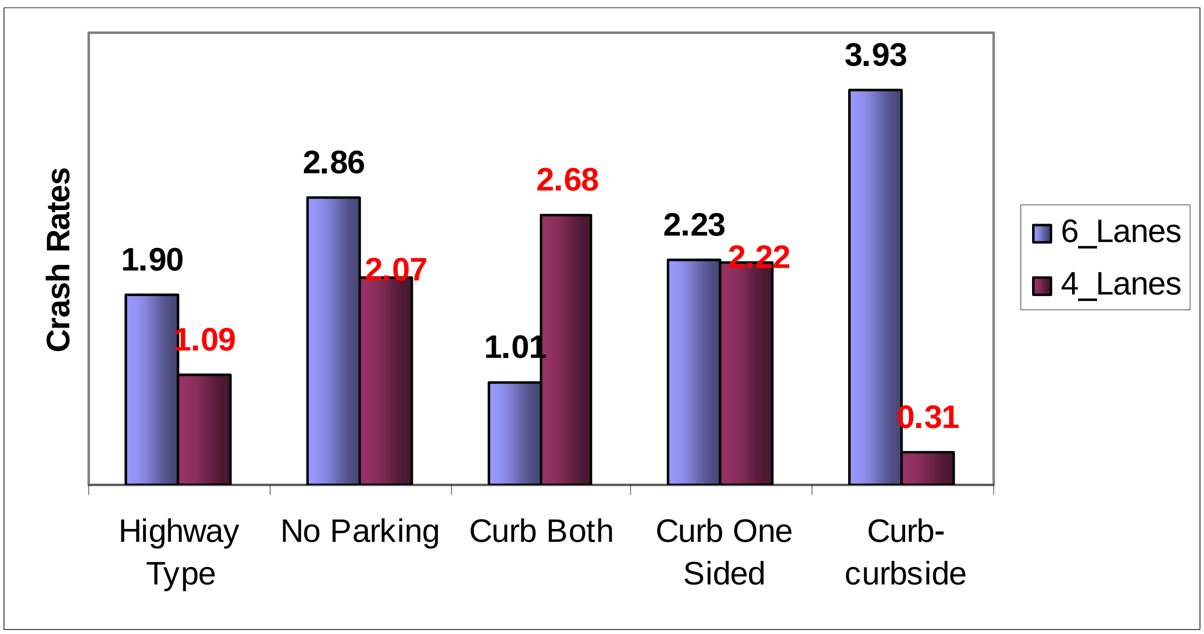


Figure 4.6(b) Comparison of Crash Rates Based on Roadside Parking Type

4.6.2 Fatality and Injury Rates

Fatality rates were higher on six-lane sections in all categories of parking compared to four-lane sections. The same trend is seen with injury rates except that four-lane sections had higher injury rates when there was parking on both sides. This difference should be viewed in the light that 98% of crashes on six-lane sections and 88% of crashes on four-lane sections were not parking-related. As shown in Figure 4.6(c), curb one-sided parking was high in fatality rate on six-lane sections while on four-lane sections, the fatality rates were almost uniform.

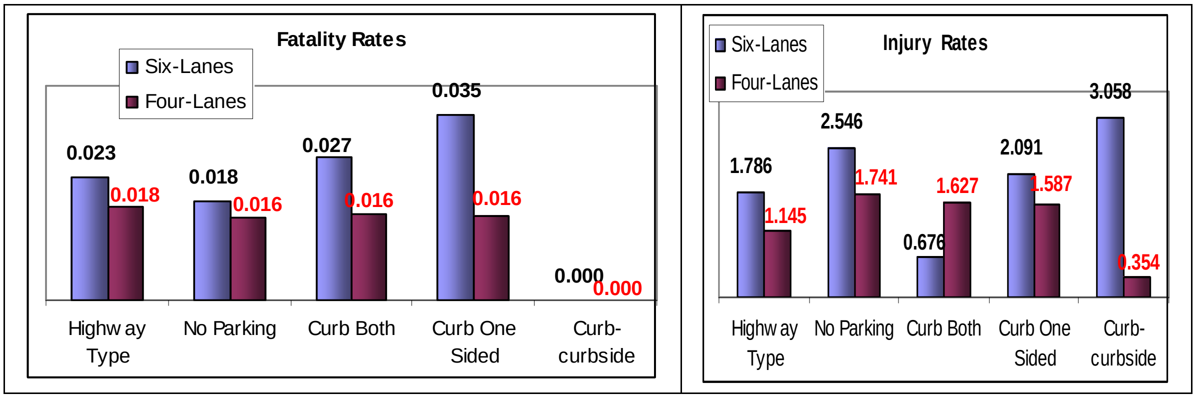


Figure 4.6(c) Fatality and Injury Rates with Respect to Roadside Parking Type

4.6.3 Hypothesis Testing on Parking Type

The trend of similarity between crashes occurring on four-lane and six-lane sections is also observed based on parking-related crashes. The Spearman rank correlation showed that crash and injury frequencies between the two distributions were not significantly different giving a high correlation of 0.9. Fatality rates on four-lane sections were shown to be independent with those on six-lane sections. Both Spearman and Pearson Chi-square showed that the distribution of fatal crashes between four- and six-lanes were not very different. Table 4.5 gives a summary of these test results.

Table 4.5 Hypothesis Testing Based on Parking Type

Test	**Value**	**Null Hypothesis**	**P-Value**	**Conclusion**
Spearman	Rho=0.900	Crash Frequencies are independent	Prob>|t|= 0.0374	Crash frequencies on six and four lanes are dependent
	Rho=0.800	Fatal Frequencies are independent	Prob>|t|= 0.1041	Fatality frequencies on six and four lanes are not dependent
	Rho=0.900	Injury Frequencies are independent	Prob>|t|= 0.0374	Injury frequencies on six and four lanes are dependent
Chi-Square Test		**Calculated Chi-Square χ^2_{cal}**	**Observed Chi-Square (α=0.05) $\chi^2_{\alpha,n-p-1}=\chi^2_{Obs}$**	Conclusion: Relation between Four- and Six-Lane Crashes
	Total crashes	6539.242	9.487728	Not Dependent

4.7 Shoulder Type

4.7.1 Number of Crashes

Paved and curb & gutter type of shoulders had more crashes for both four-lane and six-lane sections. On six-lane sections, 71.2% of crashes occurred in curb gutter shoulder areas followed by 25.9% on paved shoulder sections. On four-lane sections, 43.38% were on the sections with curb & gutter shoulders and 41.99% were on sections with paved shoulders as shown in Figure 4.7(a). Sections with curbed or raised shoulders had higher crash rates on four-lane sections compared to six-lane sections as shown in Figure 4.7(b). Six-lane sections had high crash rates at the sections with paved, lawn and curb & gutter type of shoulders. Raised curb shoulders are seen to be associated with high crash rates for both four-lane and six-lane sections.

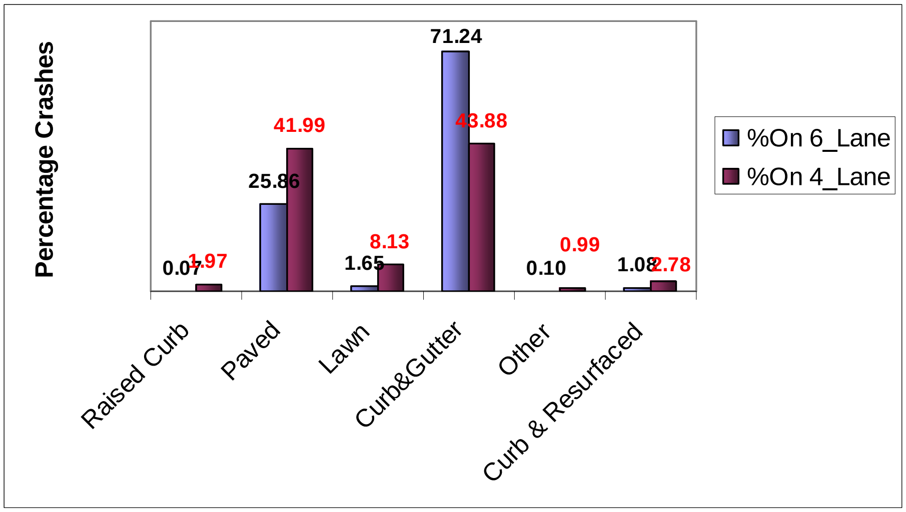


Figure 4.7(a) Percentage of Crashes Based on Shoulder Type

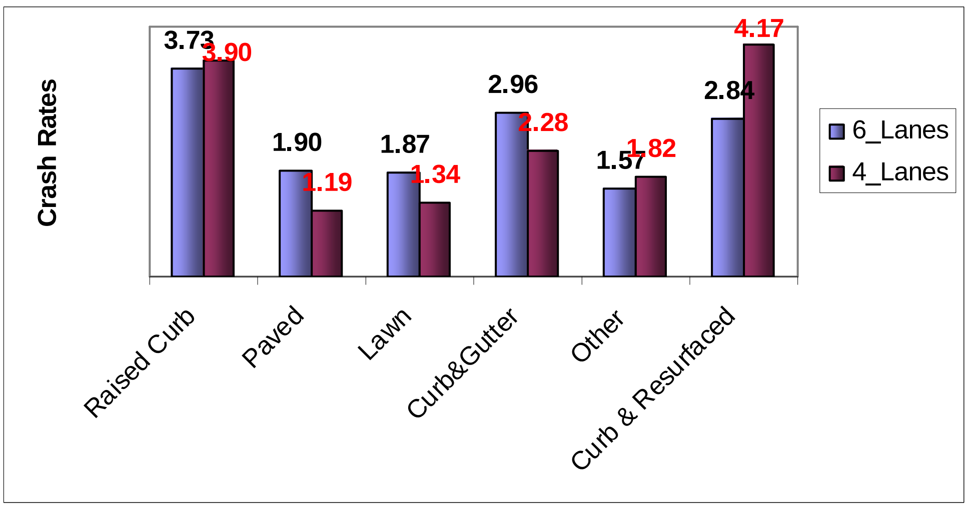


Figure 4.7(b) Comparison of Crash Rates Based on Shoulder Type

4.8 First Harmful Event

Analysis by first harmful event revealed that most crashes were rearend type followed by angle crashes and left turn types. The head-on and right turn collisions were few compared to other type of crashes. Four-lane sections had high crash rates in right-turn crash categories while for other first harmful events, six-lane sections had high crash rates as shown in Figure 4.8(a).

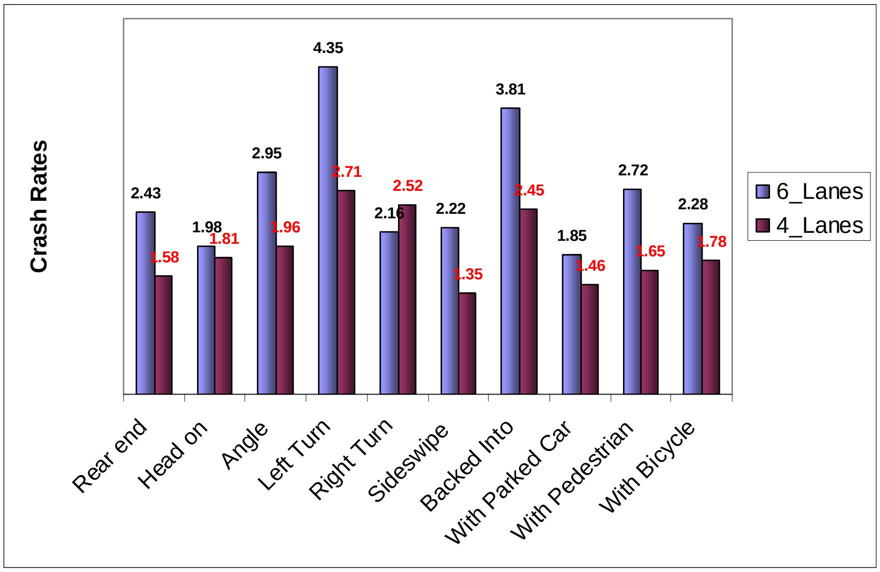


Figure 4.8(a) Comparison of Crash Rates Based on First Harmful Event

The testing of hypothesis as shown in Table 4.6 revealed that the two distributions (six- and four-lane sections) with respect to first harmful event were no significantly different.

Table 4.6 Hypothesis Testing Based on First Harmful Event

Test	**Value**	**Null Hypothesis**	**P-Value**	**Conclusion**
Spearman	Rho= 0.9713	Crash Frequencies are independent	Prob>|t|= 0.000	Crash frequencies on six and four lanes are not different
Chi-Square Test		**Calculated Chi-Square χ^2_{cal}**	**Observed Chi-Square (α=0.05) $\chi^2_{\alpha,n-p-1}= \chi^2_{Obs}$**	**Conclusion: Relation between Four- and Six-Lane Sections**
	Total crashes	930.3788	35.17246	Not Different

4.9 Contributing Causes

Contributing circumstances are divided into improper turning, careless driving, improper lane change, exceeding safe speed limit and failing to yield right of way. Six-lane sections had higher crash rates than four-lane sections in crashes reported to be caused by failing to yield right of way, improper lane change, improper turning, and exceeding safe or posted speed limit as shown in Figure 4.9(a). The presence of more lanes is hypothesized as the cause for six-lane sections to have high crash rates for the causes mentioned above compared to four-lane sections. Figures 5.9(a) and Figure 4.9(b) show injury and fatality rates, respectively.

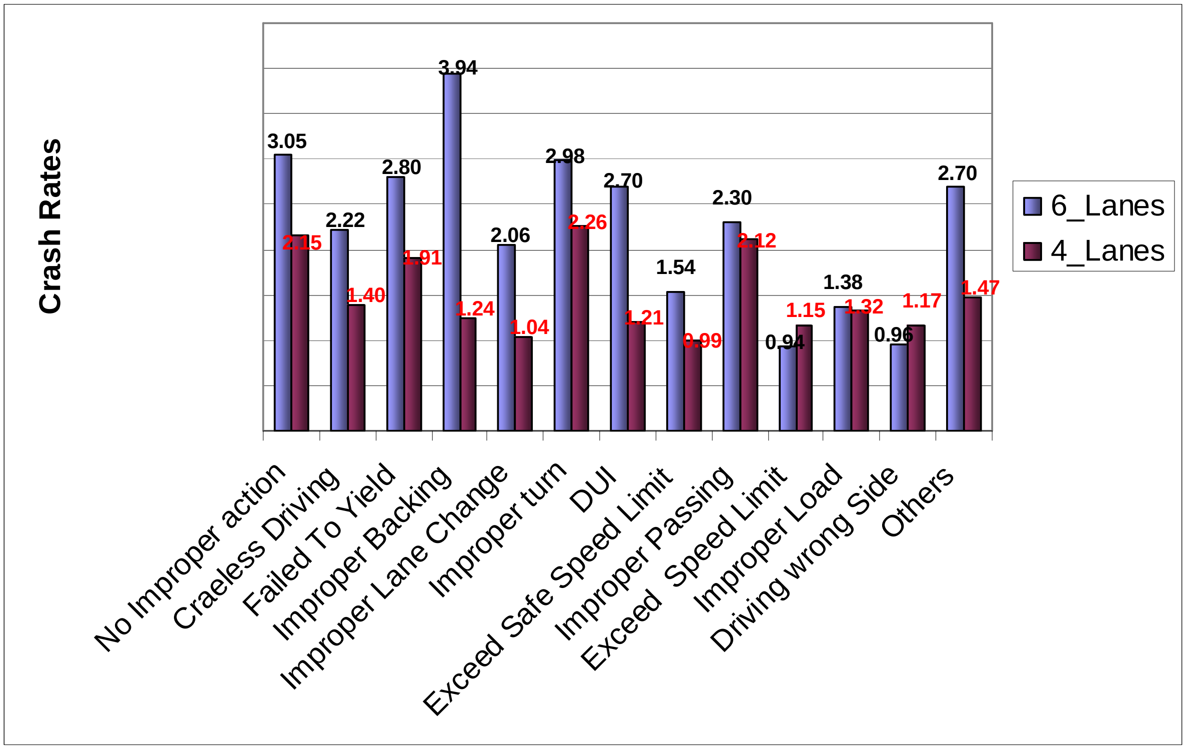


Figure 4.9(a) Comparison of Crash Rates Based on Contributing Causes

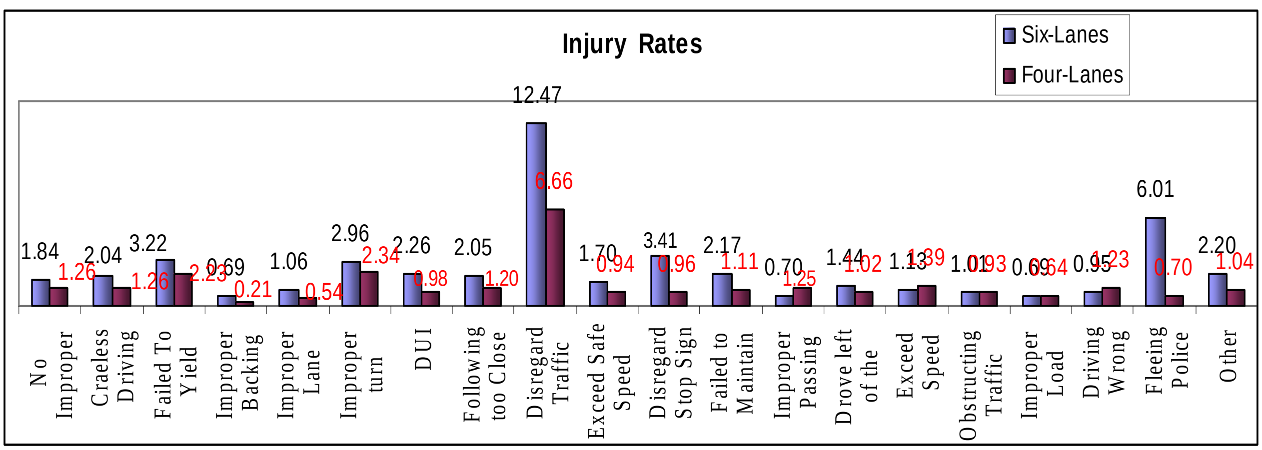


Figure 4.9(b) Comparison of Injury Rates Based on Contributing Causes

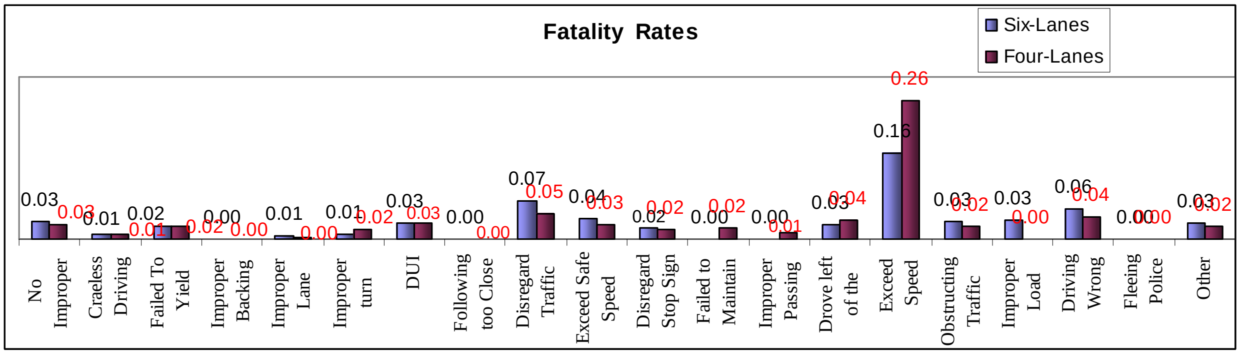


Figure 4.9(c) Comparison of Fatality Rates Based on Contributing Causes

The Chi-square test showed crash and injury frequencies to be not different on four-lane and six-lane sections while fatality frequency distributions were significantly different. The results of the hypothesis testing are displayed on Table 4.7.

Table 4.7 Hypothesis Testing Based on Contributing Causes

Chi-Square Test		**Calculated Chi-Square χ^2_{cal}**	**Observed Chi-Square(α=0.05) $\chi^2_{\alpha,n-p-1}=\chi^2_{Obs}$**	**Conclusion: Relation between Four- and Six-Lane Crashes**
	Total crashes	712.203	30.14351	Not Different
	Fatalities	19.65631	27.5871	Different
	Injuries	873.3302	30.14351	Different

4.10 Traffic Control

Figure 4.10(a) shows that the crash rate was high at sections with yield sign and special speed zones on both four-lane and six-lane sections. With respect to unsignalized intersections, the fatality rate was higher on six-lane sections with stop signs than similar four-lane sections.

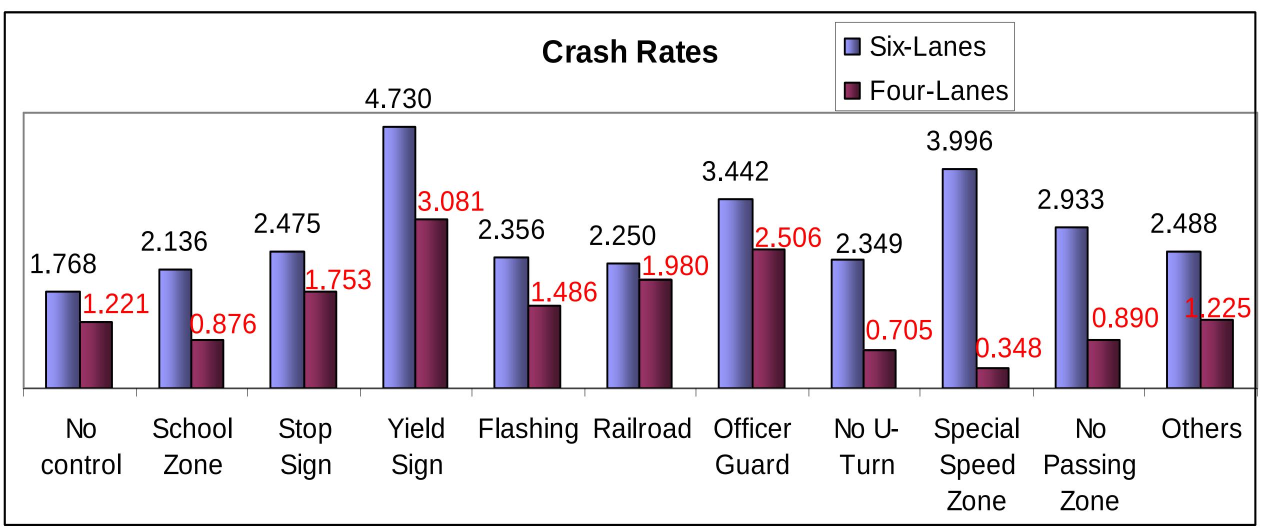


Figure 4.10(a) Comparison of Crash Rates Based on Traffic Control

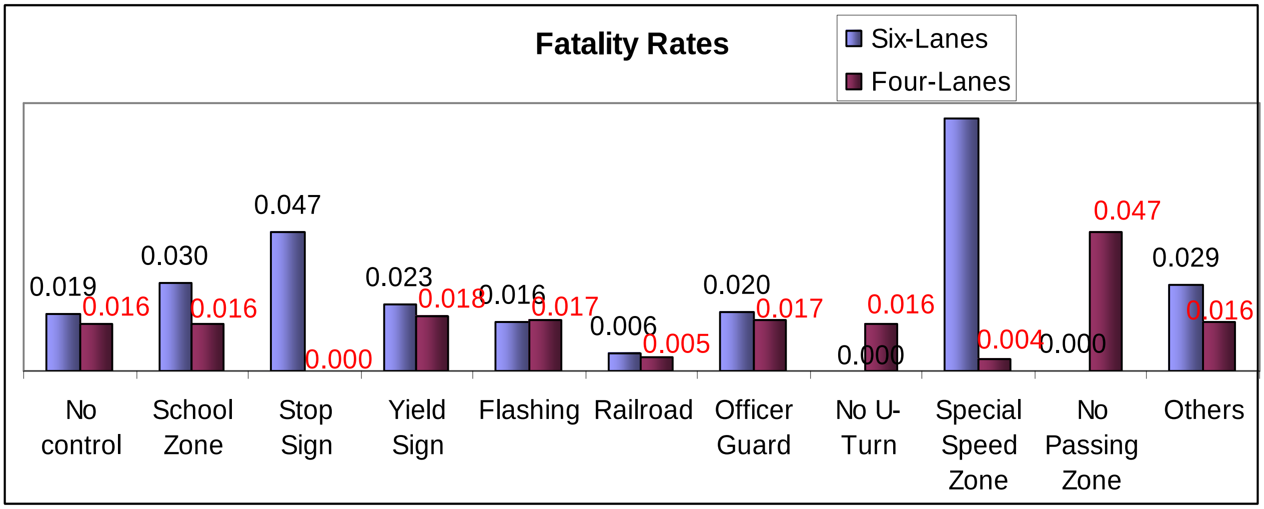


Figure 4.10(b) Comparison of Fatality Rates Based on Traffic Control

As shown in Table 4.8, crash frequencies on four-lane and six-lane sections were no significantly different but fatality frequency distribution seem to be significantly different.

Table 4.8 Hypothesis Testing Based on Traffic Control

Chi-Square Test		**Calculated Chi-Square χ^2_{cal}**	**Observed Chi-Square(α=0.05) $\chi^2_{\alpha,n-p-1}=\chi^2_{Obs}$**	**Result**	**Conclusion: Relation between Four- and Six-Lane Crashes**
	Total crashes	849.7247	18.30703	$X2_{cal}>>\chi2_{Obs}$	Not Different
	Fatalities	15.89402	18.30703	$X2_{cal}<\chi2_{Obs}$	Different

4.11 Land Use

Figure 4.11 shows that high density residential and CBD areas had high crash rates on in both four-lane and six-lane roadway sections.

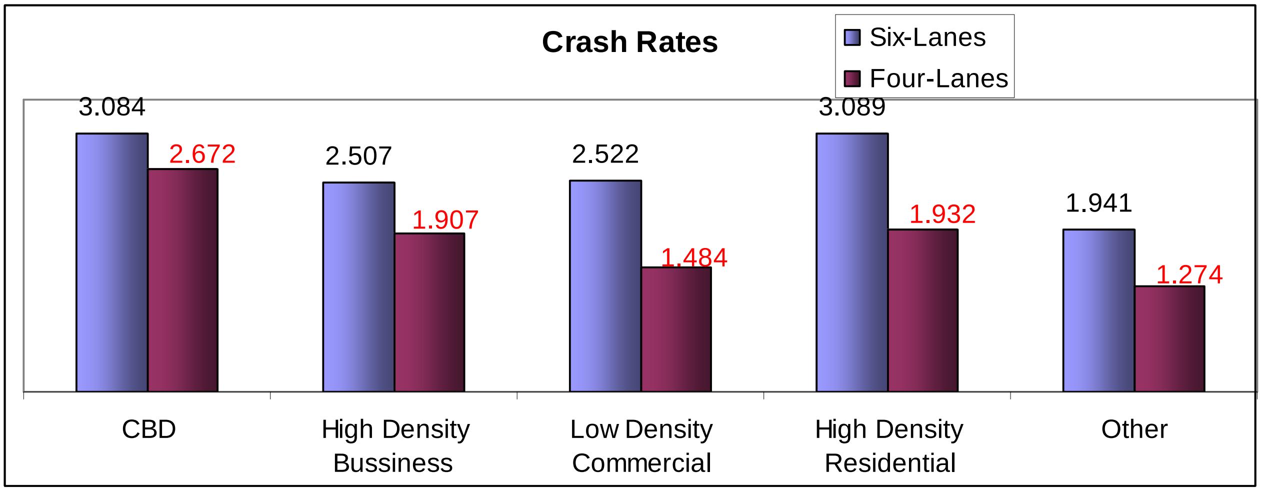


Figure 4.11 Crash Rates with Respect to Land Use

The hypothesis testing based on land use showed crash frequencies to be not significantly different on four-lane and six-lane section as shown in Table 4.9.

Table 4.9 Hypothesis Testing Based on Land Use

Chi-Square Test		**Calculated Chi-Square χ^2_{cal}**	**Observed Chi-Square (α=0.05) $\chi^2_{\alpha,n-p-1}$=χ^2_{Obs}**	**Conclusion: Relation between Four- and Six-Lane Crashes**
	Total crashes	465.8891	9.487728	Not Different

4.12 Median Width

The median separates the opposing traffic streams and reduces access from the mainline, and is also used for emergency stopping. The crash trend as the median width increases is shown in Figure 4.12. Although Figure 4.12 does not yield a clear cut decreasing trend, it can generally be said that as the median width increases, the crash rates decreased.

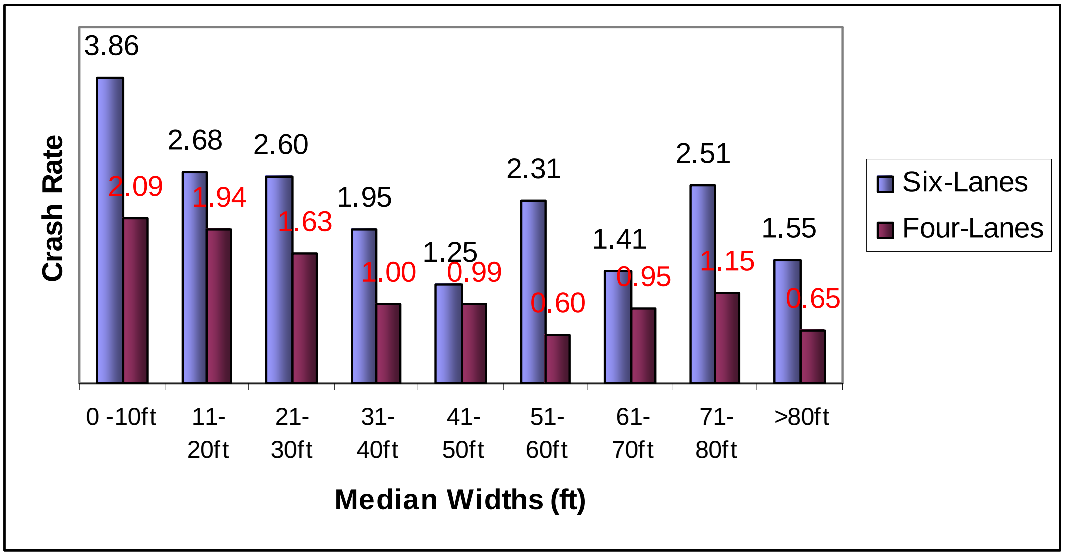


Figure 4.12 Comparison of Crash Rates Based on Median Width

4.13 Posted Speed Limit

The speed limit used in this comparison ranges from 15 mph to 65 mph. Based on posted speed limit, crash rates start at a very low level at a speed limit of 15 mph, reaches its peak at 25 mph, declines to 60 mph, and finally increases to 65mph (Figure 4.13). For both six-lane and four-lane sections, crash rates are higher at low posted speed limits but decrease gradually as speed limits increase. At higher posted speed limits, the crash rate increases for both four- and six-lane sections. Table 4.10 shows the results of hypothesis testing for crash, fatality and injury frequencies. It is revealed that the two distributions are not significantly different in crash, fatality, and injury frequencies. The Spearman correlation coefficient is also high meaning there is high correlation between four-lane and six-lane crashes based on posted speed limit.

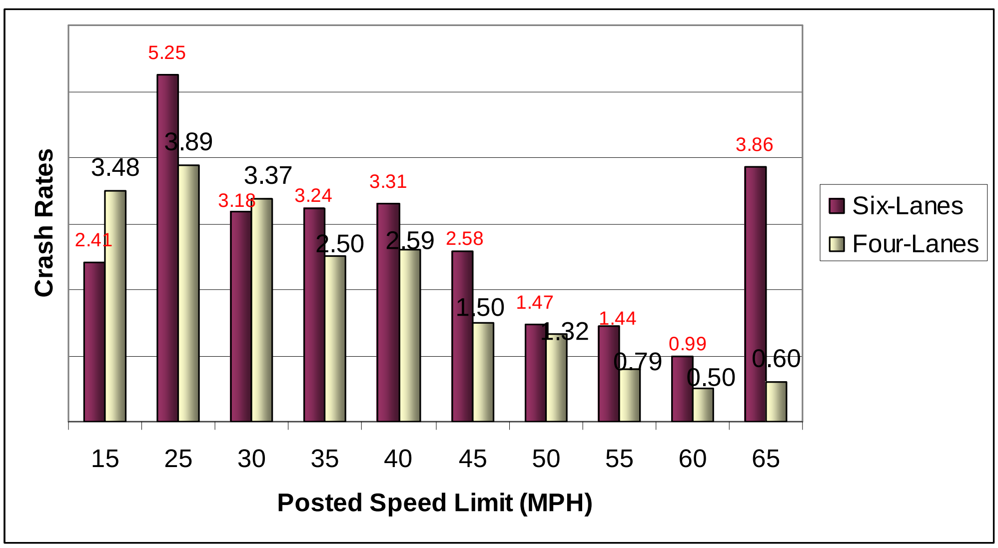


Figure 4.13 Comparison of Crash Rates Based on Posted Speed Limit

Table 4.10 Hypothesis Testing Based on Posted Speed Limit

Test	Value	Null Hypothesis	P-Value	Conclusion
Spearman	Rho= 0.8636	Crash Frequencies are independent	Prob>|t|= 0.0006	Crash frequencies on six and four lanes are not different
	Rho= 0.8613	Fatal Frequencies are independent	Prob>|t|= 0.0007	Fatality frequencies on six and four lanes are not different
	Rho= 0.9000	Injury Frequencies are independent	Prob>|t|= 0.0002	Injury frequencies on six and four lanes are not different
Chi-Square Test		**Calculated Chi-Square $\chi 2_{cal}$**	**Observed Chi-Square (α=0.05) $\chi 2_{\alpha,n-p-1=}$ $\chi 2_{Obs}$**	**Conclusion: Relation between Four- and Six- Lane Crashes**
	Total crashes	7707.255	18.30703	Not Different
	Fatalities	119.4777	18.30703	Not Different
	Injuries	6974.546	18.30703	Not Different

4.14 Shoulder Width

Figure 4.14 shows the trend of crash rates with respect to shoulder width for both four-lane and six-lane sections. The graph shows a decrease in crash rates as the shoulder width increases for both four-lane and six-lane sections. There is a rise in the crash rate as the shoulder exceeds 8 ft on six-lane sections. This effect can be explained by noting that when the shoulder width is too wide some vehicles may use it to overtake other vehicles likely causing crashes. Hypothesis testing resulted in a *p*-value of 0.9717 which means that the distributions of crashes on four-lane and six-lane sections with respect to shoulder width were different. It seems that presence of shoulders influences crashes differently.

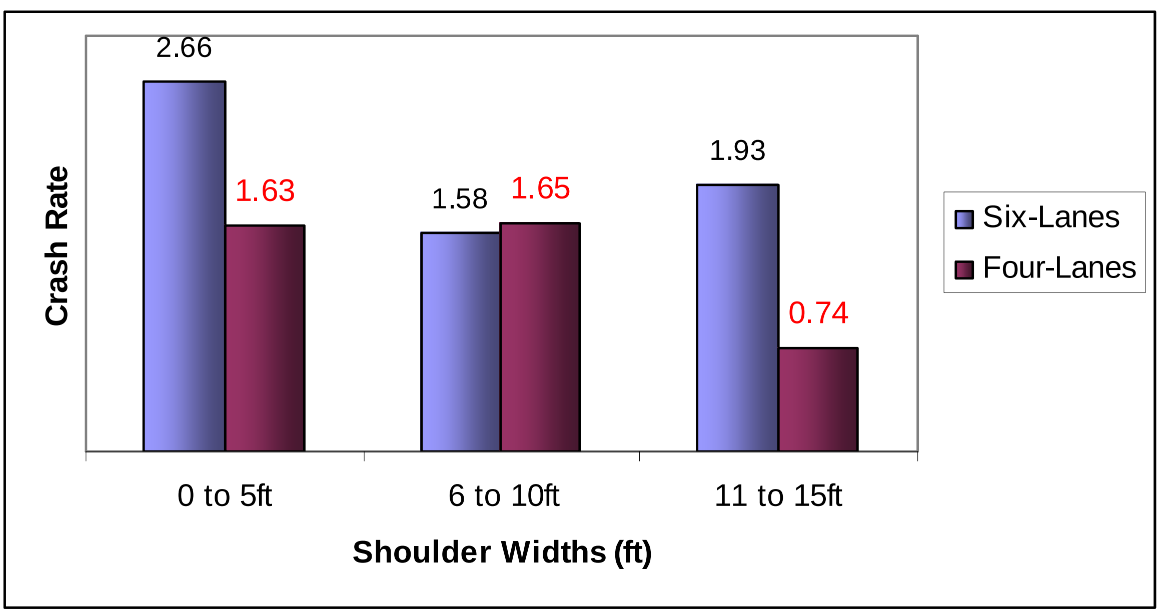


Figure 4.14 Comparisons of Crash Rates Based on Shoulder Width

Table 4.11 Hypothesis Testing Based on Shoulder Width

Test	Value	Null Hypothesis	P-Value	Conclusion
Spearman	Rho= 0.0072	Crash Frequencies are independent	Prob>|t|= 0.9717	Crash frequencies on six and four lanes are different

4.15 Summary

The descriptive statistics displayed in this chapter showed that four-lane sections had more crashes than six-lane sections when comparison is in absolute percentages. The results further show that six-lane sections had higher crash, fatality, and injury rates when compared to four-lane sections in numerous geometric and traffic factors. However, the Spearman and Pearson Chi-square tests showed that four-lane and six-lane crash frequency distributions were not significantly different based on numerous roadway factors.

CHAPTER 5 CRASH RATE MODEL DEVELOPMENT

5.1 Data Collection

Before any analysis effort could begin, extensive amounts of data from different sources had to be collected and prepared. The analysis required that the roadways be segmented and that the crash data file be linked to a roadway features data file. In the final dataset the researchers had each crash linked to the segment on which it occurred, all of the crash detail data, roadway characteristics data, and in some cases signal timing data.

The data came from several sources:

- FDOT crash databases
- Roadway Characteristics Inventory (RCI) file
- FDOT videologs
- Local traffic operations offices

5.1.1 Crash Data

Crash data for the State Highway System (SHS) during the year 2001 was obtained from the FDOT crash database. This dataset contains all crashes, each with an individual identifying number, and all the information coded on the Florida Motor Vehicle Crash Report form. Each crash record includes many crash- and vehicle-level variables. Examples include first harmful event for each vehicle, injury severity, alcohol/drug use, etc. Additionally, some roadway data have been linked to the crash details in the Crash Analysis Reporting System (CARS).

While it contains a wealth of information, the CARS data alone were not adequate to perform the analyses needed for this project. Many roadway variables suspected as being significant are not included within this database. For instance, the CARS does not distinguish between roadways with six lanes and those with more than six lanes. Consequently, the crash data had to be linked to a more comprehensive roadway characteristics data file.

5.1.2 Roadway Characteristics Inventory Data

The Roadway Characteristics Inventory (RCI) contains information on many geometric and operational variables for state-maintained roadways throughout Florida. Examples include shoulder type, pavement surface width, posted speed limit, horizontal degree of curvature, pavement condition, etc. The RCI file was obtained from Florida DOT and was dated 2004. More information about the RCI can be found online at http://www.dot.state.fl.us/planning/statistics/rci/default.htm.

To make the data useful, the six-lane roadways needed to be obtained from the dataset and segmented. As the RCI has a field identifying the number of lanes the first step was simple. However, the RCI does not have an overall segmentation; rather, each item in the RCI is coded for a begin and end milepost. To create an overall segmentation for this project, the researchers identified a set of key variables which they thought influenced crash rates (Appendix A). A spreadsheet was then programmed to determine at what mileposts any key variable changed.

Then the researchers created new segmentation based upon these break points. The segments that were used had a minimum length of 0.05 mile. The resulting roadway characteristics file contained nearly 2000 roadway segments.

5.1.3 FDOT Video Logs

Although the RCI contains a wealth of geometric information, some variables which were thought to be important are not included in the RCI. More specifically, the research team thought that the following non-included variables are important in understanding crashes along six-lane roadways:

- Number of driveways on each side, per mile
- Number of median openings per mile
- Presence of left turn bays (1=yes, 0=no)
- Number of signalized intersections per mile

Fortunately, FDOT maintains videologs of state-maintained roadways throughout Florida. The videologs contain snapshots of roadways at 0.01-mile intervals and are organized according to the roadway ID number. Depending on the roadway, the videologs were filmed from 2001 to 2004.

Each of the segments identified using the RCI database was “driven” using the videologs. The values for these variables were entered into a separate database and then were merged with the segmented RCI file.

5.1.4 Local Traffic Operations Offices

Signal timing had to be obtained from operating agencies. Signal timing plans were obtained from counties and cities and linked to the segmented RCI database. Because of the time required to obtain this data, this data collection effort was limited to FDOT’s District 7.

5.1.5 Linking the Data

The researchers wanted the information in a format that would maximize the analysis types that could be performed on the crash database. Since each crash record had a roadway segment associated with it, the crashes were linked to the RCI variables. Consequently, each crash record contained fields for all the crash, RCI, and median and driveway data, and, in some cases, signal timing information.

The researchers recommended and the FDOT Project Manager concurred that crashes at signalized intersections that should have been eliminated by the presence of the signal should not be included in the models for roadway segment analysis. After discussions with the FDOT PM, it was decided that crashes occurring at signalized intersections would likely be characterized by a violation of the traffic signal. Thus, crashes in which a driver ran a red light were not linked to the roadway segment file and consequently not used in the modeling efforts.

The final roadway segment file was quite extensive and allowed the researchers to determine the number of crashes on each segment with respect to the crash severity. For this project the research team decided to model crash rates for three different levels of crash severity: (1) severe and fatal, (2) non-incapacitating and possible injury, and (3) property damage only. Additionally, the researchers were able to evaluate the pedestrian crashes and bicycle crashes.

This dataset is such that any types of crash could be evaluated, such as wet weather, run off the road, alcohol involved, etc. Although models relating crash types to such variables might provide valuable insights into the safety of six-lane roadways, it was beyond the scope of this study to develop crash type models.

5.1.6 Data variable descriptive statistics

Each variable used to segment the dataset (see Section 3.3.5) and the data collected from the video logs and traffic ops (Section 5.1.3 & 5.1.4) were separately analyzed for potential correlations with the dependent variables (crash rates by severity). Hypotheses were made about each variable with regard to what transformations (natural log, exponential function, inverse function, etc) would likely explain varying crash rates. Then each reasonable transformation was individually evaluated to compare its correlation with the observed crash rates to that of a simple linear function.

There were also numerous options for quantifying the variables. For instance, several different variables were tested to represent the speeds on the roadway: the actual speed limit the roadway and various dummy variable configurations separating speed limits into bins. For conflicts per mile, we tested driveways per mile, unsignalized intersections per mile, and total unsignalized conflicts per mile. For any variations of variables, we also tested transformations of the variables. Based upon the above testing, numerous variables were removed from consideration because of their poor correlation with the dependent variables. Table 5.1 gives a summary of the values of the numerical variables the researchers focused on in this project's model development process.

Table 5.1 Summary of the Measures of Numerical Variables

CODE	Variable	Mean	Std. Dev.	Min	Max
LENGTH	Length	0.26	0.26	0.021	1.925
NUACCESS	Number of Access Points	3	4	0	33
ACDENS	Access Density	14	13	0	153
AVGDFACT	Directional Split	56.70	2.83	51.26	65.13
AVGKFACT	K-Factor	9.09	0.81	7	11.18
AVGTFACT	Truck Factor	4.53	2.67	0.96	19.39
HRZDGCRV	Horizontal degree of Curve	0.50	1.33	0	10.7
MAXSPEED	Posted Speed Limit	43	5	15	65
MEDWIDTH	Median Width	21	9	2	65
PAVECOND	Pavement Condition	3.7	0.9	0	5
SECTADT	AADT	47726	15620	14900	98500
SIDEWALK	Sidewalk	4.4	2.4	0	20
SLDWIDTH	Shoulder Width	2.9	2.1	1	12
SURWIDTH	Surface Width	35	2.03	30	44

IRI	International Roughness Index	102	40	0	275

To obtain an understanding of the relations among independent variables and between the dependent variable, a series of correlations tables were reviewed. Based on indications from these runs, a set of probable independent variables were identified for each of the crash types. Numerous hypotheses were tested before closing in on the set of independent variables. Variable transformations were applied where it was deemed needed to better represent a relation / phenomenon. The final models arrived at included independent variables that were found to be statistically significant at the 90^{th} percentile. Further descriptions of how the variables were used in the final models follows below.

5.2 Crash Rate Models

This study sought to mathematically express the geometric and operational characteristics of roadway segments that affect crash rates for severe/fatal, non-incapacitating/possible injury, and property damage only crashes. An examination of the data revealed that crash rates were not normally distributed. Instead, a large percentage of the roadway segments in the database had no crashes during 2001 and therefore had a crash rate equal to zero. Linear regression models are applicable only when the dependent variable (crash rates) is normally distributed. Both Poisson and negative binomial models are potentially suitable for modeling this type of data, in which many observations have values of zero for the dependent variable. The researchers tested for the presence of a dual state and found zero-inflated models to be the most appropriate. Therefore, both zero-inflated negative binomial models and zero-inflated Poisson models were considered. Because there is significant overdispersion in the data set (i.e., the variance was significantly greater than the mean), a Poisson model was not considered to be appropriate. The zero-inflated negative binomial model was selected as the appropriate model form.

The researchers were concerned that the short length of many segments could have led to a false conclusion that the zero-inflated negative binomial model was appropriate. Consequently, the researchers also checked to see if segment length had an influence in the large percentage of segments with zero crashes. Models were tested on segments with lengths >0.5 miles, >0.3 miles, and >0.05 miles and the results verified that the zero-inflated negative binomial model provided the best fit.

Additional testing was performed on this reduced dataset. Pearson correlations were computed for the variables (Appendix B). Based on the results, the following 11 variables were considered for inclusion in the crash rate models:

1. Access management classification (AcMnCl)
2. D factor (Dfac)
3. K factor (Kfac)
4. Horizontal degree of curvature (HCurDeg)
5. Median width (MedWid)
6. Pavement condition (Pavcon)
7. Outside shoulder width (SldWidth)
8. Inside shoulder width (IsldWidt)
9. Surface width (SurWidth)
10. Driveways per mile (TotdriPM)

11. Signals per mile (SigPM)

The researchers undertook an iterative modeling process, in which they tested each of these 11 variables independently, various combinations of these variables, and transformations of these variables. Seven of the variables proved to be significant in one or more of the final crash rate models:

1. Horizontal degree of curvature (HCurDeg)
2. Median width (MedWid)
3. Outside shoulder width (SldWidth)
4. Inside shoulder width (IsldWidt)
5. Surface width (SurWidth)
6. Driveways per mile (TotdriPM)
7. Signals per mile (SigPM)

Briefly the descriptive statistics for these variables follows in Table 5.2. Detailed distribution information is provided in Appendix E.

Table 5.2 Descriptive Statistics for Model Variables

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
HCurDeg	1975	.00	10.70	.4745	1.21568
MedWid	1975	2.00	800.00	23.9023	27.22210
SldWidth	1975	1.00	12.00	3.1625	2.07781
IsldWidth	1975	.00	8.00	3.5635	2.92353
SurWidth	1975	24.00	48.00	35.0754	1.80534
totdripm	1975	.00	600.00	30.1255	38.89644
sigpm	1975	.00	51.28	4.3636	5.89369
Valid N (listwise)	1975				

Sections 5.2.1 through 5.2.3 describe the final crash rate models in detail. Initially, the researchers tried to develop one model that pertained to all crashes, but the resulting model suggested that a series of three models – one for each level of crash severity – would be more appropriate. For example, horizontal degree of curvature increased the rate of severe/fatal crashes but decreased the rates of non-incapacitating/possible injury and property damage only crashes. Hence, separate models for each level of crash severity were fitted. In each model, the dependent variable was crash rate, expressed as crashes per 100 million vehicle miles (crashes/100 MVMT).

With regard to posted speed limits, the Pearson correlations revealed that most of the independent variables were highly correlated with the posted speed limit. The researchers concluded that the posted speed limit was not an influencing factor in predicting crash rates. Rather, the speed limit was a reflection of the values of the other variables.

The crash rate for a segment was considered to be an outlier if it was more than two standard deviations higher than the mean crash rate. The identification of outliers was carried out separately for severe/fatal, non-incapacitating/possible injury, and property damage only crashes. Prior to model development, segments with outliers were removed from the dataset. This was done separately for each level of crash severity. For example, a segment was deleted from the dataset used to create the severe/fatal model if its severe/fatal crash rate was an outlier. However, that segment was kept in the dataset used to create the property damage only model if its property damage only crash rate was <u>not</u> an outlier. In other words, the datasets used to create the three models were not identical, as different segments were deleted from each.

There are certainly many other (unobserved) variables for which a strong correlation cannot be shown that influence the crash rates. These include such things as the condition or awareness of the driver, weather conditions, and temporary roadway hazards. These non-modeled variables are without doubt significant contributors to the crash rates. Driver related factors are typically considered be the most important contributor to crashes (in some cases given credit for causing up to 80 %of crashes), however, that information cannot be determined through existing databases or field measurements and is therefore unobserved by the modeling process. This presents a major challenge for producing models with high correlations of fit with the source data based upon the physical characteristics of the roadway. The lack of fit of proposed models, however, should not be used to dismiss the models' usefulness. While predicting an actual crash rate cannot be done with great accuracy, the correlations of the independent variables to the crash rates do provide valuable insight into the roadway characteristics that influence crash rates.

5.2.1 Severe and Fatal Crashes

The model for severe and fatal crashes was developed based on 1,545 segments. It is as follows:
Severe and Fatal Crash Rate = 3.9026 + 0.0308 HCURDEG + 0.286 SIGPM – 0.0216 ISLDWIDT – 0.0156 SLDWIDTH – 0.0017 MEDWID

As shown in Table 5.3, these variables were found to be statistically significant: (1) Signals per mile (SIGPM), and (2) Inside shoulder width (ISLDWIDT), in feet. This model includes three additional variables that are not statistically significant: (3) Horizontal degree of curvature (HCURDEG), in degrees, (4) Outside shoulder width (SLDWIDTH), in feet, and (5) Median width (MEDWIDTH), in feet. Histograms and frequency distribution tables of these and other variables are in Appendix C.

Table 5.3 Severe and Fatal Crashes – Model Coefficients and Statistics

Variable	Coefficient	Standard Error	b/St.Er.	P[Z]>z	Mean of X
Constant	3.90259462	.07922201	49.261	.0000	
HCURDEG	.03082006	.02606036	1.183	.2370	.47368285
SIGPM	.02859905	.00535165	5.344	.0000	4.30435599
ISLDWIDT	-.02161111	.00796378	-2.714	.0067	3.56957929
SLDWIDTH	-.01558822	.01328139	-1.174	.2405	3.16796117
MEDWID	-.00170746	.00289369	-.590	.5551	23.5799353
Alpha	.37816326	.03671053	10.301	.0000	

Tau	.03664763	.01233541	2.971	.0030

Alpha is the dispersion parameter and tau is a parameter for the zero inflation model.
As can be seen from the above table the model terms have strong correlations with the crash rates. Figure 5.1 shows the observed and predicted crash rates for the fatal / severe injury model.

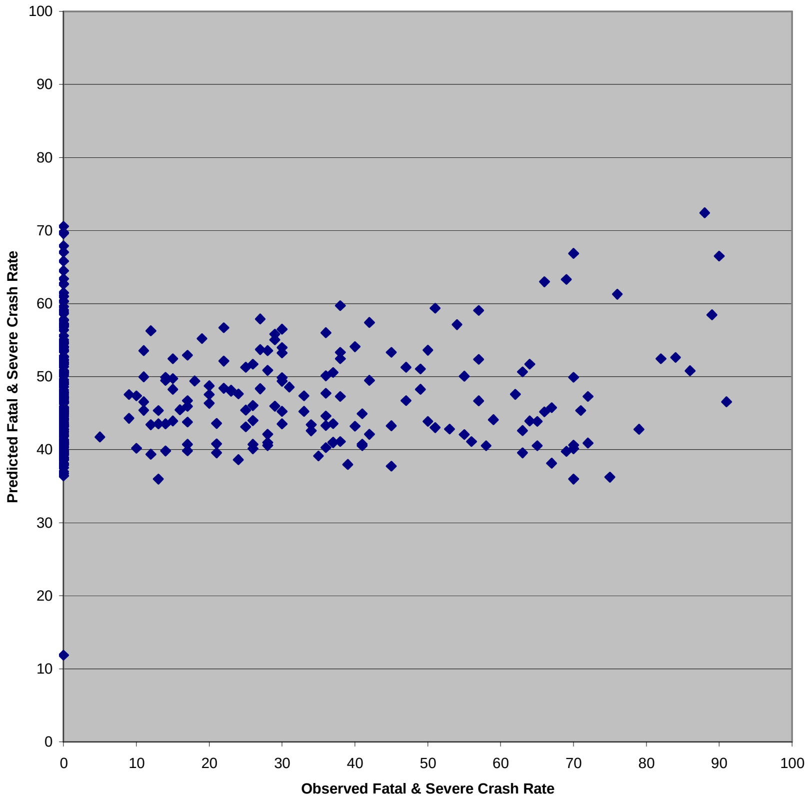


Figure 5.1 Predicted vs. Observed Crash Rates – Fatal/Severe

5.2.2 Non-incapacitating and Possible Injury Crashes

The model for non-incapacitating and possible injury crashes was developed based on 1,558 segments. It is as follows:
Non-incapacitating and Possible Injury Crash Rate = 5.0665 – 0.0447 HCURDEG + 0.0016 TOTDRIPM + 0.0509 SIGPM – 0.0245 ISLDWIDT – 0.0484 SLDWIDTH

As shown in Table 5.4, these variables were found to be significant: (1) Horizontal degree of curvature (HCURDEG), in degrees, (2) Total driveways per mile (TOTDRIPM), (3) Signals per mile (SIGPM), (4) Inside shoulder width (ISLDWIDT), and (5) Shoulder width (SLDWIDTH). The histograms and frequency distribution tables of these and other variables are in Appendix D.

As mentioned in Section 3.1, we randomly selected 80% of the data for model development and used 20% of the data for model validation. As can be seen in Table 5.3 the model terms have strong correlations with the crash rates. Figure 5.2 shows the observed and predicted crash rates for the non-incapacitating / possible injury model.

Table 5.4 Non-incapacitating and Possible Injury Crashes – Model Coefficients and Statistics

Variable	Coefficient	Standard Error	b/St.Er.	P[Z]>z	Mean of X
Constant	5.06651355	.04727706	107.166	.0000	
HCURDEG	-.04474767	.01802106	-2.483	.0130	.48989089
TOTDRIPM	.00163933	.00054235	3.023	.0025	29.7987356
SIGPM	.05090045	.00335587	15.168	.0000	4.21589859
ISLDWIDT	- .02450391	.00665571	-3.682	.0002	3.63607189
SLDWIDTH	- .04838232	.00783622	-6.174	.0000	3.17329910
Alpha	.52978498	.01919589	27.599	.0000	
Tau	- .15341166	.00801502	-19.141	.0000	

Alpha is the dispersion parameter and tau is a parameter for the zero inflation model.

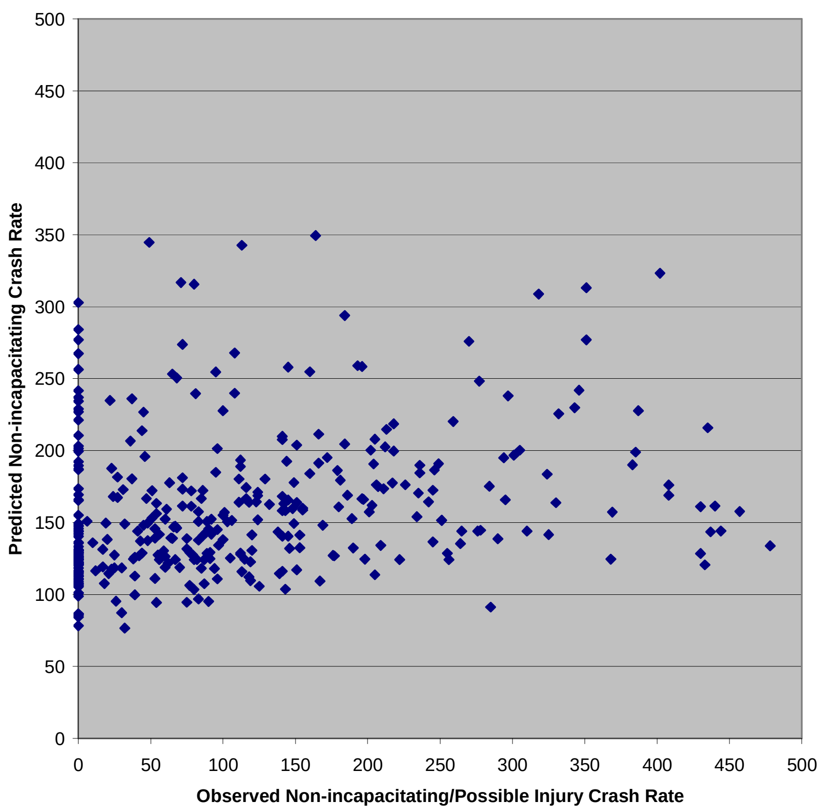


Figure 5.2 Predicted vs. Observed Crash Rates – Non-incapacitating/Possible Injury

5.2.3 Property Damage Only Crashes

The model for property damage only crashes was developed based on 1,506 segments. It is as follows:

Property Damage Only Crash Rate = 7.4675 + 0.0017 TOTDRIPM – 0.0521 HCURDEG + 0.0492 SIGPM – 0.0196 ISLDWIDT – 0.0234 SLDWIDTH – 0.0063 MEDWID – 0.0682 SURWIDTH

As shown in Table 5.5, these variables were found to be significant: (1) Total driveways per mile (TOTDRIPM), (2) Horizontal degree of curvature (HCURDEG), in degrees, (3) Signals per mile (SIGPM), (4) Inside shoulder width (ISLDWIDT), in feet, (5) Shoulder width (SLDWIDTH), in feet, (6) Median width (MEDWIDTH), in feet, and (7) Surface width (SURWIDTH), in feet. The histograms and frequency distribution tables of these and other variables are in Appendix E.

Table 5.5 Property Damage Only Crashes – Model Coefficients and Statistics

Variable	Coefficient	Standard Error	b/St.Er.	P[Z]>z	Mean of X
Constant	7.46746992	.49098425	15.209	.0000	
TOTDRIPM	.00166889	.00076008	2.196	.0281	29.1482935
HCURDEG	- .05211821	.01792429	- 2.908	.0036	.50313413
SIGPM	.04924155	.00500854	9.832	.0000	4.17300797
ISLDWIDT	- .01963261	.00772817	- 2.540	.0111	3.59694555
SLDWIDTH	- .02338018	.00869786	- 2.688	.0072	3.20385126
MEDWID	- .00630954	.00187049	- 3.373	.0007	23.7343958
SURWIDTH	- .06820171	.01394311	- 4.891	.0000	35.0876494
Alpha	.64758585	.02723195	23.780	.0000	
Tau	- .11493519	.00812804	-14.141	.0000	

Alpha is the dispersion parameter and tau is a parameter for the zero inflation model.

As can be seen from the above table the model terms have strong correlations with the crash rates. Figure 5.3 shows the observed and predicted crash rates for the PDO model.

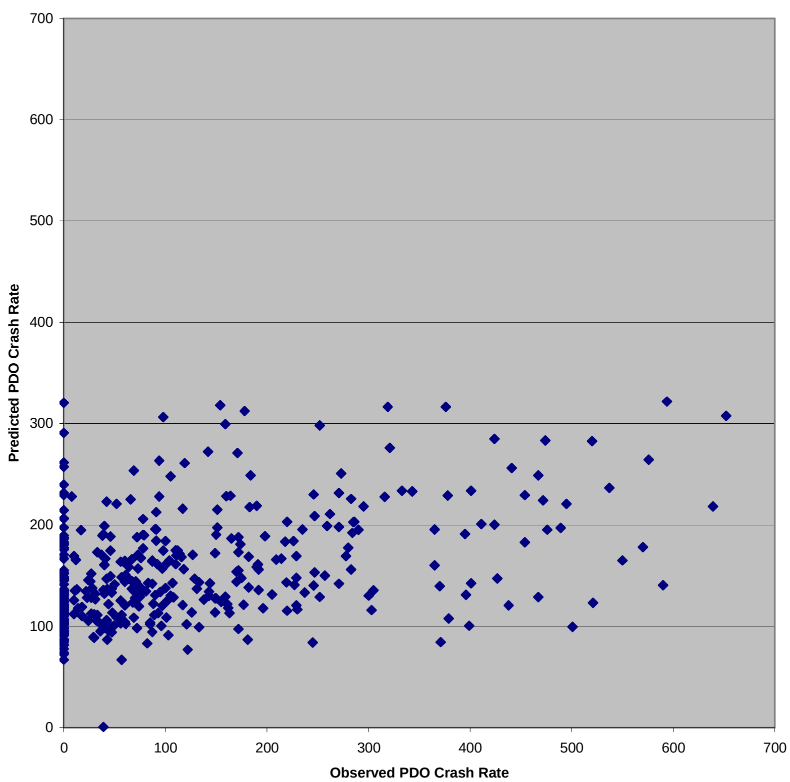


Figure 5.3 Predicted vs. Observed Crash Rates - PDO

5.2.4 *Bicycle and Pedestrian Crashes*

The researchers attempted to create models for pedestrian crashes and bicyclist crashes. While models could have been developed, the form of those models is inconsistent with reasonable explanations. Because there is no measure of exposure for pedestrians and bicyclists, the models appear to be predicting where walking and bicycling are occurring rather than the relative risks associated with the roadways.

5.2.5 *Summary*

Separate models were developed for (1) severe and fatal crashes, (2) non-incapacitating and possible injury crashes, and (3) property damage only crashes. Table 5.7 lists the variables in each model. Two variables, signals per mile (SIGPM) and inside shoulder width (ISLDWIDT), are present in all three models. In all three models, an increase in the number of signals per mile increased the crash rate. An increase in the inside shoulder width reduced the crash rate. Horizontal degree of curvature (HCURDEG) is present in both the non-incapacitating/possible injury and property damage only models; an increase in horizontal degree of curvature reduced the crash rate. Total driveways per mile is present in both the non-incapacitating/possible injury and property damage only models; an increase in the number of driveways per mile increased the crash rate. Outside shoulder width (SLDWIDTH) is present in these two models as well; an increase in the outside shoulder width reduced the crash rate. Median width (MEDWID) and surface width (SURWIDTH) are present in the property damage only model; increases in the median width or the surface width decreased the crash rate. Explanations for these findings are as follows:

- Horizontal degree of curvature (HCURDEG) – Motorists may be more alert while driving on roads with curves than on completely straight roads.
- Signalized intersections (SIGPM) – Closely-spaced signalized intersections not only create more conflict points between streams of opposing traffic, but also affect traffic operations upstream and downstream, as motorists change lanes or slow down for queues. These behaviors potentially lead to conflicts.
- Inside shoulder width (ISLDWIDT) – A wider inside shoulder gives errant motorists room to recover and reduces the likelihood that they will cross the median and collide with oncoming traffic in the opposite direction.
- Total driveways per mile (TOTDRIPM) – Closely-spaced driveways create more conflict points between traffic on the roadway and traffic entering or leaving driveways. They also affect traffic operations upstream and downstream, as motorists change lanes or slow down for motorists turning into or out of driveways. These behaviors potentially lead to conflicts.
- Outside shoulder width (SLDWIDTH) – A wider outside shoulder gives errant motorists room to recover and reduces the likelihood that they will collide with a fixed object alongside the roadway.
- Median width (MEDWIDTH) – A wider median gives errant motorists room to recover and reduces the likelihood that they will cross the median and collide with oncoming traffic in the opposite direction.
- Surface width (SURWIDTH) – As lane width increases, motorists have more room to travel and are less likely to encounter one another.

Table 5.7 Comparison of Crash Models

Variable	Severe/Fatal	Non-Incapacitating / Possible Injury	Property Damage Only
HCURDEG	+ (n.s.)	- [a]	-
SIGPM	+	+	+
ISLDWIDT	-	-	-
TOTDRIPM	NA [b]	+	+
SLDWIDTH	- (n.s.)	-	-
MEDWID	- (n.s.)	NA	-
SURWIDTH	NA	NA	-

[a] A plus sign (+) indicates that, as the value of the variable increases, the crash rate also increases. A minus sign (-) indicates that, as the value of the variable increases, the crash rate decreases. "n.s." indicates that the variable is not statistically significant but is included in the model. A blank indicates that the variable is not included in the model.
[b] NA = Not applicable – this variable is not in this model.

5.3 Implications for FDOT

The models show that crash rates are affected by a variety of variables (Tables 5.1 through 5.5). As described below, these variables can be controlled by FDOT:

5.3.1 Horizontal Degree of Curvature

The model results indicate that increasing the horizontal degree of curvature reduces the rates of non-incapacitating and property damage only crashes. The researchers believe this is attributable to a higher level of driver awareness when driving on curves. Sensitivity analyses for horizontal degree of curvature are shown in Figures C-5 (severe/fatal crashes), D-5 (non-incapacitating/possible injury crashes), and E-1 (PDO crashes). Figure E-1 shows, for example, that increasing the degree of curvature from 2^{o} to 4^{o} would reduce the PDO crash rate from about 138 to about 123 per MVMT.

For freeways, the American Association of State Highway and Transportation Officials (AASHTO) recommends a proper combination of flat curvature, shorter tangents, gentle grades, variable median widths, and separate roadway elevations to enhance the safety and aesthetic aspects of freeways. This might hold true in the case of six-lane highways in Florida. The FDOT Plans Preparation Manual recommends a maximum horizontal degree of curvature of 10^{o} 15' for a rural environment and 8^{o} 15' for an urban environment on a 45 mph roadway.

As shown below there is a negative correlation (increasing curvature correlated with decreasing crash rates) for horizontal curvature to crash rates for PDO and non-incapacitating injury crashes (Figures 5.4 and 5.5). With respect to fatal injury crash rates, there is no well defined correlation (Figure 5.6). However, the correlation that is suggested is that when the horizontal degree of curvature is increased the incapacitating and fatal injury crash rate increases. Given the statistically significant correlations of increasing horizontal curvature with decreasing PDO and non-incapacitating injury crashes, the researchers believe that this potential undesirable correlation is the result of the increasing difficulty to recover from a run off the road crash that occurs on a curved section versus on a tangent section.

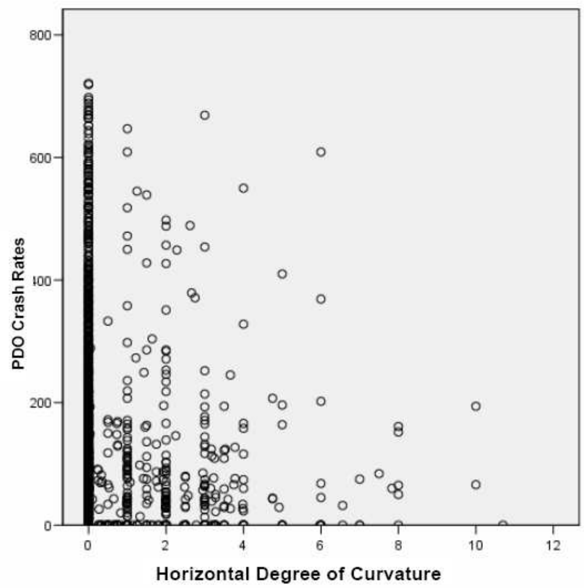


Figure 5.4 PDO Crash Rates v. Degree of Horizontal Curvature

Essentially, if vehicle leaves the roadway on the outside of a curve, the vehicle's angle of departure from the roadway is increased with increasing degree of curvature. This would result in decreased time to cross the available clear zone. Motorists may also experience difficulties recovering on the inside of a curve because of over compensating but this was seen as a less likely scenario.

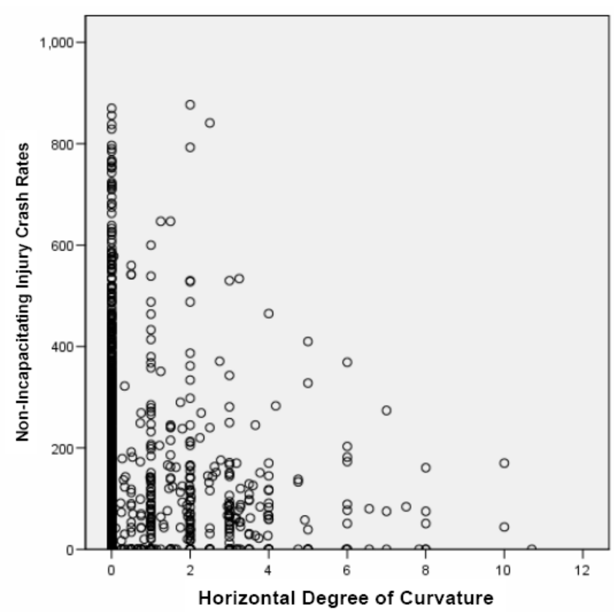


Figure 5.5 Non-incapacitating Injury Crash Rates v. Degree of Horizontal Curvature

Because of the potential for increasing crashes and the theoretical rational for the increasing degree of curve, increasing incapacitating and fatal injury correlation, the researchers decided to retain this term in this model.

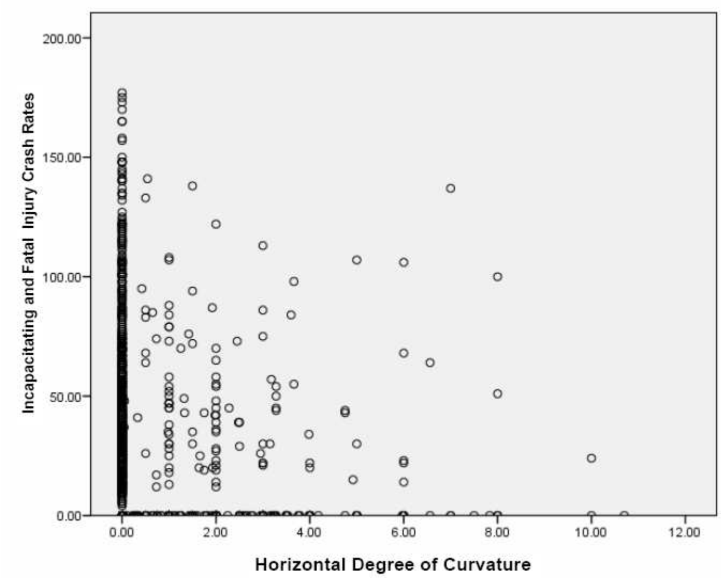


Figure 5.6 Incapacitating and Fatal Injury Crash Rates v. Degree of Horizontal Curvature

5.3.2 Median Width

The median separates opposing directions of the traveled way. Median width is defined as the distance between the edges of the roadway in each direction plus the widths of any inside shoulders. AASHTO recommends that where possible, medians be wide enough so that there is no median barrier needed. Table 2.2.1 of the FDOT Plans Preparation Manual requires a median width of at least 40 feet on arterial roadways with design speeds in excess of 45 mph, and at least 22 feet on arterial roads with design speeds of 45 mph or less. The minimums may be reduced to either 15.5 ft or 19.5 ft, depending on design speed, on reconstruction projects with severe right-of-way constraints.

The models indicate that increasing the median width reduces crash rates. Sensitivity analyses for severe/fatal crashes (Figure C-3) and for PDO crashes (Figure E-4) are shown in the Appendices. Figure E-4 shows, for example, that increasing the median width from 20 ft to 40 ft would reduce the PDO crash rate from just over 150 to about 135 crashes per 100 MVMT. The results support FDOT's median width policy. The researchers strongly endorse FDOT's efforts to implement the median width requirements on all new roadways. Moreover, where right-of-way is available, deficient median widths should be widened during projects on existing roadways.

5.3.3 Shoulder Width and Inside Shoulder Width

Wider shoulder widths reduce crash rates and hence a wider shoulder width is recommended to reduce crash rates on six-lane highways in Florida. AASHTO recommends a minimum shoulder width of 8 ft for divided six-lane rural arterials and 10 ft for urban arterials. AASHTO also recommends 10-ft shoulders for heavily-traveled roadways. Table 2.3.2 of the FDOT Plans Preparation Manual requires outside shoulder widths of 8, 10, or 12 ft, depending on low, normal, or high volume, for divided six-lane arterials .

Sensitivity analyses for shoulder width are shown in Figures C-1 (severe/fatal crashes), D-2 (non-incapacitating/possible injury crashes), and E-5 (PDO). Figure D-2 shows, for example, that increasing shoulder width from 2 ft to 4 ft would reduce the non-incapacitating/possible injury crash rate from about 165 to 150 per 100 MVMT. Figures C-4 (severe/fatal crashes), D-4 (non-incapacitating/possible injury crashes), and E-5 (PDO crashes) depict the sensitivity analyses for inside shoulder width.

The results support FDOT's shoulder width policy. The researchers strongly endorse FDOT's efforts to implement the shoulder width requirements on all new roadways. Moreover, where right-of-way is available, deficient shoulder widths should be widened during new roadway construction projects, and on reconstruction/resurfacing projects.

5.3.4 Surface Width

An increased surface width was found to reduce crash rates. The Roadway Characteristics Inventory defines surface width as the total width of all through lanes in a single direction. That is, surface width depends on both the number of through lanes and the lane widths. The Plans Preparation Manual states that the standard practice is to provide lane widths as wide as practical, up to 12 ft (Section 2.1.1). The results of the present research support FDOT's current practice (versus narrower lane widths), as wider lane widths mean wider surface widths, which would reduce crash rates and hence result in safer driving conditions.

5.3.5 Signals per Mile and Driveways per Mile

The number of signals per mile ranged from 0 to 51. This value was measured on a per-segment basis and is not indicative of the entire roadway length. For example, suppose that Segment #1 is 300 feet and Segment #2 is 600 feet. If both segments have one signal, the number of signals per mile on Segment #1 will be twice the number on Segment #2, because Segment #1 is half the length. However, the reader should not conclude that the roadway containing Segment #1 has more closely-spaced signals along its entire length than the roadway containing Segment #2.

The number of driveways per mile referred to the total in both directions of travel and ranged from 0 to 600. Again, this value was measured on a per-segment basis and is not indicative of the entire roadway length. For example, suppose that Segment #1 is 300 feet and Segment #2 is 600 feet. If both segments have one driveway, the number of driveways per mile on Segment #1 will be twice the number on Segment #2, because Segment #1 is half the length. However, the reader should not conclude that the roadway containing Segment #1 has more closely-spaced driveways along its entire length than the roadway containing Segment #2.

Roughly 80 percent of the roadway segments included in this study had Access Management Class 3 or 5. FDOT's State Highway Access Management Classification System and Standards provide for minimum driveway spacing of 440 feet (Class 3) and 245 feet (Class 5), when the posted speed limit is 45 mph or less. On higher-speed roads, the spacings increase to 660 feet and 440 feet, respectively. On Class 3 roadways, the minimum signal spacing is 0.5 mile. On Class 5 roadways, the minimum signal spacing is 0.25 mile (posted speed limit 45 mph or less) and 0.5 mile (higher speed limits). The standards are contained within Section 1.8 of the Plans Preparation Manual (the entire rule is available online at http://www.dot.state.fl.us/planning/systems/sm/accman/pdfs/1497.pdf).

Sensitivity analyses for driveways per mile are shown in Figures D-1 (non-incapacitating/possible injury crashes) and E-2 (PDO crashes). Figure C-1 shows, for example, that reducing the number of driveways per mile from 40 to 20 would reduce the PDO crash rate from about 151 to 146 per 100 MVMT. Figures D-3 (non-incapacitating/possible injury crashes) and E-3 (PDO) depict the sensitivity analyses for signalized intersections per mile.

The results support FDOT's access management policies. The researchers acknowledge that FDOT must balance safety with the access needs of residents and businesses. Nevertheless, we strongly endorse FDOT's efforts to enforce its access management policies when considering applications for new driveway connections and signalized intersections.

5.4 Concluding Remarks

The results of this research strongly support FDOT’s standards, as stated in the Plans Preparation Manual and the State Highway Access Management Classification System and Standards. The information obtained by this research will help designers make decisions on what roadway treatments may be appropriate and under what conditions. Although FDOT has comprehensive design and operational standards, these standards provide some flexibility to individual designers / engineers. In some cases, this flexibility is required to address right-of-way or environmental constraints. At other times, the flexibility allows for the accommodation of local community preferences. Additionally, various designers / engineers may apply the standards differently from each other. However, the researchers strongly recommend that FDOT weigh the advantages of granting exceptions to the standards against the potential for reduced safety. By implementing the results of this research, FDOT will be able to continue to provide for the roadway capacity needs of Florida while maintaining or improving the safety of its roadways.

CHAPTER 6 IMPLEMENTATION

6.1 Awareness Presentation

The Florida Department of Transportation has excellent roadway design standards and operations standards. The values for the criteria contained within the standards provide for safe roadways. However, there are situations where, because of constraints, the design or recommended values cannot be attained. The researchers understand that this is unavoidable; in some cases the designer must consider variances and/or exceptions to the design standards.

The researchers feel that awareness presentations to make engineers aware of the results of this study would serve to inform them of the safety impacts of specific design scenarios. Consequently, we recommend awareness presentations of our models – how and why they were developed, what the results mean, and how they can be applied. Additionally, the findings of this research could be incorporated into future Plans Preparation Manual (PPM) update trainings and Access Management training. An annotated PowerPoint presentation is included in Appendix G.

6.2 Project Information Sheet

It is important to realize that the models developed in this research are not intended to be used in “what-if” analyses (such as “What if we had a 14-foot lane, instead of the 12 feet required by the PPM?”). Rather, the models can assist the engineer in a comparative analysis of roadway safety in accordance with standards vs. designed type of analysis. This analysis would analyze the safety impacts of designs implemented with one or more exceptions granted. The reader is advised that the removal or flattening of a curve is a singular design decision and should be analyzed as such. That is, the removal of each curve should be reviewed separately.

An example of how this analysis could be implemented is through a Project Information Sheet (Appendix F, also available as a Microsoft Excel spreadsheet). Such a calculation sheet could be incorporated into the PPM to address the requirements of Chapter 23 (Section 23.2.2.4). The top portion of the sheet contains the following information:

- Project Description - This is a brief description such as “Add one travel lane in each direction” or “Construct paved shoulder.”
- Financial Project ID
- County Section Number
- State Road Number
- Federal Aid Number
- Begin Project MP
- End Project MP
- Date
- Completed by
- Length of Section (miles)
- Life of Project (years)
- ADT

- Year – This is the year for which the ADT is applicable.
- Annual Growth Rate (percent)
- Vehicle Miles, 1st Year – This cell contains a formula and a value of "0" initially appears in this cell as a "placeholder." Once Life of Project and ADT are entered, the calculated Vehicle Miles, 1st Year appears in this cell.

For the following, both the standard values (from the PPM) and the proposed values (may be PPM values or may be exception values) should be entered into the appropriate cells:

- Horizontal Degree of Curvature (degrees)
- Signals per Mile
- Inside Shoulder Width (feet)
- Median Width (feet)
- Outside Shoulder Width (feet)
- Total Driveways per Mile
- Surface Width (feet)

The spreadsheet calculates the following:

- Projected Crash Rate (per 100 million vehicle miles) – These are calculated for (1) fatal and severe crashes, (2) non-incapacitating and possible injury crashes, and (3) PDO crashes, using the respective models and either the standard or the proposed values. As these cells contain formulas, initially various values appear as "placeholders." Once Horizontal Degree of Curvature, Signals per Mile, etc., have been entered, the projected crash rates will appear in these cells.
- Projected Number of Crashes – These are annual numbers of crashes for each level of crash severity and for standard vs. proposed. The volume used to calculate the projected number of crashes is an average volume over the life of the project. Initially, various values appear as "placeholders."
- Projected Number of Crashes over Lifetime of Project – These are the projected total number of crashes for each level of crash severity and for standard vs. proposed. Again, the volume used for this calculation is the average volume over the life of the project. Initially, various values appear as "placeholders."
- Difference – A positive difference indicates that constructing the roadway using the proposed values for Horizontal Degree of Curvature, Signals per Mile, etc., would result in more crashes for that level of crash severity, compared to using the standard values from the PPM. That is, the exceptions would <u>worsen</u> safety. A negative difference indicates that constructing the roadway using the proposed values would result in fewer crashes, compared to using the standard values from the PPM. In that case, the exceptions would <u>improve</u> safety. Initially, zeroes appear as "placeholders."
- Cost per Crash – These are the average costs per crash for each level of crash severity.
- Projected Crash Costs over Lifetime of Project – These are the projected total costs for crashes with each level of severity, over the lifetime of the project, and for standard vs. proposed. The inflation rate is assumed to be zero. Initially, zeroes appear as "placeholders."
- Savings – A positive savings indicates that constructing the roadway using the exceptions would reduce crash costs (because of fewer crashes). A negative savings indicates that

constructing the roadway using the exceptions would increase crash costs (because of more crashes). Initially, zeroes appear as “placeholders.”

By completing the Project Information Sheet, the engineer can easily see the safety and cost effects of applying the standards versus granting exceptions to standards.

REFERENCES

Abdel-Aty, M.A., and Radwan, A.E. "Modeling Traffic Accident Occurrence and Involvement." *Accident Analysis and Prevention* 34, 2000, pp. 633-642.

American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 2004.

Aruldhas, J. *Examination of Statistical Relationships between Highway Crashes and Highway Geometric and Operational Characteristics of Two-Lane Urban Highways*. PhD Thesis, University of Florida, 1998.

Cameron, A.C. and Trivedi, P.K. *Regression Analysis of Count Data.* Cambridge University Press, 1998.

Clarke, R.M., Leasure, W.A., Jr., Radlinski, R.W., Smith, M. *Heavy Truck Safety Study*. Publication No. HS-807 109. National Highway Traffic Safety Administration, Washington, DC, 1987.

Florida Department of Transportation. *2002 Quality / Level of Service Handbook*. Tallahassee, FL. Available online at http://www11.myflorida.com/planning/systems/sm/ los/default.htm.

Garber, N.J. *The Effect of Speed, Flow, and Geometric Characteristics on Crash Rates for Different Types of Virginia Highways*. Virginia Transportation Council, 2000.

Garber, J.N., and Gadiraju, R. "Factors Affecting Speed Variance and Its Influence on Accidents." *Transportation Research Record No. 1213*, 1989, pp. 64-71.

Gluck, J., Levinson H.S., and Stover, V.G. *Impacts of Access Management Techniques*. NCHRP Report 420, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1999.

Greibe, P. "Accident Models for Urban Roads." *Accident Analysis and Prevention* 35, 2001, pp. 273-285.

Hadi, M.A., Aruldhas, J., Chow, L.F., and Wattleworth, J.A. *Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression*. Transportation Research Center, University of Florida, 1995.

Hardin, J. and Hilbe, J. *Generalized Linear Models and Extension*. Stata Corportation, 2001.

Harwood, D.W. *Multilane Design Alternatives for Improving Suburban Highways*. NCHRP Report 282, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1986.

Harwood, D.W., Council, F.M., Hauer, E., Hughes, W.E., and Vogt, A. *Prediction of the Expected Safety Performance of Rural Two-Lane Highways.* Publication No. FHWA-RD-99-207. Federal Highway Administration, McLean, VA, September 2000.

Hiselius, L.W. "Estimating the Relationship between Accident Frequency and Homogeneous and Inhomogeneous Traffic Flows." *Accident Analysis and Prevention* 36, 2004, pp. 985-992.

Ivan, J.N., Pasupathy, R.K., and Ossenbruggen, P.J. "Differences in Causality Factors for Single and Multi-Vehicle Crashes on Two-lane Roads." *Accident Analysis and Prevention* 31, 1999, pp. 695-704.

Johnston, I.R. "Modifying Driver Behaviour on Rural Road Curves--A Review of Recent Research." *Proceedings of the Eleventh Australian Road Research Board Conference*. University of Melbourne, Australia, 1982.

Karlaftis, M.G., and Golias, I. "Effect of Road Geometry and Traffic Volumes on Rural Roadway Accident Rates." *Accident Analysis and Prevention 34*, 2002, pp. 357-365.

Lee, J. and Mannering, F. "Impact of Roadside Features on the Frequency and Severity of Run-Off-Roadway Accidents: An Empirical Analysis." *Accident Analysis and Prevention* 34, 2000, pp. 149-161.

Long, J. and Freese, J. *Regression Models for Categorical Dependent Variables Using Stata*. Stata Corportation, 2003.

Martin, J.L. "Relationship between Crash Rate and Hourly Traffic Flow on Interurban Motorways." *Accident Analysis and Prevention* 34, 2002, pp. 619-629.

Miaou, S. "The Relationship between Truck Accidents and Geometric Design of Road Sections: Poisson versus Negative Binomial Regressions." *Accident Analysis and Prevention* 26, 1993, pp. 471-482.

Miaou, S. and Lump, H. "Modeling Vehicle Accidents and Highway Geometric Design Relationships." *Accident Analysis and Prevention* 25, 1993, pp. 689-709.

Milton, J., and Mannering, F. "The Relationship among Highway Geometrics, Traffic-Related Elements and Motor-Vehicle Accident Frequencies." *Transportation* 25, 1998, pp. 395-413.

Mouskos, K. C., Sun, W., and Qu, T. *Impact of Access Driveways on Accident Rates At Multilane Highways*. National Center for Transportation and Industrial Productivity, New Jersey Institute of Technology, 1999.

Noland, R.B., and Oh, L. "The Effect of Infrastructure and Demographic Change on Traffic-Related Fatalities and Crashes: A Case Study of Illinois County-Level Data." *Accident Analysis and Prevention* 36, 2004, pp 525–532.

Ossenbruggen, P.J., Pendharkar, J., and Ivan, J. "Roadway Safety in Rural and Small Urbanized Areas." *Accident Analysis and Prevention* 33, 2001, pp. 485-495.

Papayannoulis, V., Gluck, J.S., and Feeney, K. "Access Spacing and Traffic Safety." *Transportation Research Circular E-C019: Urban Street Symposium*. Conference Proceedings, Dallas, TX, June 28-30, 1999.

Persaud, B., Hauer E., Retting, R., Vallurupalli, R., and Mucsi, K. *Crash Reductions Related to Traffic Signal Removal in Philadelphia*, 1997.

Poch, M., and Mannering, F. "Negative Binomial Analysis of Intersection-Accident Frequencies." *Journal of Transportation Engineering* 122, 1996, pp. 105-113.

Qin, X., Ivan, J.N., and Ravishanker, N. "Selecting Exposure Measures in Crash Rate Prediction for Two-Lane Highway Segments." *Accident Analysis and Prevention* 36, 2004, pp.183-191.

Retting, R. A., Weinstein, H.B., Williams, A.F., and Preusser, D.F. "A Simple Method for Identifying and Correcting Crash Problems on Urban Arterial Streets." *Accident Analysis and Prevention* 33, 2001, pp.723-734.

Sawalha, Z. "Statistical Issues in Traffic Accident Modeling." In *Proceedings of the 82th Annual Meeting of the Transportation Research Board*, January 12-16, Washington, D.C, 2003.

Sawalha, Z., and Sayed, T. "Evaluating Safety of Urban Arterial Roadways." *Journal of Transportation Engineering* 127, 2001, pp. 151-158.

Staplin, L., Lococo, K., Byington, S., and Harkey, D. *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*. Publication No. FHWA-RD-01-051. Federal Highway Administration, McLean, VA, May 2001.

Tarso, P., Resende, V., and Benekohal, R.F. "Effects of Roadway Section Length on Accident Modeling." *Traffic Congestion and Traffic Safety in the 21$_{st}$ Century*. Proceedings of the ASCE Conference, Chicago, IL, June 8-11, 1997, pp. 403-409.

Turner, S., and Nicholson, A. "Intersection Accident Estimation: The Role of Intersection Location and Non-Collision Flows." *Accident Analysis and Prevention* 30, 1998, pp. 505-517.

Washington. S.P., Karlaftis, M.G., and Mannering, F.L. *Statistical and Econometric Methods for Transportation Data Analysis*. Chapman & Hall/CRC, 2002.

Zegeer, C.V., Stewart, R., and Council, F. *Roadway Width for Low-Traffic-Volume Roads.* NCHRP Report 362, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1994.

APPENDIX A LIST AND DEFINITIONS OF VARIABLES USED IN SEGMENTATION

This Appendix includes the variable names and appropriate codes for each variable. A complete description of most variables is include in the RCI Field Handbook (available online at http://www.dot.state.fl.us/planning/statistics/RCI/fieldhandbook/fulldoc121505.pdf). Non-RCI variables have more complete definitions and some variables that were not considered in this project were removed from the list.

Variable Name	Description	Data Type	Code	Detail
ACMANCLS	Access Management Classified Code	Character		This code is used for all driveway permitting and design in all major capacity improvements
			Not Applicable	
			Freeway	
			Access Class 02	
			Access Class 03	
			Access Class 04	
			Access Class 05	
			Access Class 06	
			Access Class 07	
			Corridor Access Plan	
AVGDFACT	Roadway Section Average "D" Factor	Numeric (Version00)	*	AVGDFACT Characteristic shows the percentage of 30th highest hourly volume in the predominant direction. It is a percentage of SECTADT.
	Roadway Section Average "D" Factor Number	Decimal (Version01)		
AVGKFACT	Roadway Section Average "K" Factor	Numeric (Version00)	*	AVGKFACT Characteristic shows the percentage of the AADT that occurs during the 30th highest volume hour of the year. It is a percentage of SECTADT.
	Roadway Section Average "K" Factor Number	Decimal (Version01)		

AVGTFACT	Roadway Section Average "K" Factor	Numeric (Version00)	*	AVGTFACT Characteristic shows the percentage of the AADT that consists of trucks. Here "trucks" means vehicles in Classifications 4 through 13 of FHWA's Scheme F. This includes buses and trucks larger than pickups. It does not include motorcycles, passenger cars, pickups , or SUVs. It is a percentage of SECTADT.
	Roadway Section Average "K" Factor Number	Decimal (Version01)		
HRZDGCRV	Horizontal Degree of Curve	Character		
DIVUNDIV	Divided Undivided Raised Median	Character		
ISLDTYPE	Inside Shoulder Type	Character		
			00000000	Raised Curb
			00000001	Paved
			00000002	Paved Warn
			00000003	Lawn
			00000004	Gravel/Marl
			00000005	Dirt
			00000006	Curb&Gutter
			00000007	Other
			00000008	Curb with Resfacing
ISLDWDTH	Inside Shoulder Width	Numeric (Version00)		Occurs only when a median is present
	Inside Shoulder Width Number	Decimal (Version01)		
MAXSPEED	Maximum Posted Speed Limit	Numeric (Version00)		
		Character (Version01)		
MEDWIDTH	Highway Median Width	Character		
PAVECOND	Pavement Condition	Numeric		
	Pavement Condition Number	Decimal		
RDMEDIAN	Roadway Median Type	Character		
			00000001	Painted
			00000002	Median Curb< 6 inches
			00000003	Curb > 6 inches
			00000004	Guardrail
			00000005	Fence
			00000006	Barrier wall>1.5 ft

			00000007	1 way pr.(c.blk)
			00000008	Grassed
			00000009	Gravel/Marl
			00000010	Paved
			00000011	Depressed Curb
			00000012	Painted and Guardrail
			00000013	Painted with barrier
			00000014	Curb < 6 in & Guardrail
			00000015	Curb < 6 in & Fence
			00000016	Curb < 6 in & Barrier
			00000017	Curb < 6 in & Lawn
			00000018	Curb > 6 in & Guardrail
			00000019	Curb > 6 in & Fence
			00000020	Other
			00000021	Curb > 6 in & Barrier
			00000022	Curb > 6 in & Lawn
			00000023	Lawn & Guardrail
			00000024	Grassed with fence
			00000025	Lawn & Barrier
			00000026	Lawn, Barrier & Curb < 6 inches
			00000027	Lawn, Barrier & Curb > 6 inches
			00000028	Canal, Ditch Etc.
			00000029	Com 02,03 & 28
			00000030	Com 02,03,05,28
			00000031	Lawn w/dbl Guardrail
SECTADT	Sectional Average Annual Daily Traffic	Numeric (Version00) Character (Version01)		
SHLDTYPE	Highway Shoulder Type	Character		
			00000000	Raised Curb
			00000001	Paved
			00000002	Paved Warn
			00000003	Lawn
			00000004	Gravel/Marl
			00000005	Valley Gutr
			00000006	Curb & Gutter
			00000007	Other
			00000008	Curb with Resurfacing
SIDEWALK	Sidewalk Width	Numeric (Version00)		
	Sidewalk Width Number	Decimal (Version01)		

SLDWIDTH	Highway Shoulder Width	Numeric (Version00)		
	Highway Shoulder Width Number	Decimal (Version01)		
SURWIDTH	Thru Pavement Surface Width	Character		
URSUBRUR	Urban, Suburban, Rural	Character		
STROADNO	State Road Number	Character		
TYPEPARK	Type of Roadway Parking	Character		
			00000000	Highway Type
			00000001	No Parking
			00000002	Curb Both
			00000003	Angle Both
			00000004	Curb One-sided
			00000005	Angle Oneside
			00000006	Curb Oneside Angle Oneside
			00000007	None- Curbside
			00000008	Curb-curbside
			00000009	Angle-Curbside
BEGSECPT	Begin Section Milepoint	Numeric	Non RCI Variable	
ENDSECPT	End Section Milepoint	Numeric	Non RCI Variable	
RDWYID	Specific ID Number for Segment			

* These values are entered as a percent of the total ADT for the roadway segment.

APPENDIX B PEARSON CORRELATIONS

Pearson Correlations – Severe and Fatal Crashes

		Crp10vmr	AcMaCl	Dfac	Kfac	Tfac	HCurDeg	IslnWidth	MedWid	PavCon	SldWidth	SurWidth	TotdriPM	SigPM
Crp10vmr (Severe and Fatal Crash Rate)	Pearson Correlation	1	.043	-.026	-.049(*)	-.040	-.081(**)	-.041	-.042	-.013	-.076(**)	-.072(**)	.015	.092(**)
	Sig. (2-tailed)		.062	.248	.032	.081	.000	.075	.063	.578	.001	.002	.516	.000
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
AcMaCl (Access Management Classification)	Pearson Correlation	.043	1	.191(**)	-.091(**)	.008	-.061(**)	-.046(*)	-.048(*)	-.032	-.203(**)	-.257(**)	.187(**)	.075(**)
	Sig. (2-tailed)	.062		.000	.000	.742	.008	.044	.036	.160	.000	.000	.000	.001
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
Dfac (D Factor)	Pearson Correlation	-.026	.191(**)	1	.297(**)	-.188(**)	-.018	-.178(**)	.006	-.049(*)	-.107(**)	.047(*)	-.018	-.006
	Sig. (2-tailed)	.248	.000		.000	.000	.424	.000	.784	.030	.000	.038	.427	.783
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
Kfac (K Factor)	Pearson Correlation	-.049(*)	-.091(**)	.297(**)	1	.112(**)	.081(**)	-.241(**)	.053(*)	.125(**)	.129(**)	.260(**)	-.040	-.123(**)
	Sig. (2-tailed)	.032	.000	.000		.000	.000	.000	.019	.000	.000	.000	.076	.000
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
Tfac (T Factor)	Pearson Correlation	-.040	.008	-.188(**)	.112(**)	1	-.032	-.189(**)	.035	.081(**)	.134(**)	.054(*)	-.030	-.089(**)
	Sig. (2-tailed)	.081	.742	.000	.000		.156	.000	.127	.000	.000	.017	.190	.000
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
HCurDeg (Horizontal Degree of Curvature)	Pearson Correlation	-.081(**)	-.061(**)	-.018	.081(**)	-.032	1	.006	.069(**)	.079(**)	.010	.033	.002	-.054(*)
	Sig. (2-tailed)	.000	.008	.424	.000	.156		.776	.003	.001	.646	.152	.947	.018
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
IslnWidth (Inside Shoulder Width)	Pearson Correlation	-.041	-.046(*)	-.178(**)	-.241(**)	-.189(**)	.006	1	-.032	-.025	-.080(**)	-.035	-.036	-.033
	Sig. (2-tailed)	.075	.044	.000	.000	.000	.776		.165	.278	.000	.124	.111	.145
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
MedWid (Median Width)	Pearson Correlation	-.042	-.048(*)	.006	.053(*)	.035	.069(**)	-.032	1	.104(**)	.186(**)	.022	-.076(**)	-.052(*)
	Sig. (2-tailed)	.063	.036	.784	.019	.127	.003	.165		.000	.000	.345	.001	.022
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
PavCon (Pavement Condition)	Pearson Correlation	-.013	-.032	-.049(*)	.125(**)	.081(**)	.079(**)	-.025	.104(**)	1	.154(**)	.127(**)	-.047(*)	-.111(**)
	Sig. (2-tailed)	.578	.160	.030	.000	.000	.001	.278	.000		.000	.000	.039	.000
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
SldWidth (Shoulder Width)	Pearson Correlation	-.076(**)	-.203(**)	-.107(**)	.129(**)	.134(**)	.010	-.080(**)	.186(**)	.154(**)	1	.212(**)	-.157(**)	-.097(**)
	Sig. (2-tailed)	.001	.000	.000	.000	.000	.646	.000	.000	.000		.000	.000	.000
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
SurWidth (Surface Width)	Pearson Correlation	-.072(**)	-.257(**)	.047(*)	.260(**)	.054(*)	.033	-.035	.022	.127(**)	.212(**)	1	-.084(**)	-.066(**)
	Sig. (2-tailed)	.002	.000	.038	.000	.017	.152	.124	.345	.000	.000		.000	.004
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
TotdriPM (Total Driveways per Mile)	Pearson Correlation	.015	.187(**)	-.018	-.040	-.030	.002	-.036	-.076(**)	-.047(*)	-.157(**)	-.084(**)	1	.285(**)
	Sig. (2-tailed)	.516	.000	.427	.076	.190	.947	.111	.001	.039	.000	.000		.000
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
SigPM (Signals per Mile)	Pearson Correlation	.092(**)	.075(**)	-.006	-.123(**)	-.089(**)	-.054(*)	-.033	-.052(*)	-.111(**)	-.097(**)	-.066(**)	.285(**)	1
	Sig. (2-tailed)	.000	.001	.783	.000	.000	.018	.145	.022	.000	.000	.004	.000	
	N	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Pearson Correlations – Non-incapacitating and Possible Injury Crashes

		Crinvmr	AcMnCl	Dfac	Kfac	Tfac	HCurDeg	IslnWidth	MedWid	Pavcon	SldWidth	SurWidth	TotdriPM	SigPM
Crinvmr (Non-incapacitating and Possible Injury Crash Rate)	Pearson Correlation	1	.158(**)	.015	-.143(**)	-.038	-.098(**)	-.039	-.036	-.088(**)	-.133(**)	-.101(**)	.098(**)	.300(**)
	Sig. (2-tailed)		.000	.497	.000	.090	.000	.085	.110	.000	.000	.000	.000	.000
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
AcMnCl (Access Management Classification)	Pearson Correlation	.158(**)	1	.192(**)	-.092(**)	.004	-.055(*)	-.045(*)	-.048(*)	-.031	-.209(**)	-.258(**)	.184(**)	.071(**)
	Sig. (2-tailed)	.000		.000	.000	.846	.015	.046	.033	.175	.000	.000	.000	.002
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
Dfac (D Factor)	Pearson Correlation	.015	.192(**)	1	.297(**)	-.192(**)	-.013	-.176(**)	.006	-.046(*)	-.108(**)	.046(*)	-.010	-.005
	Sig. (2-tailed)	.497	.000		.000	.000	.580	.000	.781	.041	.000	.042	.673	.843
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
Kfac (K Factor)	Pearson Correlation	-.143(**)	-.092(**)	.297(**)	1	.114(**)	.081(**)	-.239(**)	.054(*)	.127(**)	.129(**)	.263(**)	-.035	-.117(**)
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.017	.000	.000	.000	.120	.000
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
Tfac (T Factor)	Pearson Correlation	-.038	.004	-.192(**)	.114(**)	1	-.033	-.189(**)	.037	.087(**)	.138(**)	.054(*)	-.035	-.090(**)
	Sig. (2-tailed)	.090	.846	.000	.000		.142	.000	.103	.000	.000	.018	.122	.000
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
HCurDeg (Horizontal Degree of Curvature)	Pearson Correlation	-.098(**)	-.055(*)	-.013	.081(**)	-.033	1	.006	.068(**)	.079(**)	.010	.033	.007	-.051(*)
	Sig. (2-tailed)	.000	.015	.580	.000	.142		.804	.003	.001	.675	.141	.767	.025
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
IslnWidth (Inside Shoulder Width)	Pearson Correlation	-.039	-.045(*)	-.176(**)	-.239(**)	-.189(**)	.006	1	-.031	-.030	-.076(**)	-.030	-.043	-.031
	Sig. (2-tailed)	.085	.046	.000	.000	.000	.804		.173	.191	.001	.183	.058	.176
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
MedWid (Median Width)	Pearson Correlation	-.036	-.048(*)	.006	.054(*)	.037	.068(**)	-.031	1	.104(**)	.186(**)	.023	-.074(**)	-.052(*)
	Sig. (2-tailed)	.110	.033	.781	.017	.103	.003	.173		.000	.000	.312	.001	.023
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
Pavcon (Pavement Condition)	Pearson Correlation	-.088(**)	-.031	-.046(*)	.127(**)	.087(**)	.079(**)	-.030	.104(**)	1	.155(**)	.128(**)	-.035	-.110(**)
	Sig. (2-tailed)	.000	.175	.041	.000	.000	.001	.191	.000		.000	.000	.127	.000
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
SldWidth (Shoulder Width)	Pearson Correlation	-.133(**)	-.209(**)	-.108(**)	.129(**)	.138(**)	.010	-.076(**)	.186(**)	.155(**)	1	.211(**)	-.151(**)	-.098(**)
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.675	.001	.000	.000		.000	.000	.000
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
SurWidth (Surface Width)	Pearson Correlation	-.101(**)	-.258(**)	.046(*)	.263(**)	.054(*)	.033	-.030	.023	.128(**)	.211(**)	1	-.085(**)	-.062(**)
	Sig. (2-tailed)	.000	.000	.042	.000	.018	.141	.183	.312	.000	.000		.000	.006
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
TotdriPM (Total Driveways per Mile)	Pearson Correlation	.098(**)	.184(**)	-.010	-.035	-.035	.007	-.043	-.074(**)	-.035	-.151(**)	-.085(**)	1	.290(**)
	Sig. (2-tailed)	.000	.000	.673	.120	.122	.767	.058	.001	.127	.000	.000		.000
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941
SigPM (Signals per Mile)	Pearson Correlation	.300(**)	.071(**)	-.005	-.117(**)	-.090(**)	-.051(*)	-.031	-.052(*)	-.110(**)	-.098(**)	-.062(**)	.290(**)	1
	Sig. (2-tailed)	.000	.002	.843	.000	.000	.025	.176	.023	.000	.000	.006	.000	
	N	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941	1941

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Pearson Correlations – Property Damage Only Crashes

		Crninvmr	AcMaCl	Dfac	Kfac	Tfac	HCurDeg	IslnWidth	MedWid	Pavcon	SldWidth	SurWidth	TotdriPM	SigPM
Crninvmr (PDO Crash Rate)	Pearson Correlation	1	.187(**)	-.046(*)	-.191(**)	-.023	-.094(**)	-.043	-.065(**)	-.095(**)	-.124(**)	-.168(**)	.105(**)	.266(**)
	Sig. (2-tailed)		.000	.047	.000	.316	.000	.060	.005	.000	.000	.000	.000	.000
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
AcMaCl (Access Management Classification)	Pearson Correlation	.187(**)	1	.198(**)	-.092(**)	.005	-.057(*)	-.044	-.047(*)	-.027	-.197(**)	-.251(**)	.179(**)	.065(**)
	Sig. (2-tailed)	.000		.000	.000	.841	.013	.053	.041	.235	.000	.000	.000	.004
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
Dfac (D Factor)	Pearson Correlation	-.046(*)	.198(**)	1	.281(**)	-.191(**)	-.016	-.175(**)	.003	-.054(*)	-.112(**)	.036	-.006	.005
	Sig. (2-tailed)	.047	.000		.000	.000	.481	.000	.882	.019	.000	.120	.809	.824
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
Kfac (K Factor)	Pearson Correlation	-.191(**)	-.092(**)	.281(**)	1	.116(**)	.075(**)	-.237(**)	.052(*)	.123(**)	.128(**)	.254(**)	-.036	-.098(**)
	Sig. (2-tailed)	.000	.000	.000		.000	.001	.000	.024	.000	.000	.000	.111	.000
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
Tfac (T Factor)	Pearson Correlation	-.023	.005	-.191(**)	.116(**)	1	-.034	-.194(**)	.037	.084(**)	.145(**)	.057(*)	-.034	-.088(**)
	Sig. (2-tailed)	.316	.841	.000	.000		.137	.000	.110	.000	.000	.013	.142	.000
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
HCurDeg (Horizontal Degree of Curvature)	Pearson Correlation	-.094(**)	-.057(*)	-.016	.075(**)	-.034	1	.009	.068(**)	.078(**)	.006	.032	.004	-.041
	Sig. (2-tailed)	.000	.013	.481	.001	.137		.695	.003	.001	.777	.158	.863	.075
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
IslnWidth (Inside Shoulder Width)	Pearson Correlation	-.043	-.044	-.175(**)	-.237(**)	-.194(**)	.009	1	-.034	-.033	-.086(**)	-.034	-.039	-.034
	Sig. (2-tailed)	.060	.053	.000	.000	.000	.695		.136	.156	.000	.141	.092	.133
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
MedWid (Median Width)	Pearson Correlation	-.065(**)	-.047(*)	.003	.052(*)	.037	.068(**)	-.034	1	.103(**)	.188(**)	.020	-.073(**)	-.050(*)
	Sig. (2-tailed)	.005	.041	.882	.024	.110	.003	.136		.000	.000	.372	.001	.028
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
Pavcon (Pavement Condition)	Pearson Correlation	-.095(**)	-.027	-.054(*)	.123(**)	.084(**)	.078(**)	-.033	.103(**)	1	.154(**)	.121(**)	-.033	-.088(**)
	Sig. (2-tailed)	.000	.235	.019	.000	.000	.001	.156	.000		.000	.000	.152	.000
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
SldWidth (Shoulder Width)	Pearson Correlation	-.124(**)	-.197(**)	-.112(**)	.128(**)	.145(**)	.006	-.086(**)	.188(**)	.154(**)	1	.206(**)	-.154(**)	-.089(**)
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.777	.000	.000	.000		.000	.000	.000
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
SurWidth (Surface Width)	Pearson Correlation	-.168(**)	-.251(**)	.036	.254(**)	.057(*)	.032	-.034	.020	.121(**)	.206(**)	1	-.076(**)	-.055(*)
	Sig. (2-tailed)	.000	.000	.120	.000	.013	.158	.141	.372	.000	.000		.001	.017
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
TotdriPM (Total Driveways per Mile)	Pearson Correlation	.105(**)	.179(**)	-.006	-.036	-.034	.004	-.039	-.073(**)	-.033	-.154(**)	-.076(**)	1	.289(**)
	Sig. (2-tailed)	.000	.000	.809	.111	.142	.863	.092	.001	.152	.000	.001		.000
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908
SigPM (Signals per Mile)	Pearson Correlation	.266(**)	.065(**)	.005	-.098(**)	-.088(**)	-.041	-.034	-.050(*)	-.088(**)	-.089(**)	-.055(*)	.289(**)	1
	Sig. (2-tailed)	.000	.004	.824	.000	.000	.075	.133	.028	.000	.000	.017	.000	
	N	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908	1908

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

APPENDIX C FREQUENCY DISTRIBUTIONS, HISTOGRAMS, AND SENSITIVITY ANALYSIS – SEVERE AND FATAL CRASHES

Appendix C contains frequency distribution tables for selected variables and histograms for model variables. Under each histogram is a frequency distribution table for the variable depicted in that histogram. Appendix C also contains sensitivity analysis plots. Figure C-1 shows, for example, that reducing the number of driveways per mile from 40 to 20 would reduce the PDO crash rate from about 151 to 146 per 100 MVMT.

Number of Observations

		AcMaCl	Raise_M	Pave_M	MedTyp	ShldTyp	Rural	Suburban	Urban	ParkTyp
N	Valid	1545	1545	1545	1545	1545	1545	1545	1545	1545
	Missing	0	0	0	0	0	0	0	0	0

Access Management Class

		Frequency	Percent[1]	Valid Percent[1]	Cumulative Percent
Valid	0	93	6.0	6.0	6.0
	1	4	.3	.3	6.3
	2	16	1.0	1.0	7.3
	3	437	28.3	28.3	35.6
	5	810	52.4	52.4	88.0
	6	70	4.5	4.5	92.6
	7	115	7.4	7.4	100.0
	Total	1545	100.0	100.0	

[1] The percent and valid percent columns are included in the software outputs to detect missing or out of range values (for instance, a negative distance). That the numbers are the same indicates the anomalies did not occur in the final datasets.

Raised Median

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	51	3.3	3.3	3.3
	1	1494	96.7	96.7	100.0
	Total	1545	100.0	100.0	

Paved Median

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1494	96.7	96.7	96.7
	1	51	3.3	3.3	100.0
	Total	1545	100.0	100.0	

Median Type

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.0	45	2.9	2.9	2.9
	2.0	189	12.2	12.2	15.1
	3.0	160	10.4	10.4	25.5
	6.0	5	.3	.3	25.8
	8.0	121	7.8	7.8	33.7
	10.0	6	.4	.4	34.0
	13.0	6	.4	.4	34.4
	17.0	590	38.2	38.2	72.6
	18.0	6	.4	.4	73.0
	20.0	20	1.3	1.3	74.3
	21.0	1	.1	.1	74.4
	22.0	389	25.2	25.2	99.5
	26.0	5	.3	.3	99.9
	28.0	2	.1	.1	100.0
	Total	1545	100.0	100.0	

Shoulder Type

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	.1	.1	.1
	1	544	35.2	35.2	35.3
	3	36	2.3	2.3	37.6
	6	955	61.8	61.8	99.4
	7	1	.1	.1	99.5
	8	8	.5	.5	100.0
	Total	1545	100.0	100.0	

Rural

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1515	98.1	98.1	98.1
	1	30	1.9	1.9	100.0
	Total	1545	100.0	100.0	

Suburban

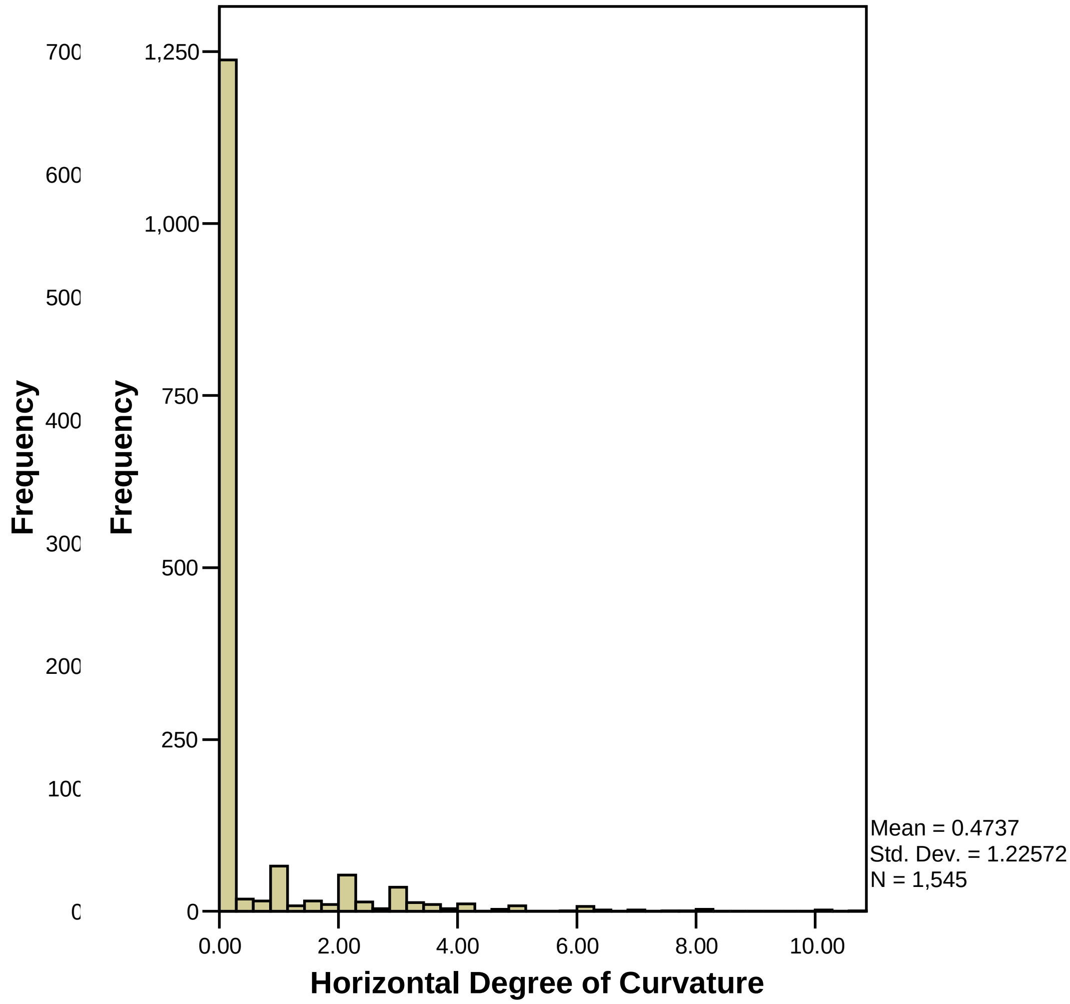
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1234	79.9	79.9	79.9
	1	311	20.1	20.1	100.0
	Total	1545	100.0	100.0	

Urban

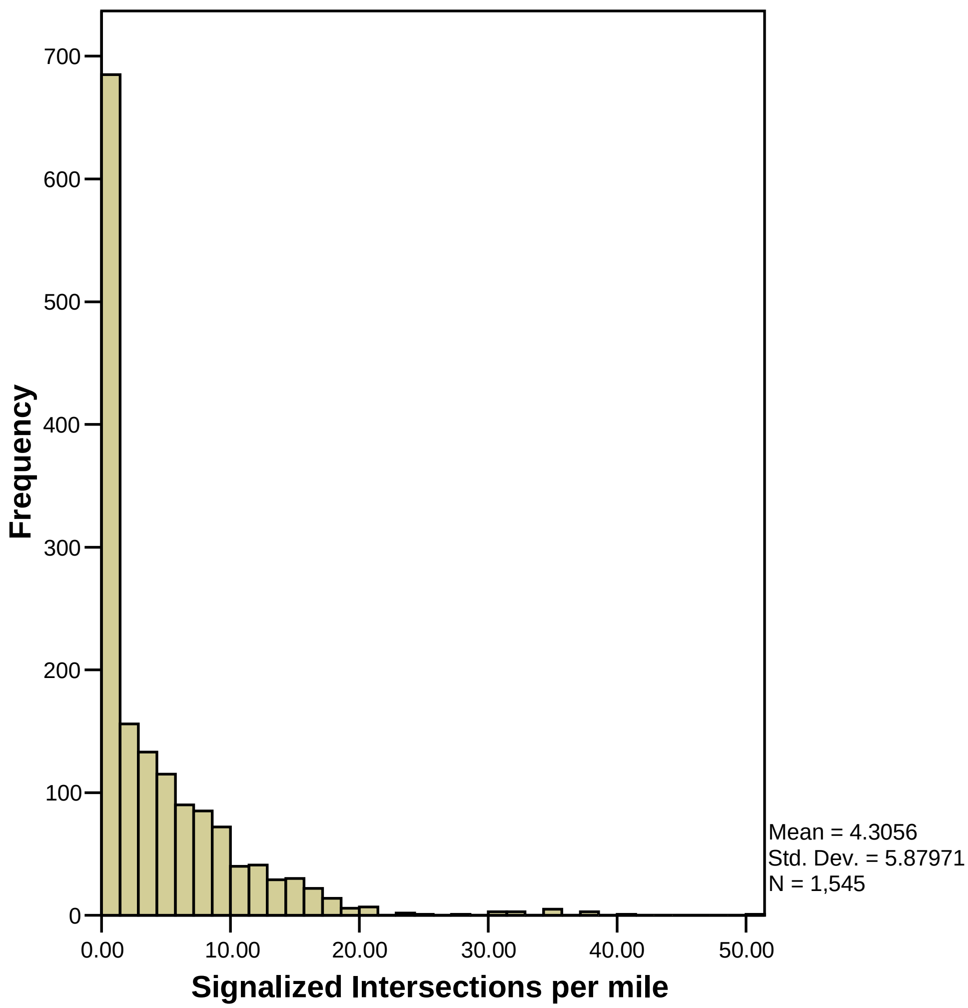
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	341	22.1	22.1	22.1
	1	1204	77.9	77.9	100.0
	Total	1545	100.0	100.0	

Parking Type

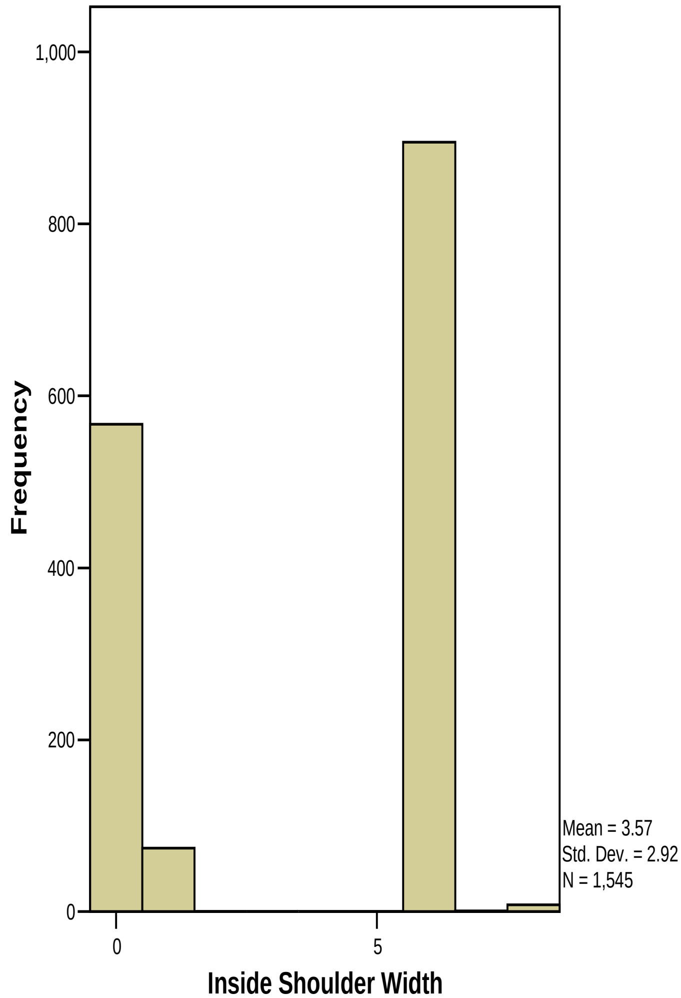
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	301	19.5	19.5	19.5
	1	656	42.5	42.5	61.9
	2	582	37.7	37.7	99.6
	4	6	.4	.4	100.0
	Total	1545	100.0	100.0	



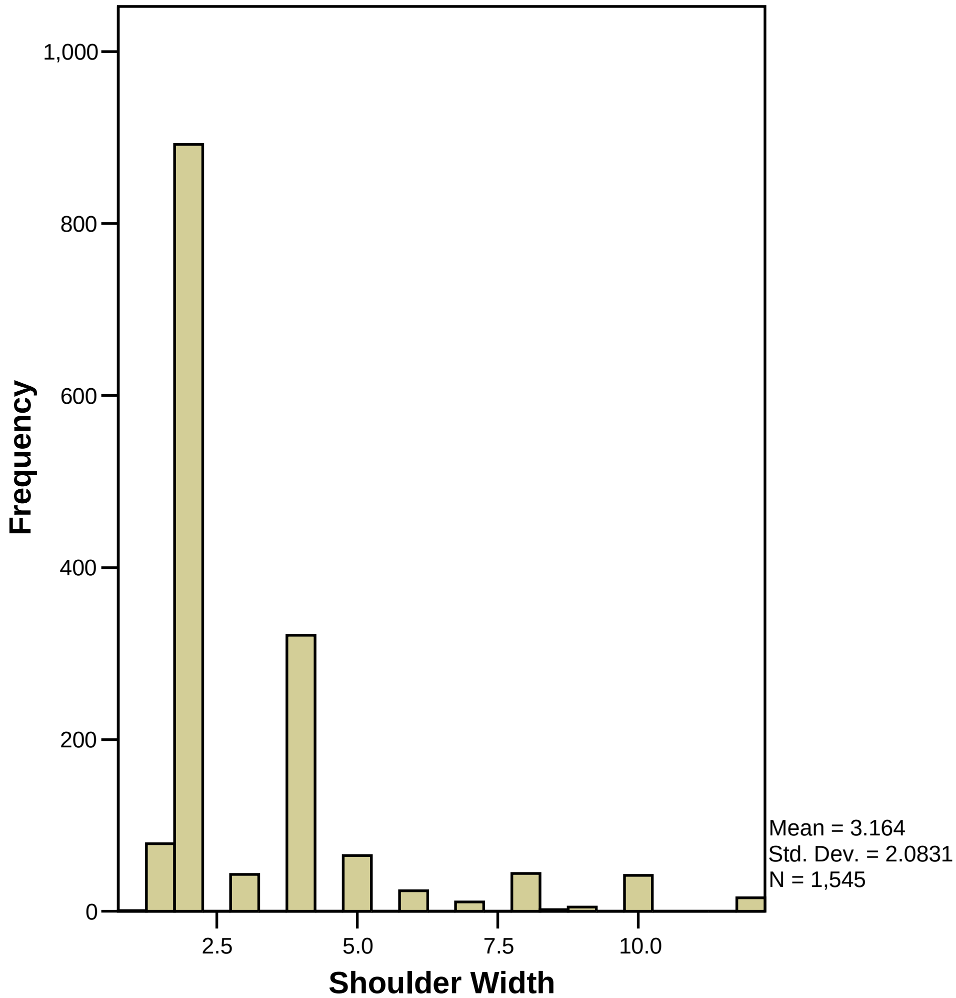
CURVATURE (degrees)	FREQUENCY	PERCENT
0	1230	79.6
0.01 – 0.50	25	1.6
0.51 – 1.00	80	5.2
1.01 – 1.50	22	1.4
1.51 – 2.00	64	4.1
2.01 – 2.50	15	1.0
2.51 – 3.00	40	2.6
3.01 – 3.50	20	1.3
3.51 – 4.00	17	1.1
4.01 and higher	32	2.1
TOTAL	1545	



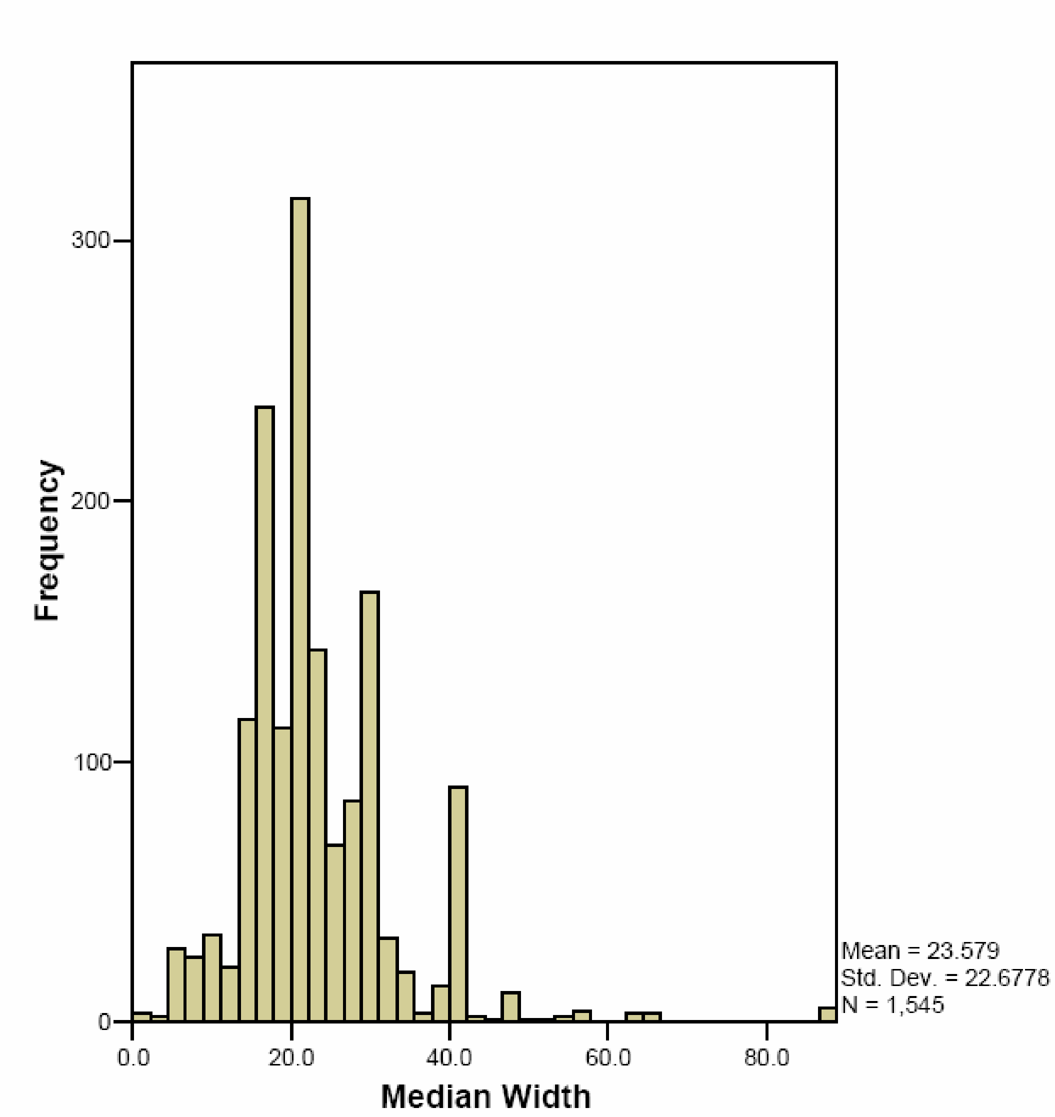
SIGNALIZED INTERSECTIONS PER MILE	FREQUENCY	PERCENT
0	650	42.1
0.01 – 2.00	82	5.3
2.01 – 4.00	216	14.0
4.01 – 6.00	153	9.9
6.01 – 8.00	124	8.0
8.01 – 10.00	111	7.2
10.01 – 15.00	127	8.2
15.01 – 20.00	57	3.7
20.01 and higher	25	1.6
TOTAL	1545	



INSIDE SHOULDER WIDTH (ft)	FREQUENCY	PERCENT
0	567	36.7
1	74	4.8
2	0	0.0
3	0	0.0
4	0	0.0
5	0	0.0
6	895	57.9
7	1	0.1
8	8	0.5
TOTAL	1545	



SHOULDER WIDTH (ft)	FREQUENCY	PERCENT
1 or 1.5	80	5.2
2	892	57.7
3	43	2.8
4	321	20.8
5	65	4.2
6	24	1.6
7	11	0.7
8 or 8.5	46	3.0
9	5	0.3
10	42	2.7
11	0	0.0
12	16	1.0
TOTAL	1545	



One median in the dataset was 800 feet wide. This point was removed from this plot to create a more readable graph. This wide median is, however, represented in the mean and standard deviation.

MEDIAN WIDTH (ft)	FREQUENCY	PERCENT
0 – 10	82	5.3
11 – 15	146	9.4
16 – 20	508	32.9
21 – 25	336	21.7
26 – 30	233	15.1
31 – 40	176	11.4
41 – 50	46	3.0
51 and higher	18	1.2
TOTAL	1545	

For the following sensitivity analyses the average value for each independent variable of the model was changes as the others were held constant. The constant values used for these analyses were as follows:

Dependent Variable	**Value**
Horizontal Degree of Curvature	0.47
Signals Per Mile	4.0
Inside Shoulder Width	3.57
Outside Shoulder Width	3
Median Width	24

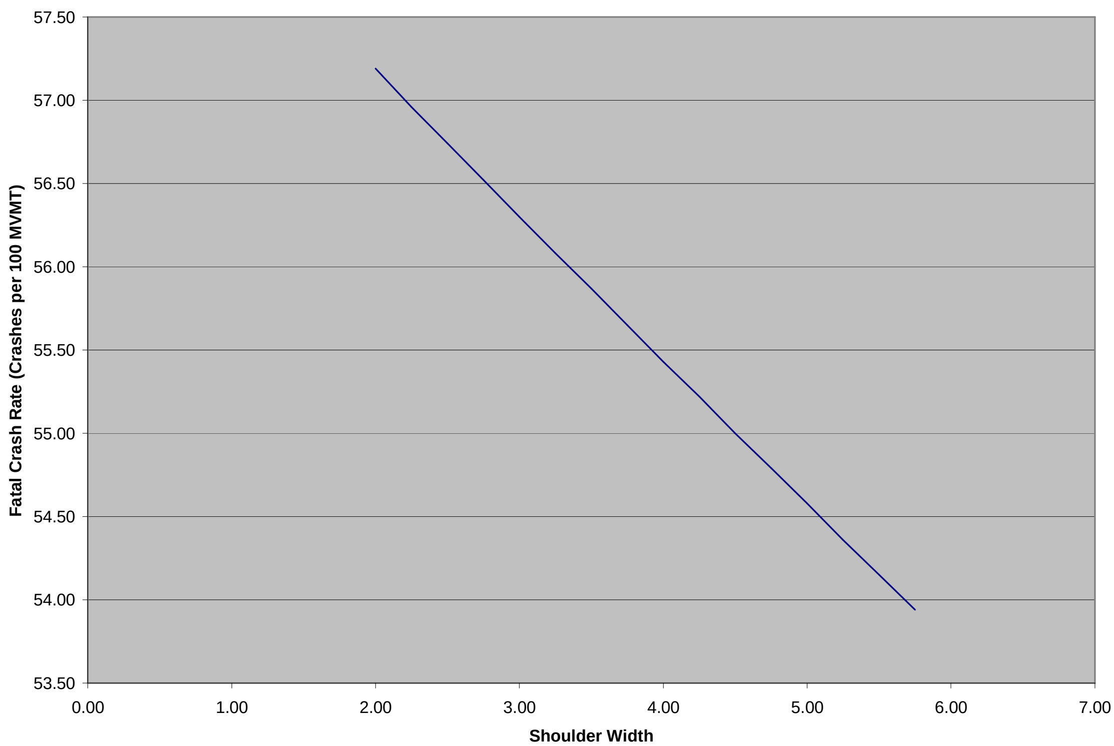


Figure C-1 Sensitivity Analysis (Severe/Fatal) – Shoulder Width

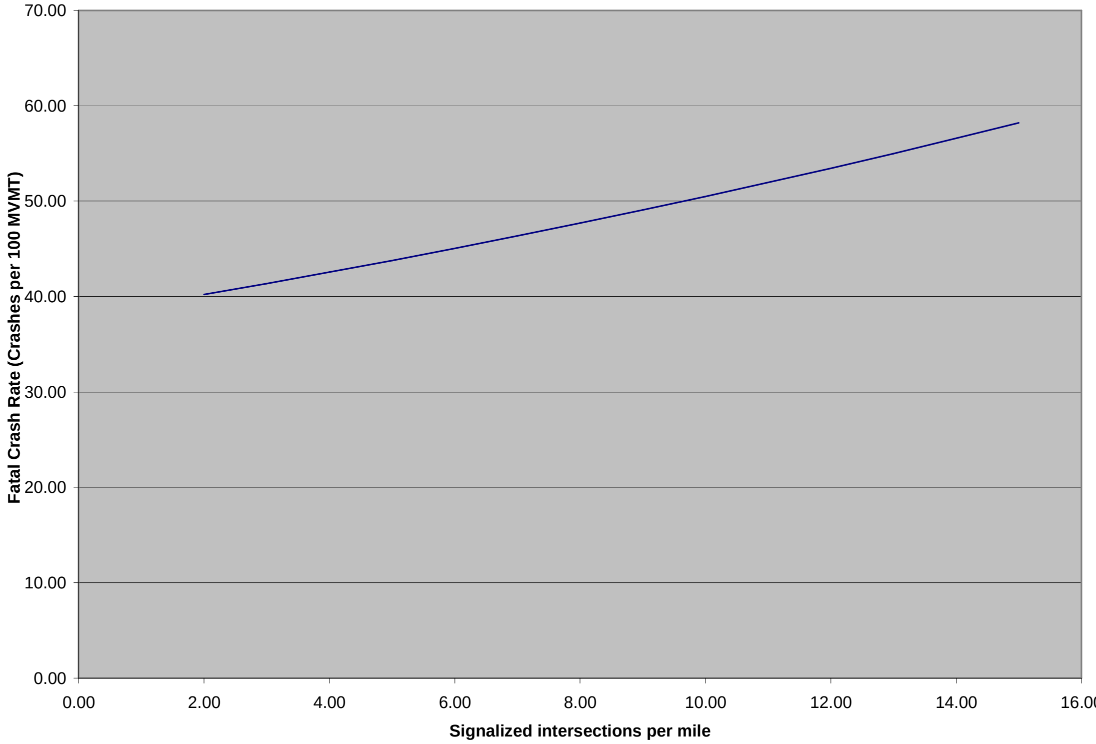


Figure C-2 Sensitivity Analysis (Severe/Fatal) – Signalized Intersections per Mile

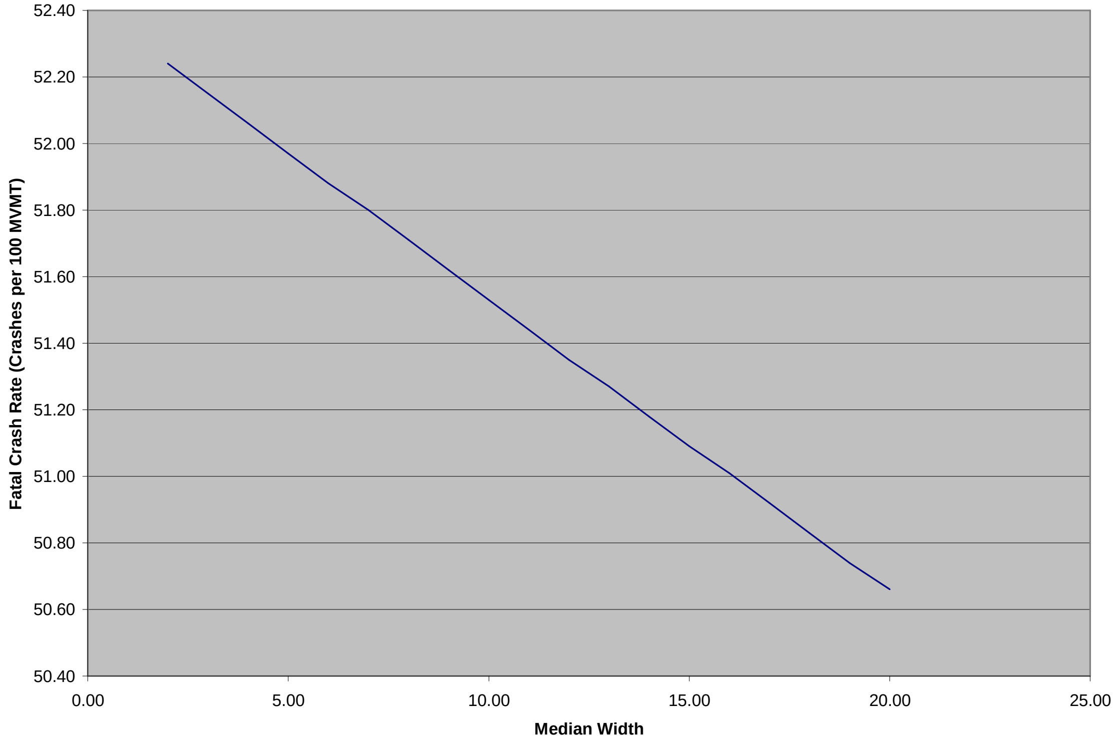


Figure C-3 Sensitivity Analysis (Severe/Fatal) – Median Width

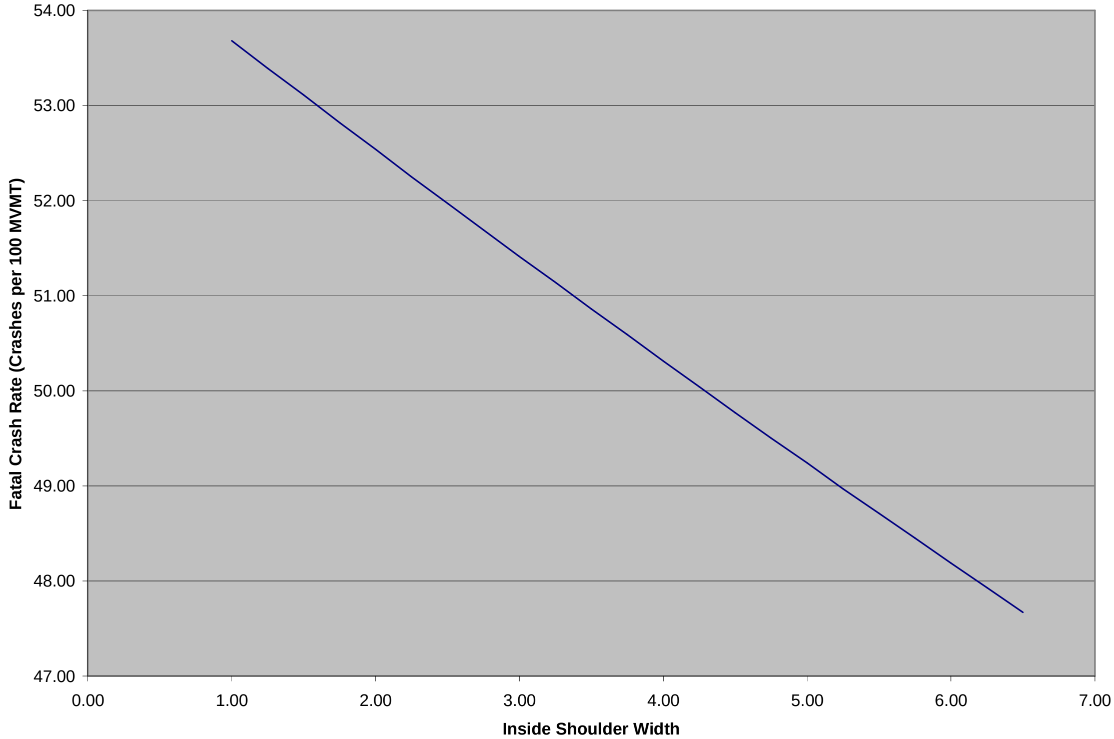


Figure C-4 Sensitivity Analysis (Severe/Fatal) – Inside Shoulder Width

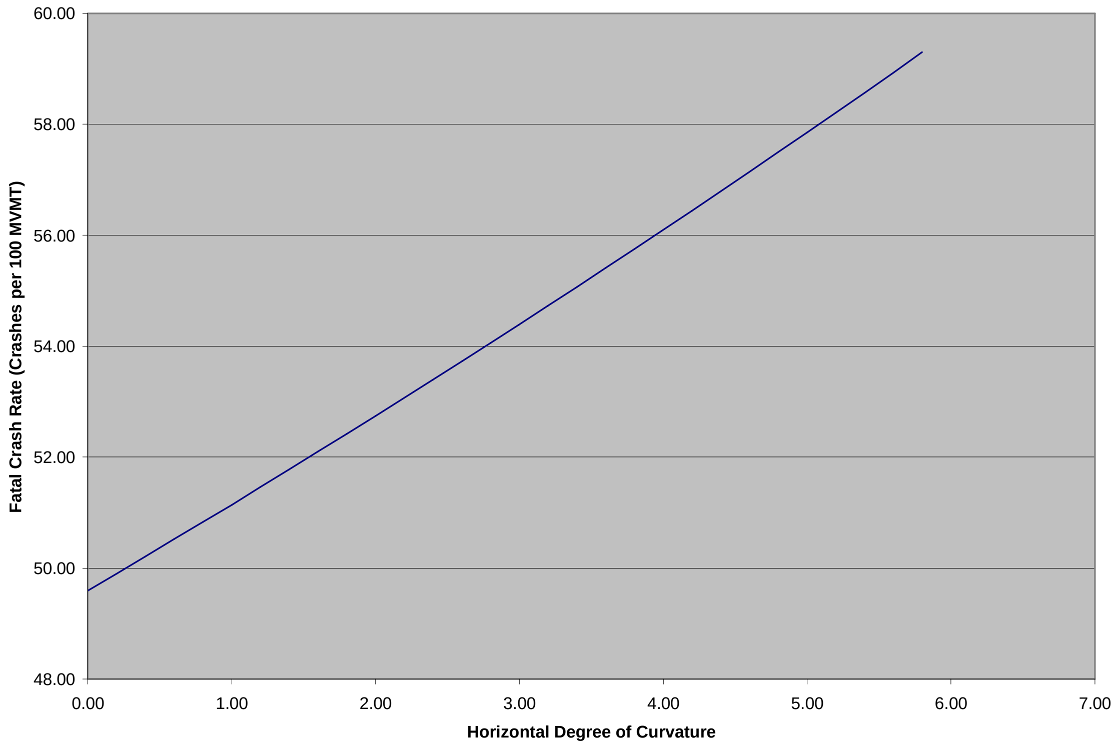


Figure C-5 Sensitivity Analysis (Severe/Fatal) – Horizontal Degree of Curvature

APPENDIX D FREQUENCY DISTRIBUTIONS, HISTOGRAMS, AND SENSITIVITY ANALYSIS – NON-INCAPACITATING AND POSSIBLE INJURY CRASHES

This Appendix contains frequency distribution tables for selected variables and histograms for model variables. Under each histogram is a frequency distribution table for the variable depicted in that histogram. The Appendix also contains sensitivity analysis plots. Figure D-2 shows, for example, that increasing shoulder width from 2 ft to 4 ft would reduce the non-incapacitating/possible injury crash rate from about 165 to 150 per 100 MVMT.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Dfac	1558	51.26	99.99	56.7	3
Kfac	1558	7.00	11.39	9.4	1
Tfac	1558	.82	44.65	5.8	4
HCurDeg	1558	.0	10.7	.5	1.2
IslnWidth	1558	0	8	3.6	3
MaxSpd	1558	15	65	44	5
MedWid	1558	2.0	800.0	24.1	30
Pavcon	1558	.00	5.00	3.8	1
ADT	1558	8900	98500	44683	15314
Sidewalk	1558	0	10	4.2	3
SldWidth	1558	1.0	12.0	3.2	2
SurWidth	1558	24.0	48.0	35.1	2
MOPM	1558	0	53	7	7
DrivupPM	1558	0	220	15	20
DrivdoPM	1558	0	308	15	20
TotdriPM	1558	0	527	30	36
SigPM	1558	0	51	4	6
Valid N (listwise)	1558				

Number of Observations

		AcMaCl	Raise_M	Pave_M	MedTyp	ShldTyp	Rural	Suburban	Urban	ParkTyp
N	Valid	1558	1558	1558	1558	1558	1558	1558	1558	1558
	Missing	0	0	0	0	0	0	0	0	0

AcMnCl

		Frequency	Percent[1]	Valid Percent[1]	Cumulative Percent
Valid	0	83	5.3	5.3	5.3
	1	4	.3	.3	5.6
	2	14	.9	.9	6.5
	3	456	29.3	29.3	35.8
	4	1	.1	.1	35.8
	5	827	53.1	53.1	88.9
	6	64	4.1	4.1	93.0
	7	109	7.0	7.0	100.0
	Total	1558	100.0	100.0	

[1] The percent and valid percent columns are included in the software outputs to detect missing or out of range values (for instance, a negative distance). That the numbers are the same indicates the anomalies did not occur in the final datasets.

Raise_M

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	52	3.3	3.3	3.3
	1	1506	96.7	96.7	100.0
	Total	1558	100.0	100.0	

Pave_M

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1506	96.7	96.7	96.7
	1	52	3.3	3.3	100.0
	Total	1558	100.0	100.0	

MedTyp

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.0	45	2.9	2.9	2.9
	2.0	169	10.8	10.8	13.7
	3.0	152	9.8	9.8	23.5
	6.0	6	.4	.4	23.9
	8.0	125	8.0	8.0	31.9
	10.0	7	.4	.4	32.3
	13.0	5	.3	.3	32.7
	17.0	615	39.5	39.5	72.1
	18.0	9	.6	.6	72.7
	20.0	21	1.3	1.3	74.1
	21.0	1	.1	.1	74.1
	22.0	393	25.2	25.2	99.4
	25.0	1	.1	.1	99.4
	26.0	7	.4	.4	99.9
	28.0	2	.1	.1	100.0
	Total	1558	100.0	100.0	

ShldTyp

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	.1	.1	.1
	1	554	35.6	35.6	35.6
	3	37	2.4	2.4	38.0
	6	953	61.2	61.2	99.2
	7	3	.2	.2	99.4
	8	10	.6	.6	100.0
	Total	1558	100.0	100.0	

Rural

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1528	98.1	98.1	98.1
	1	30	1.9	1.9	100.0
	Total	1558	100.0	100.0	

Suburban

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1241	79.7	79.7	79.7
	1	317	20.3	20.3	100.0
	Total	1558	100.0	100.0	

Urban

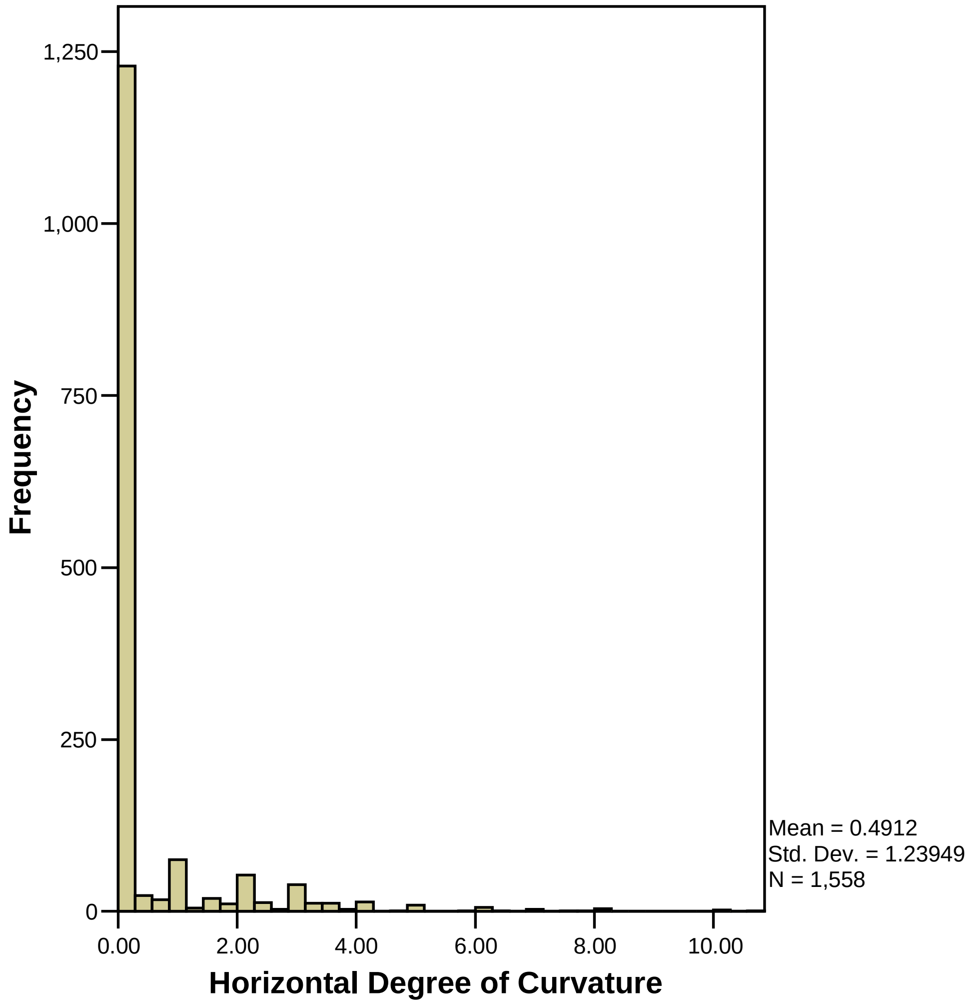
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	347	22.3	22.3	22.3
	1	1211	77.7	77.7	100.0
	Total	1558	100.0	100.0	

ParkTyp

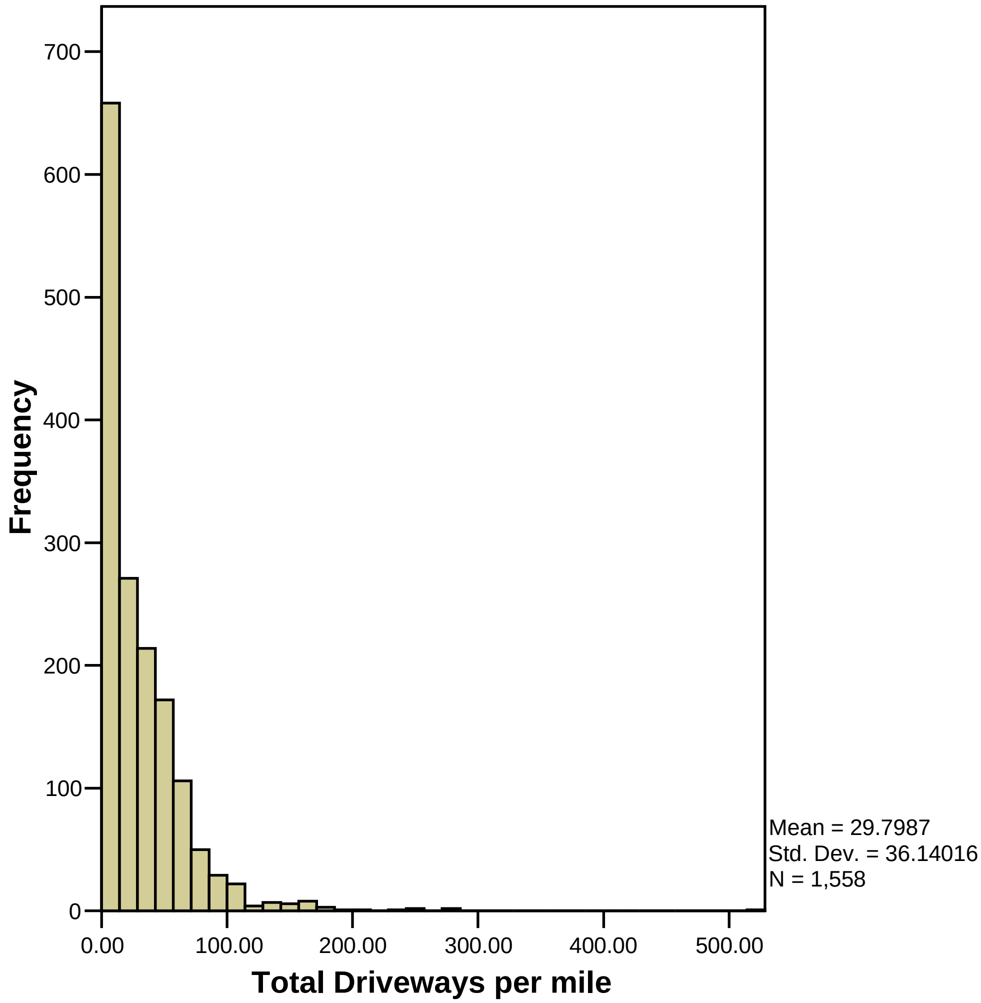
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	312	20.0	20.0	20.0
	1	670	43.0	43.0	63.0
	2	569	36.5	36.5	99.6
	4	7	.4	.4	100.0
	Total	1558	100.0	100.0	

LTB

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	587	37.7	37.7	37.7
	1	971	62.3	62.3	100.0
	Total	1558	100.0	100.0	

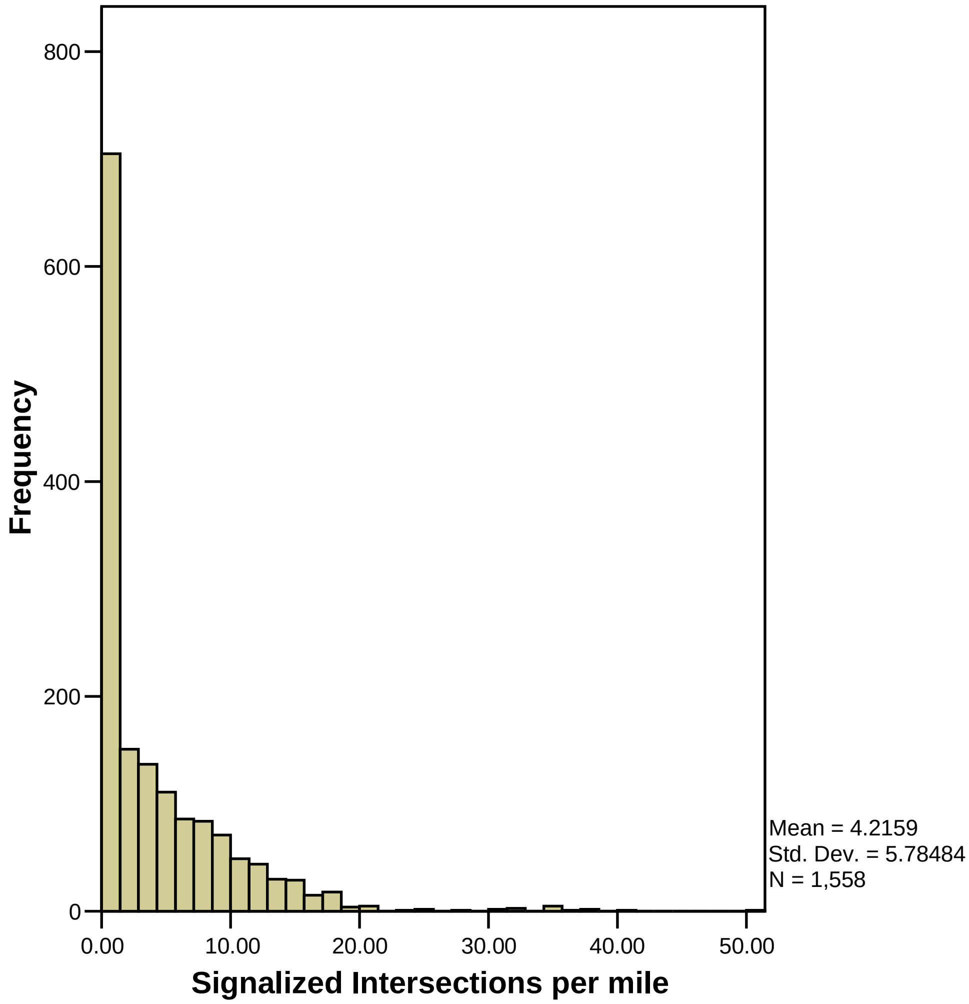


CURVATURE (degrees)	FREQUENCY	PERCENT
0	1220	78.3
0.01 – 0.50	30	1.9
0.51 – 1.00	92	5.9
1.01 – 1.50	22	1.4
1.51 – 2.00	65	4.2
2.01 – 2.50	15	1.0
2.51 – 3.00	43	2.8
3.01 – 3.50	21	1.3
3.51 – 4.00	19	1.2
4.01 and higher	31	2.0
TOTAL	1558	



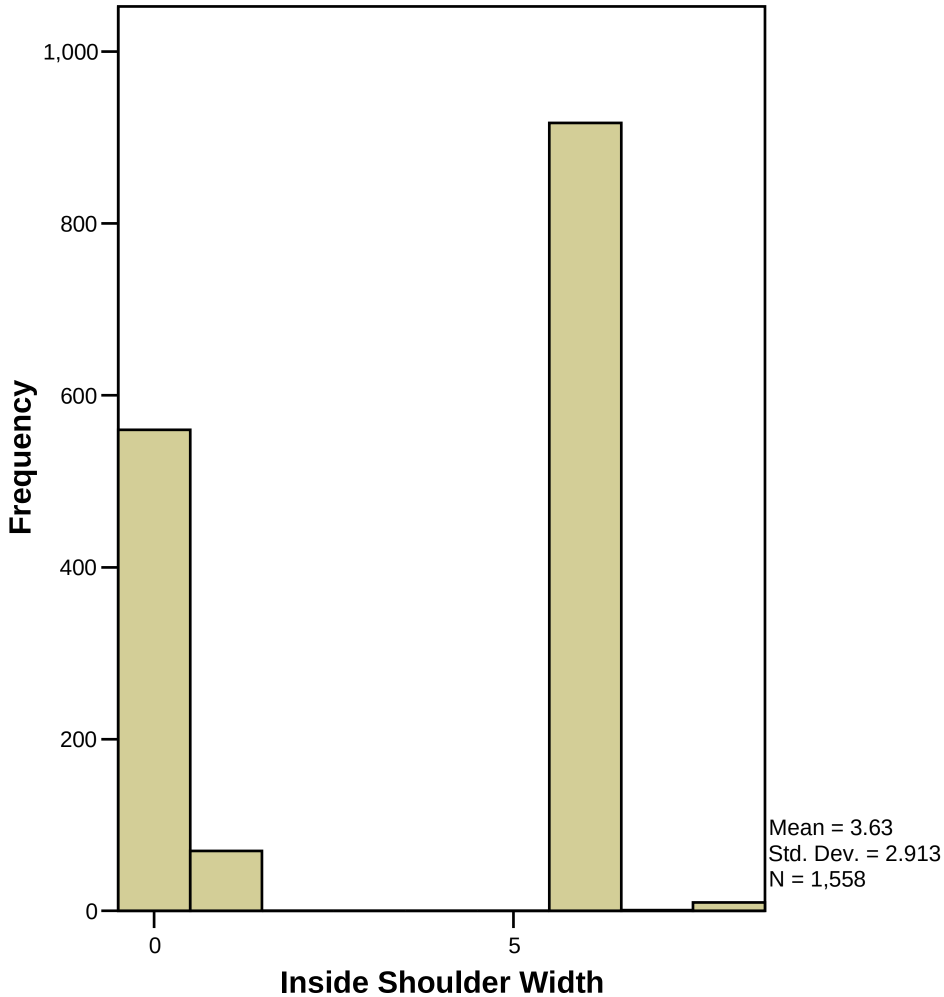
DRIVEWAYS PER MILE	FREQUENCY	PERCENT[1]
0	358	23.0
0.01 – 10.00	191	12.3
10.01 – 20.00	230	14.8
20.01 – 30.00	171	11.0
30.01 – 40.00	156	10.0
40.01 – 50.00	118	7.6
50.01 – 60.00	119	7.6
60.01 – 70.00	66	4.2
70.01 – 80.00	42	2.7
80.01 – 100.00	51	3.3
100.01 and higher	56	3.6
TOTAL	1558	

[1] Percentages do not add to 100 due to rounding.

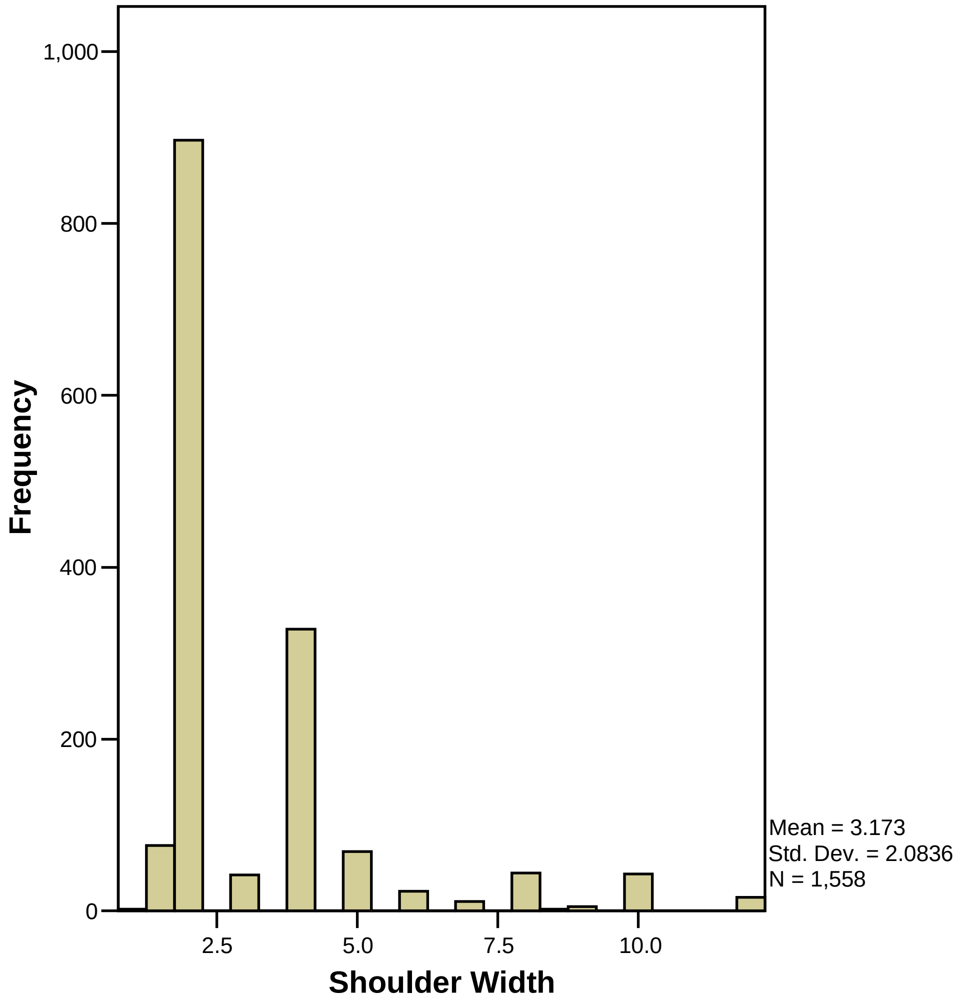


SIGNALIZED INTERSECTIONS PER MILE	FREQUENCY	PERCENT[1]
0	662	42.5
0.01 – 2.00	91	5.8
2.01 – 4.00	210	13.5
4.01 – 6.00	157	10.0
6.01 – 8.00	119	7.6
8.01 – 10.00	109	7.0
10.01 – 15.00	136	8.7
15.01 – 20.00	52	3.3
20.01 and higher	23	1.5
TOTAL	1545	

[1] Percentages do not add to 100 due to rounding.



INSIDE SHOULDER WIDTH (ft)	FREQUENCY	PERCENT
0	560	35.9
1	70	4.5
2	0	0.0
3	0	0.0
4	0	0.0
5	0	0.0
6	917	58.9
7	1	0.1
8	10	0.6
TOTAL	1558	



SHOULDER WIDTH (ft)	FREQUENCY	PERCENT[1]
1 or 1.5	78	5.0
2	897	57.6
3	42	2.7
4	328	21.1
5	69	4.4
6	23	1.5
7	11	0.7
8 or 8.5	46	3.0
9	5	0.3
10	43	2.8
11	0	0.0
12	16	1.0
TOTAL	1558	

[1] Percentages do not add to 100 due to rounding.

For the following sensitivity analyses the average each independent variable of the model was changes as the others were held constant. The constant values used for these analyses were as follows:

Dependent Variable	Value
Horizontal Degree of Curvature	0.49
Signals per Mile	4.22
Inside Shoulder Width	4.0
Total Driveways per Mile	29.8
Outside Shoulder Width	3.2

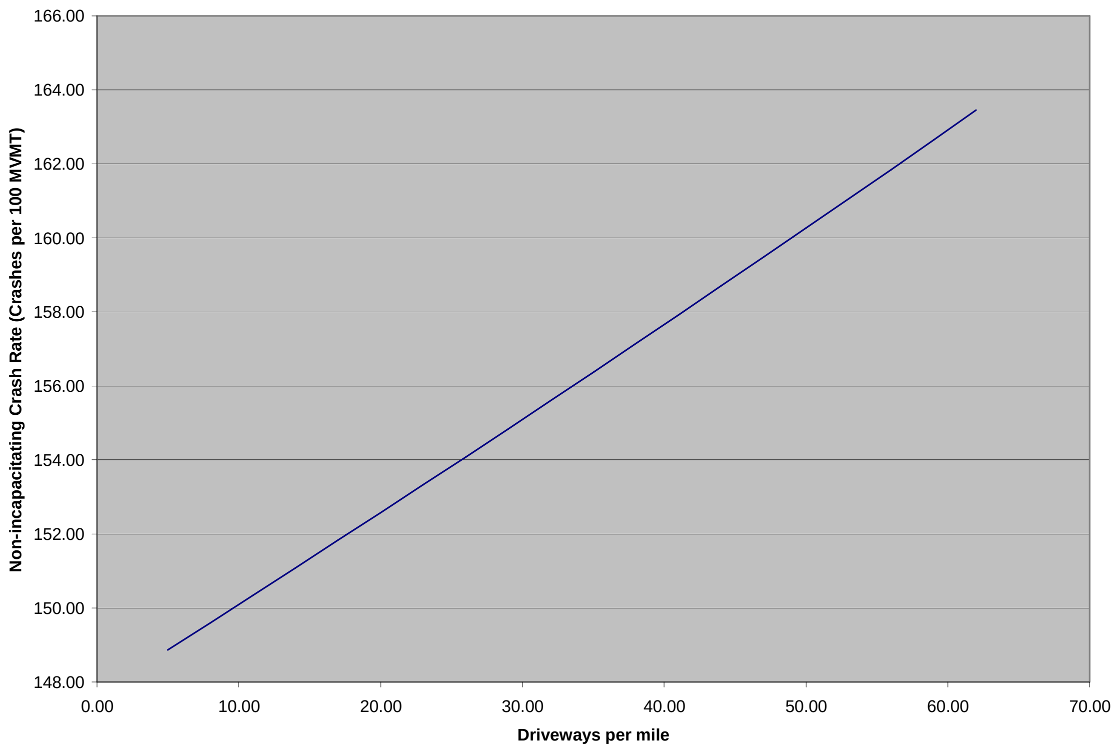


Figure D-1 Sensitivity Analysis (Non-Incapacitating) – Driveways per Mile

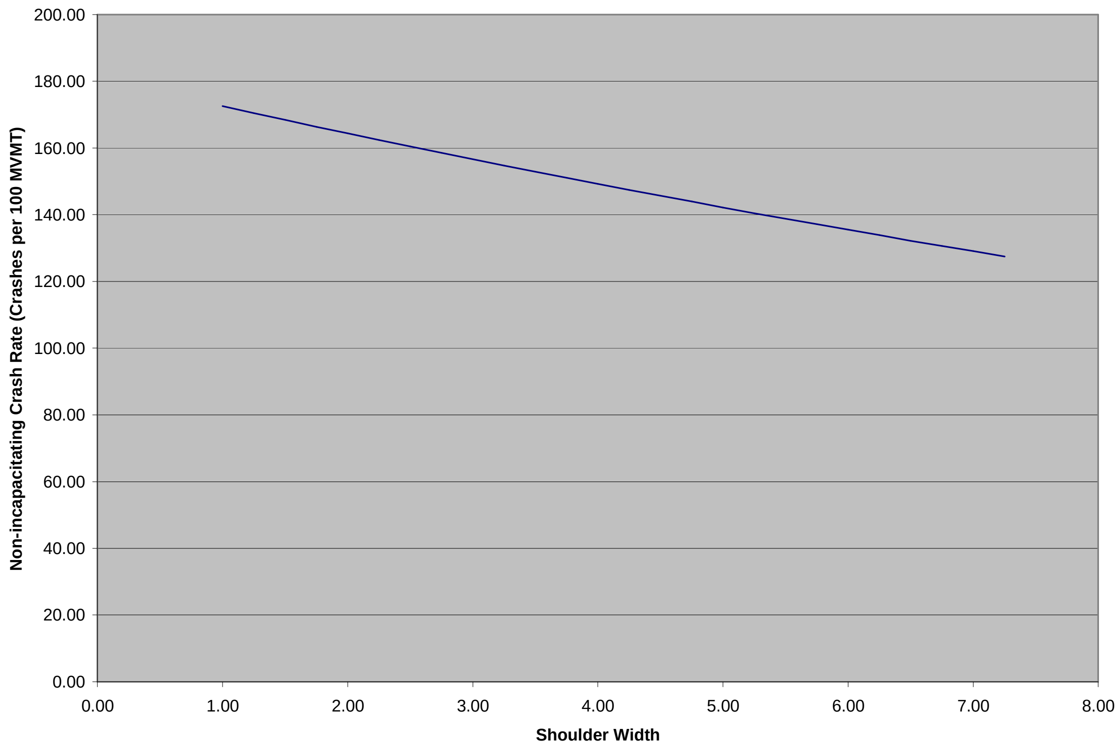


Figure D-2 Sensitivity Analysis (Non-Incapacitating) – Shoulder Width

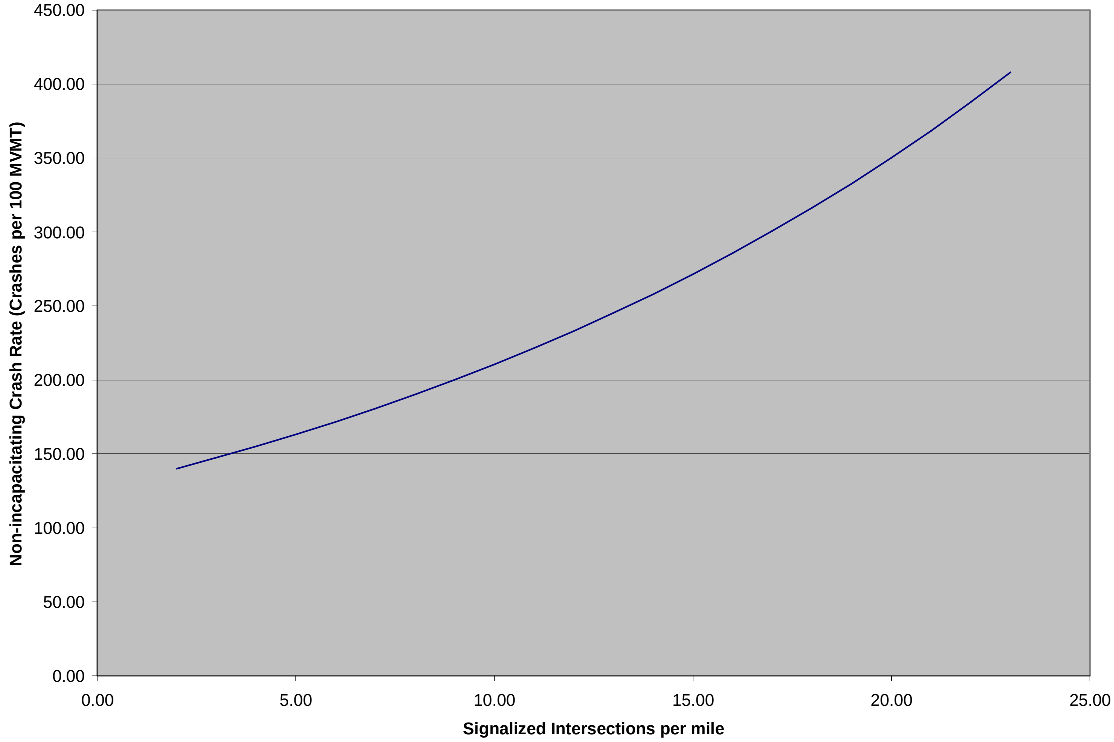


Figure D-3 Sensitivity Analysis (Non-Incapacitating) – Signalized Intersections per Mile

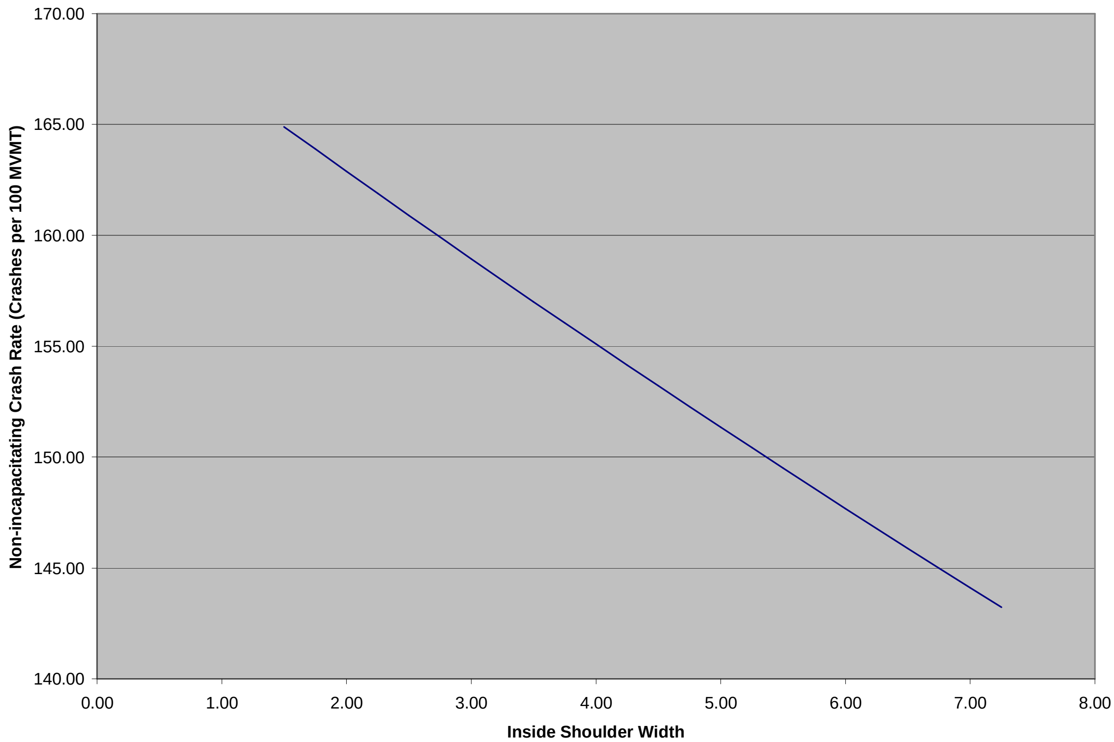


Figure D-4 Sensitivity Analysis (Non-Incapacitating) – Inside Shoulder Width

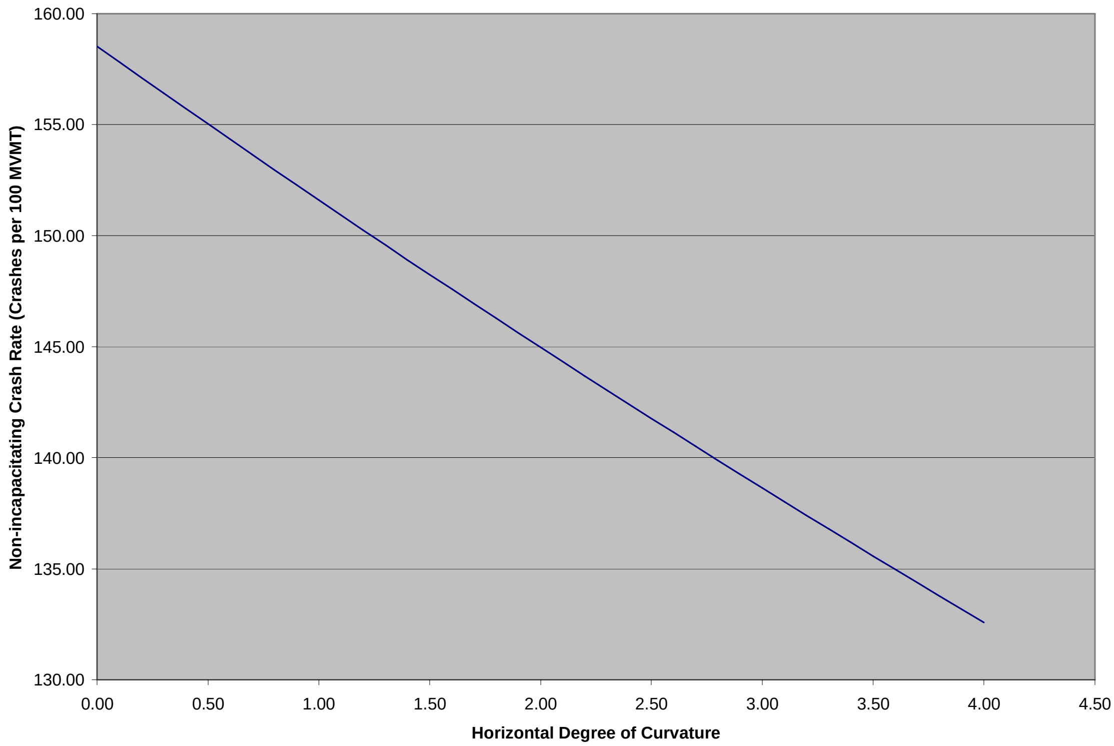


Figure D-5 Sensitivity Analysis (Non-Incapacitating) – Horizontal Degree of Curvature

APPENDIX E FREQUENCY DISTRIBUTIONS, HISTOGRAMS, AND MODEL SENSITIVITY - PDO CRASHES

This Appendix contains frequency distribution tables for selected variables and histograms for model variables. Under each histogram is a frequency distribution table for the variable depicted in that histogram. The Appendix also contains sensitivity analysis plots. Figure E-1 shows, for example, that increasing the degree of curvature from 2^o to 4^o would reduce the PDO crash rate from about 138 to about 123 per MVMT.

Descriptive Statistics

	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Dfac	1506	51.26	99.99	85449.89	56.74	3.23
Kfac	1506	7.00	11.39	14128.98	9.38	.69
Tfac	1506	.82	44.65	8634.07	5.73	4.29
HCurDeg	1506	.00	10.70	757.72	.50	1.28
IslnWidth	1506	0	8	5411	4	3
MaxSpd	1506	15	65	67050	45	5
MedWid	1506	2	800	35755	24	23
Pavcon	1506	.0	5.0	5702.3	3.8	.8
ADT	1506	8900	98500	66921063	44436	15209
Sidewalk	1506	.0	10.0	6385.7	4.2	2.5
SldWidth	1506	1.0	12.0	4823.0	3.2	2.1
SurWidth	1506	24.0	48.0	52842.0	35.1	1.8
SegLen	1506	.05	2.70	430.85	.29	.29
MOPM	1506	.0	53.2	10311.9	6.8	7.1
DrivupPM	1506	.0	250.0	21436.6	14.2	19.6
DrivdoPM	1506	.0	350.0	22447.4	14.9	20.4
TotdriPM	1506	.0	600.0	43883.7	29.1	36.4
SigPM	1506	.0	51.3	6295.8	4.2	5.8
Valid N (listwise)	1506					

Number of Observations

		AcMaCl	Raise_M	Pave_M	MedTyp	ShldTyp	Rural	Suburban	Urban	ParkTyp
N	Valid	1506	1506	1506	1506	1506	1506	1506	1506	1506
	Missing	0	0	0	0	0	0	0	0	0

Access Managment Classification

		Frequency	Percent[1]	Valid Percent[1]	Cumulative Percent
Valid	Class Not Applicable	96	6.4	6.4	6.4
	Access Class 01	6	.4	.4	6.8
	Access Class 02	14	.9	.9	7.7
	Access Class 03	419	27.8	27.8	35.5
	Access Class 04	1	.1	.1	35.6
	Access Class 05	806	53.5	53.5	89.1
	Access Class 06	59	3.9	3.9	93.0
	Access class 07	105	7.0	7.0	100.0
	Total	1506	100.0	100.0	

[1] The percent and valid percent columns are included in the software outputs to detect missing or out of range values (for instance, a negative distance). That the numbers are the same indicates the anomalies did not occur in the final datasets.

Raised Median

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	46	3.1	3.1	3.1
	Yes	1460	96.9	96.9	100.0
	Total	1506	100.0	100.0	

Paved Median

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	1460	96.9	96.9	96.9
	Yes	46	3.1	3.1	100.0
	Total	1506	100.0	100.0	

Median Type

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.0	41	2.7	2.7	2.7
	2.0	176	11.7	11.7	14.4
	3.0	154	10.2	10.2	24.6
	6.0	5	.3	.3	25.0
	8.0	119	7.9	7.9	32.9
	10.0	5	.3	.3	33.2
	12.0	1	.1	.1	33.3
	13.0	5	.3	.3	33.6
	17.0	600	39.8	39.8	73.4
	18.0	8	.5	.5	74.0
	20.0	12	.8	.8	74.8
	21.0	1	.1	.1	74.8
	22.0	372	24.7	24.7	99.5
	25.0	1	.1	.1	99.6
	26.0	5	.3	.3	99.9
	28.0	1	.1	.1	100.0
	Total	1506	100.0	100.0	

ShldTyp

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	.1	.1	.1
	1	544	36.1	36.1	36.2
	3	36	2.4	2.4	38.6
	6	913	60.6	60.6	99.2
	7	2	.1	.1	99.3
	8	10	.7	.7	100.0
	Total	1506	100.0	100.0	

Rural

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1476	98.0	98.0	98.0
	1	30	2.0	2.0	100.0
	Total	1506	100.0	100.0	

Suburban

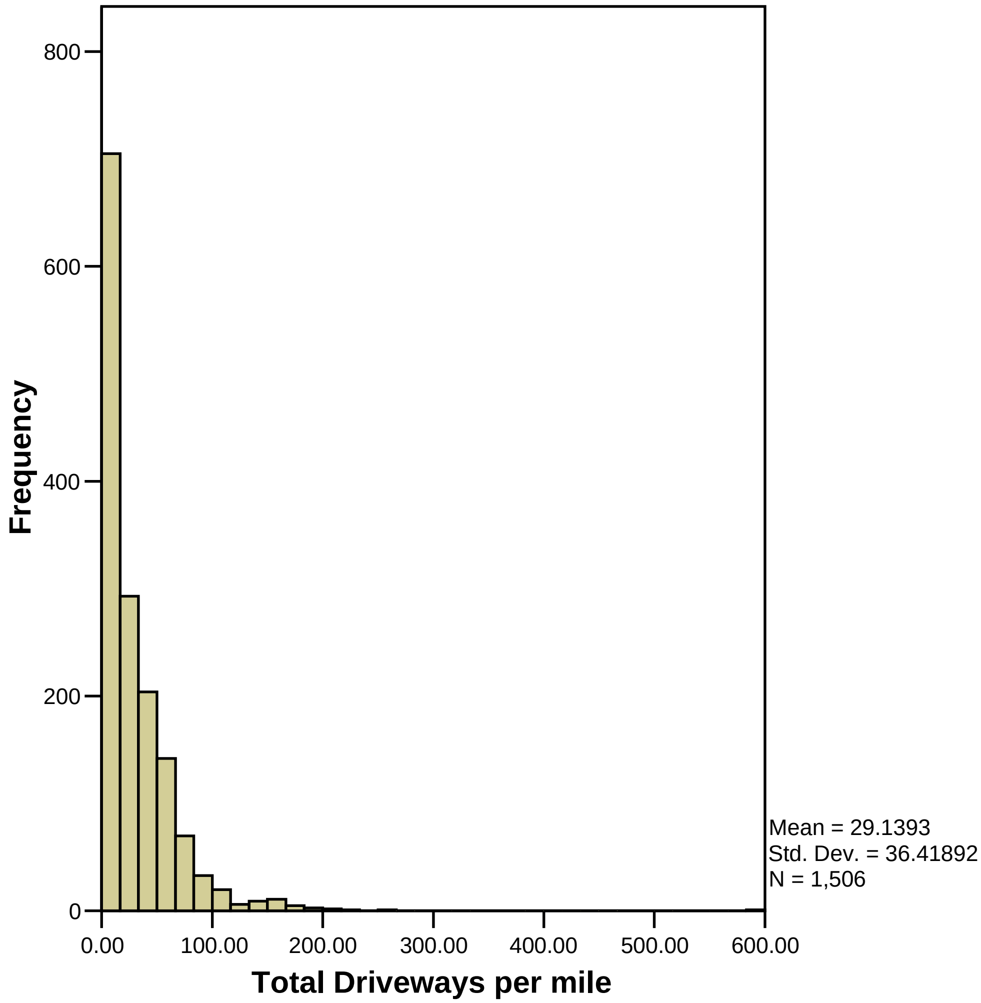
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1203	79.9	79.9	79.9
	1	303	20.1	20.1	100.0
	Total	1506	100.0	100.0	

Urban

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	333	22.1	22.1	22.1
	1	1173	77.9	77.9	100.0
	Total	1506	100.0	100.0	

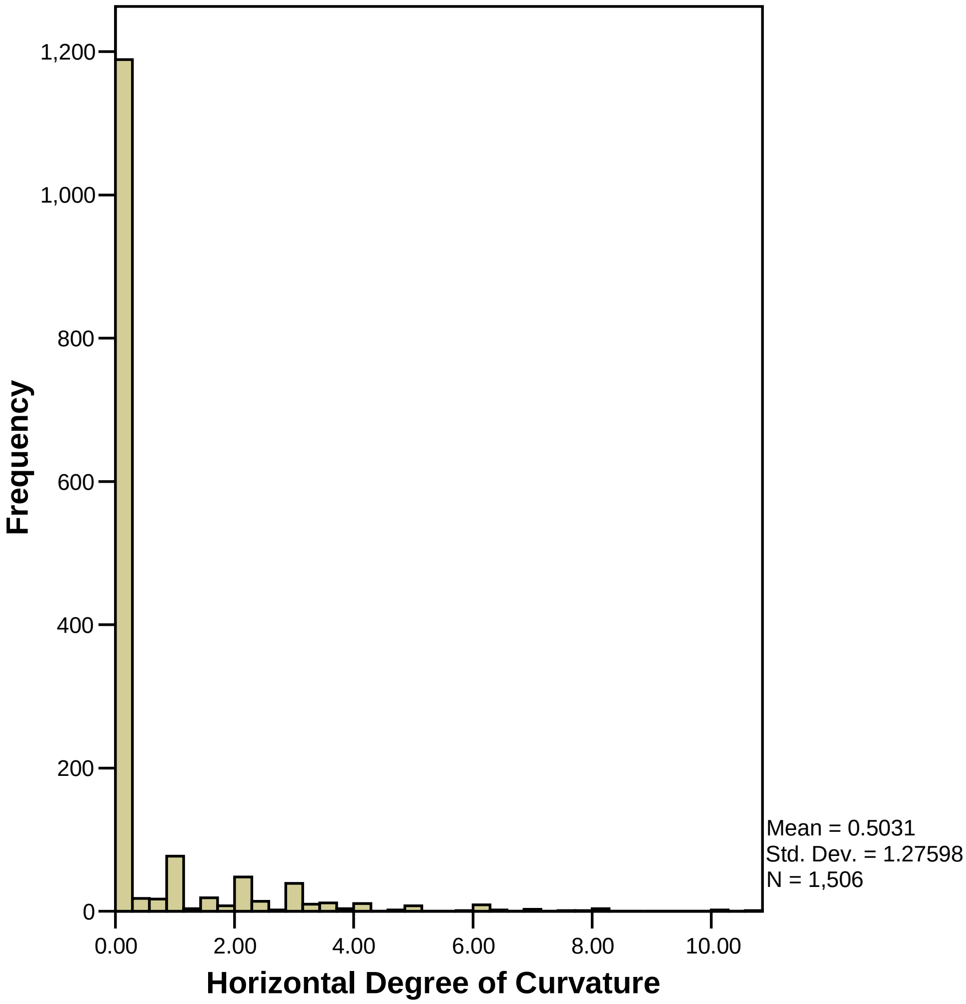
ParkTyp

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	287	19.1	19.1	19.1
	1	641	42.6	42.6	61.6
	2	573	38.0	38.0	99.7
	4	5	.3	.3	100.0
	Total	1506	100.0	100.0	



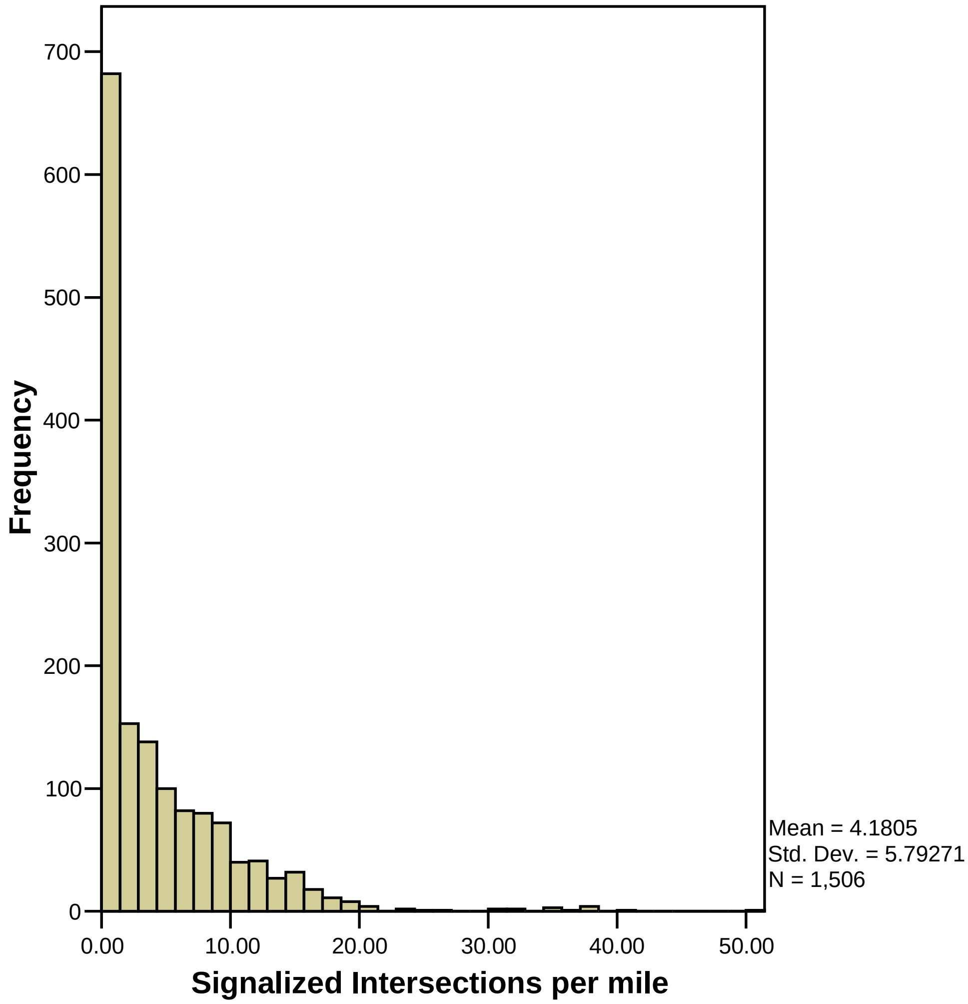
DRIVEWAYS PER MILE	FREQUENCY	PERCENT[1]
0	354	23.5
0.01 – 10.00	187	12.4
10.01 – 20.00	228	15.1
20.01 – 30.00	172	11.4
30.01 – 40.00	151	10.0
40.01 – 50.00	111	7.4
50.01 – 60.00	100	6.6
60.01 – 70.00	65	4.3
70.01 – 80.00	35	2.3
80.01 – 100.00	45	3.0
100.01 and higher	58	3.9
TOTAL	1506	

[1] Percentages do not add to 100 due to rounding.



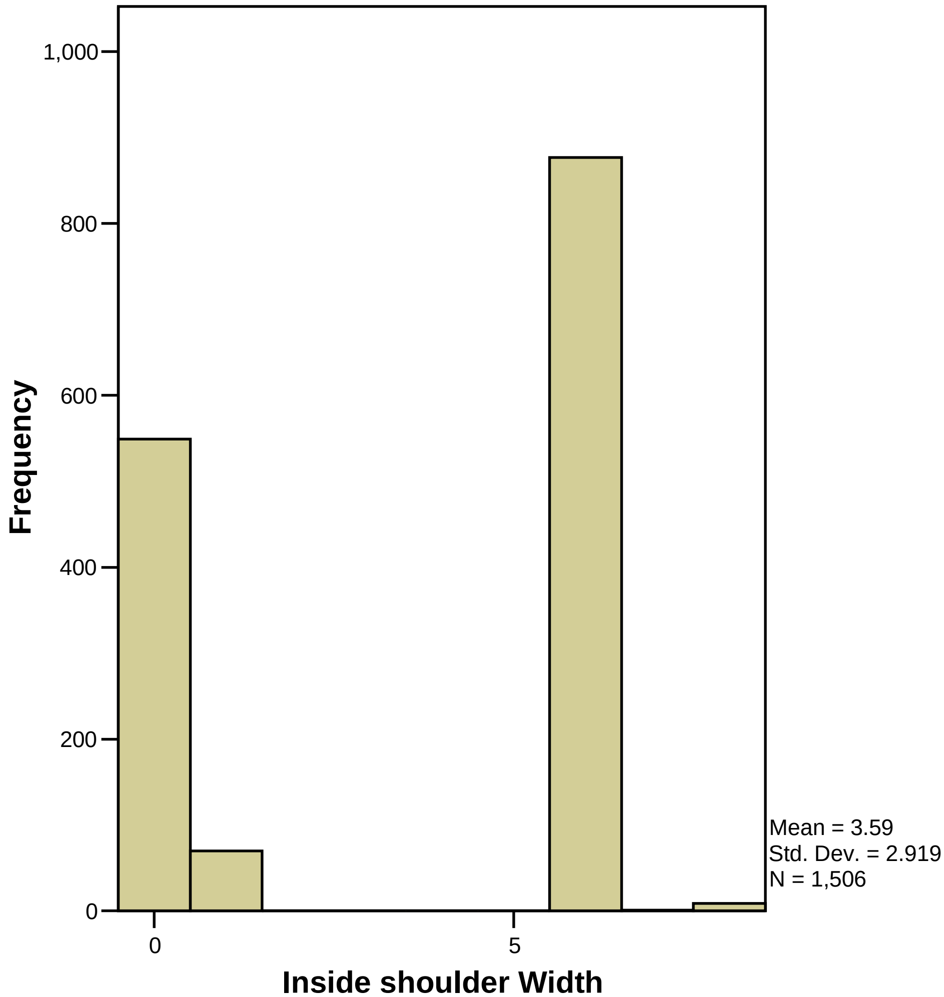
CURVATURE (degrees)	FREQUENCY	PERCENT[1]
0	1181	78.4
0.01 – 0.50	24	1.6
0.51 – 1.00	94	6.2
1.01 – 1.50	21	1.4
1.51 – 2.00	58	3.9
2.01 – 2.50	15	1.0
2.51 – 3.00	42	2.8
3.01 – 3.50	19	1.3
3.51 – 4.00	18	1.2
4.01 and higher	34	2.3
TOTAL	1506	

[1] Percentages do not add to 100 due to rounding.

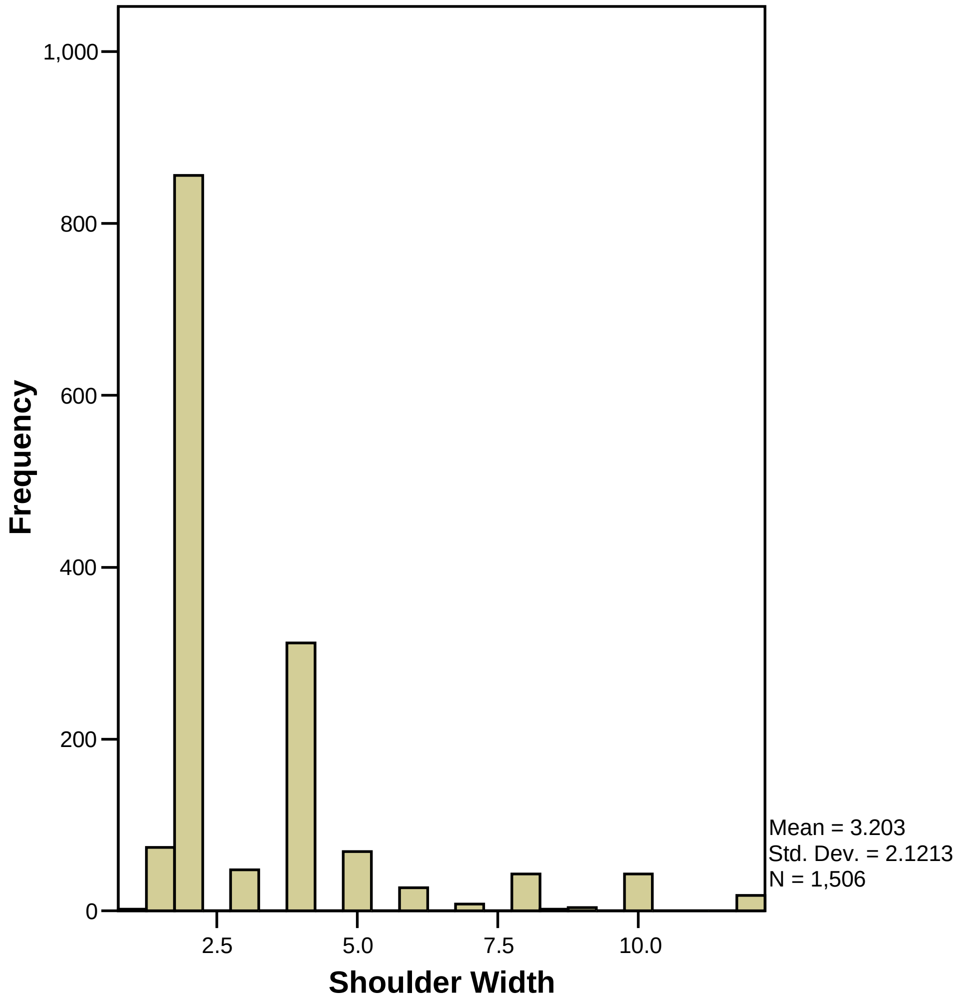


SIGNALIZED INTERSECTIONS PER MILE	FREQUENCY	PERCENT[1]
0	642	42.6
0.01 – 2.00	88	5.8
2.01 – 4.00	220	14.6
4.01 – 6.00	140	9.3
6.01 – 8.00	111	7.4
8.01 – 10.00	107	7.1
10.01 – 15.00	123	8.2
15.01 – 20.00	56	3.7
20.01 and higher	21	1.4
TOTAL	1506	

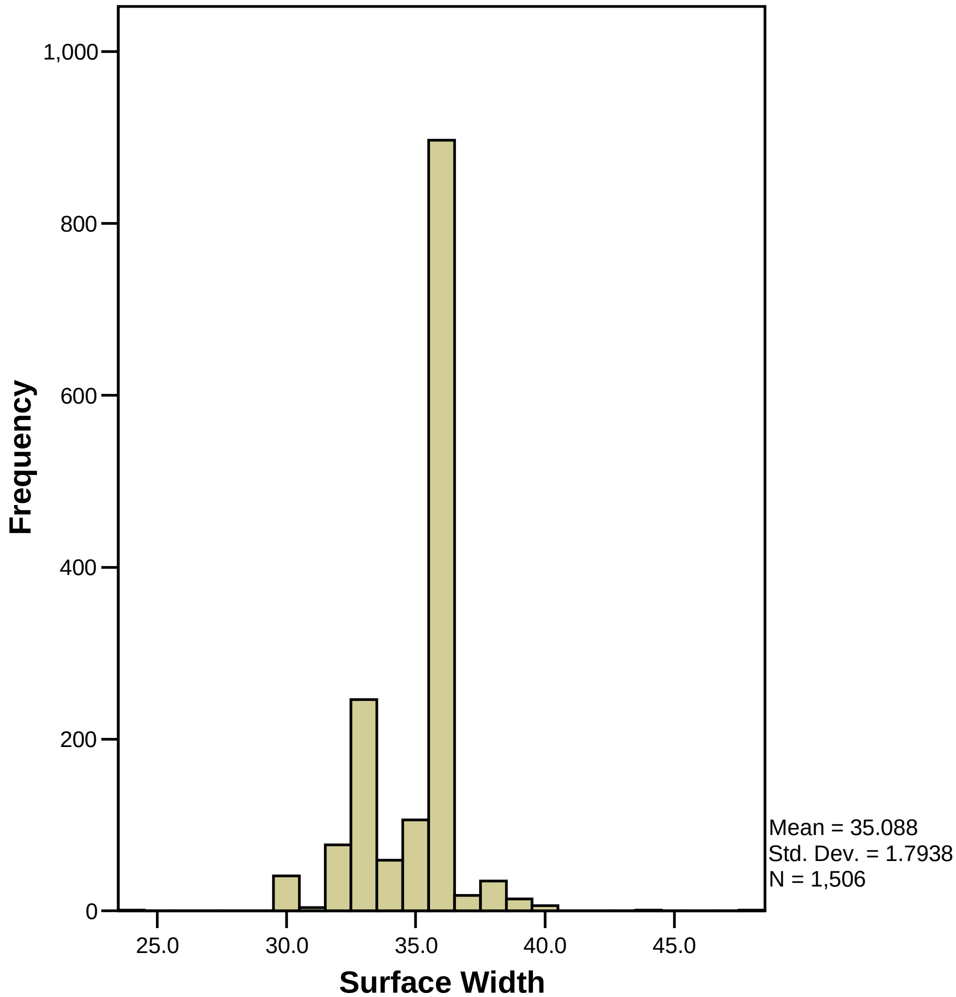
[1] Percentages do not add to 100 due to rounding.



INSIDE SHOULDER WIDTH (ft)	FREQUENCY	PERCENT
0	549	36.5
1	70	4.6
2	0	0.0
3	0	0.0
4	0	0.0
5	0	0.0
6	877	58.2
7	1	0.1
8	9	0.6
TOTAL	1506	



SHOULDER WIDTH (ft)	FREQUENCY	PERCENT
1 or 1.5	76	5.0
2	856	56.8
3	48	3.2
4	312	20.7
5	69	4.6
6	27	1.8
7	8	0.5
8 or 8.5	45	3.0
9	4	0.3
10	43	2.9
11	0	0.0
12	18	1.2
TOTAL	1506	



SURFACE WIDTH (ft)	FREQUENCY	PERCENT
24, 30, or 31	46	3.1
32	77	5.1
33	246	16.3
34	59	3.9
35	106	7.0
36	897	59.6
37 and higher	75	5.0
TOTAL	1506	

For the following sensitivity analyses the average each independent variable of the model was changes as the others were held constant. The constant values used for these analyses were as follows:

Dependent Variable	Value
Horizontal Degree of Curvature	0.50
Signals per Mile	4.0
Inside Shoulder Width	4.0
Total Driveways per Mile	29.0
Outside Shoulder Width	3.0
Median Width	24.0
Surface Width	35.0

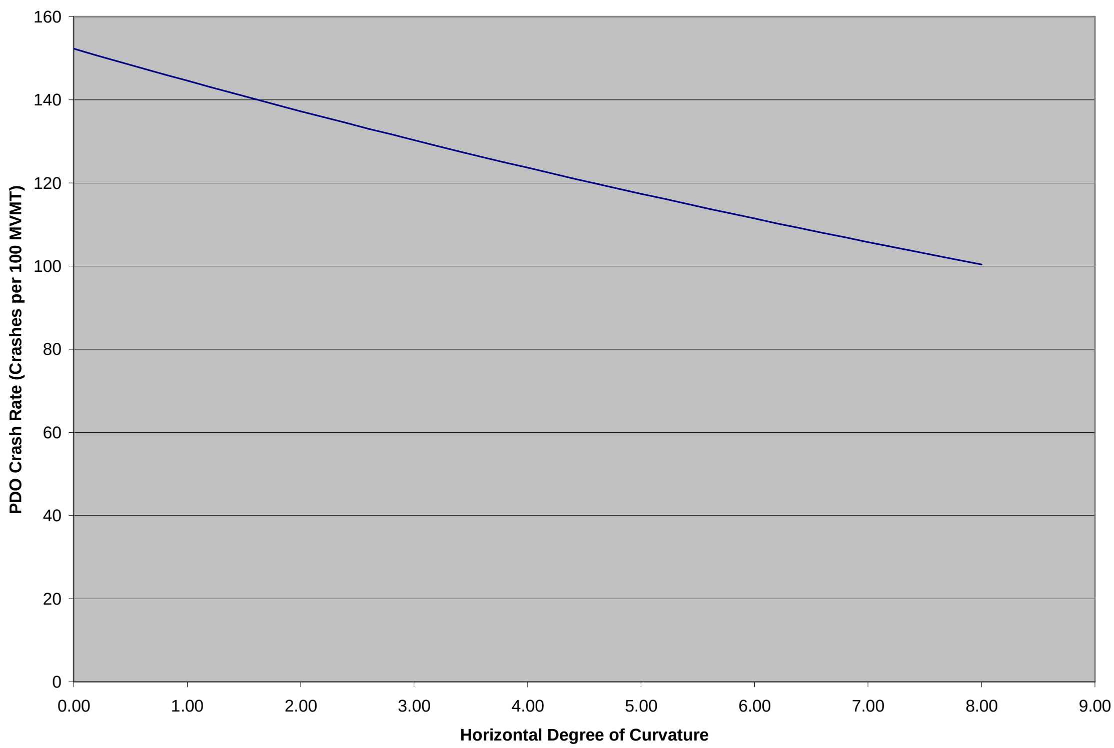


Figure E-1 Sensitivity Analysis (PDO) – Horizontal Degree of Curvature

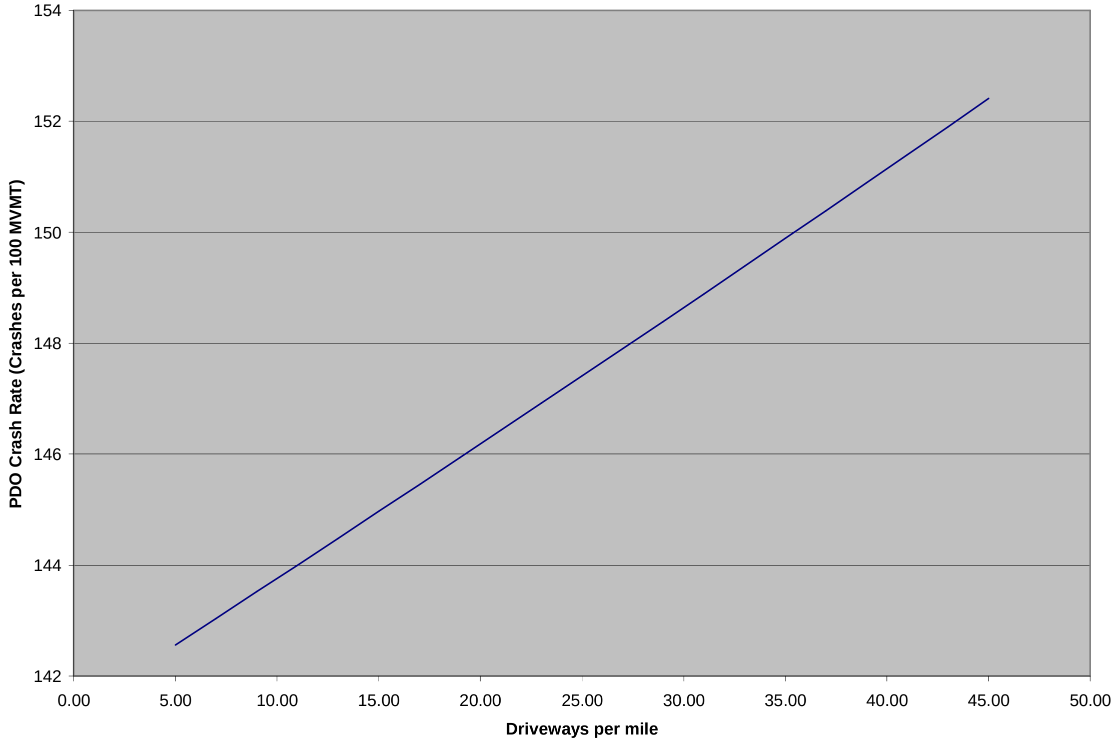


Figure E-2 Sensitivity Analysis (PDO) – Driveways per Mile

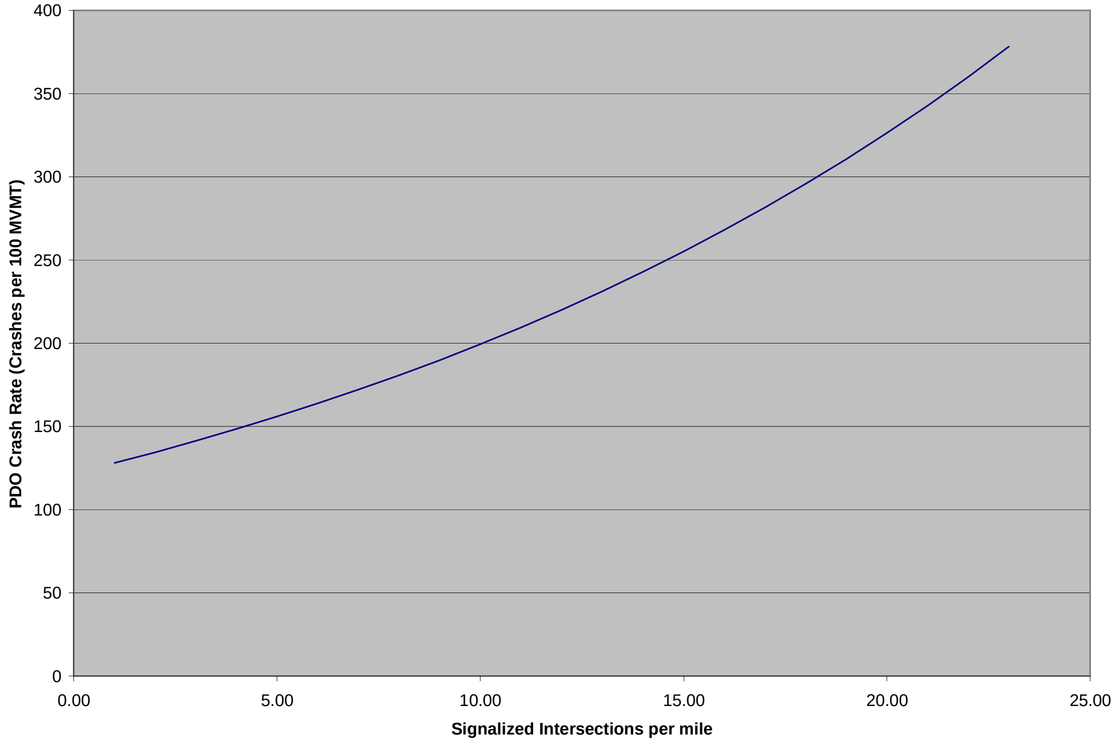


Figure E-3 Sensitivity Analysis (PDO) – Signalized Intersections per Mile

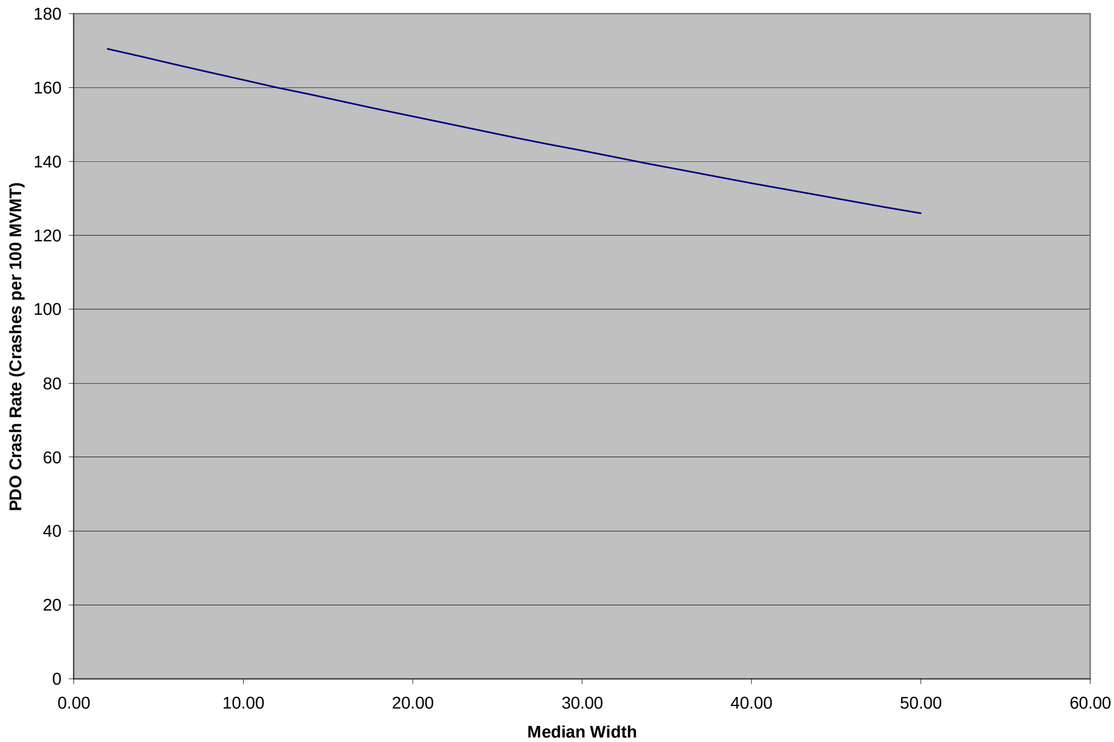


Figure E-4 Sensitivity Analysis (PDO) – Median Width

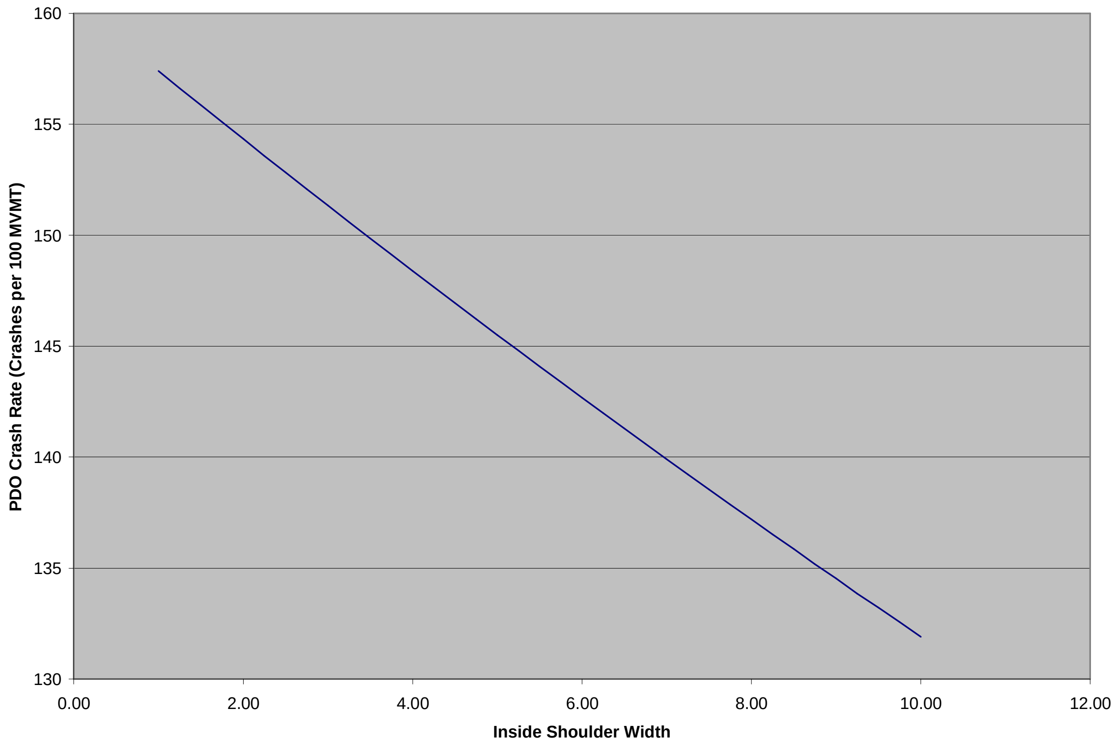


Figure E-5 Sensitivity Analysis (PDO) – Inside Shoulder Width

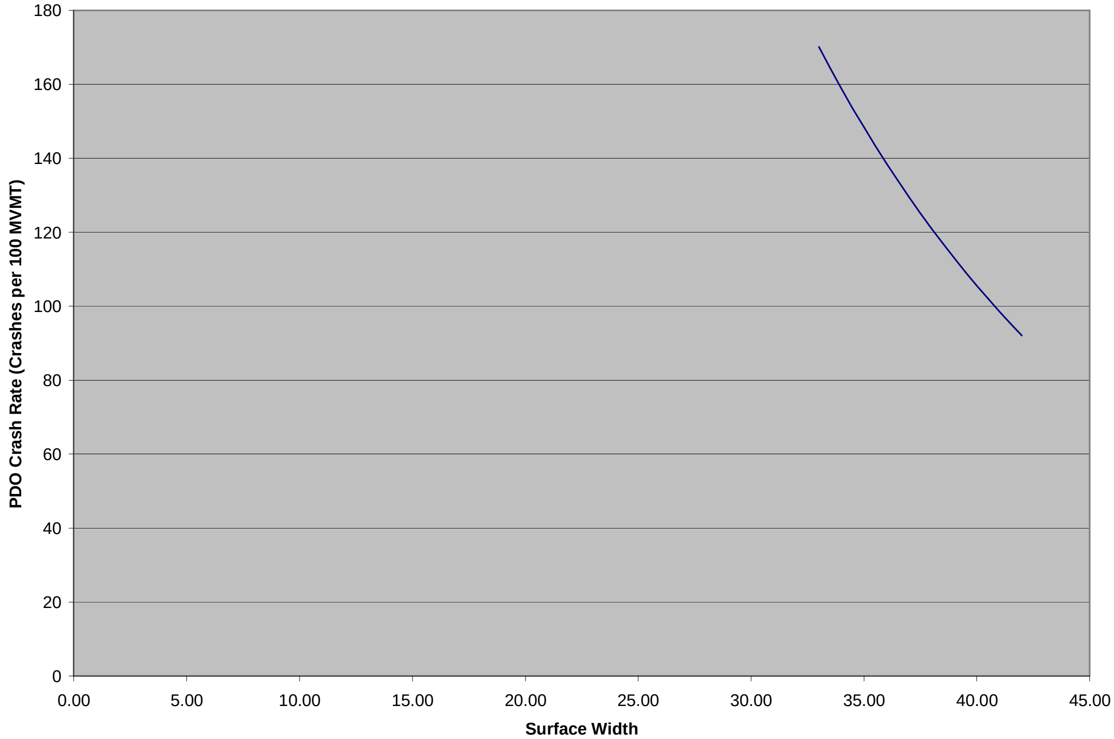


Figure E-6 Sensitivity Analysis (PDO) – Surface Width

APPENDIX F PROJECT INFORMATION SHEET

PROJECT INFORMATION SHEET

Project Description:	
Financial Project ID:	
County Section Number:	
State Road Number:	
Federal Aid Number:	
Begin Project MP:	
End Project MP:	
Date:	
Completed by:	
Length of Section (miles):	
Life of Project (years):	
ADT	
- enter year	
- enter annual ADT growth rate (percent)	
Vehicle Miles, 1st Year (ADT*Section Length*365)	0

Variable	**Standard Values**	**Proposed Values**
Horizontal Degree of Curvature		
Signals per Mile		
Inside Shoulder Width		
Outside Shoulder Width		
Median Width		
Total Driveways per Mile		
Surface Width		

Projected Crash Rate (per 100 million vehicle miles)	**Standard Values**	**Proposed Values**
Fatal (K) and Severe (A)	7.47	7.47
Non-incapacitating (B) and Possible Injury (C)	5.07	5.07
PDO (O)	7.47	7.47

Projected Number of Crashes	**Standard Values**	**Proposed Values**
Fatal (K) and Severe (A)	0.00	0.00

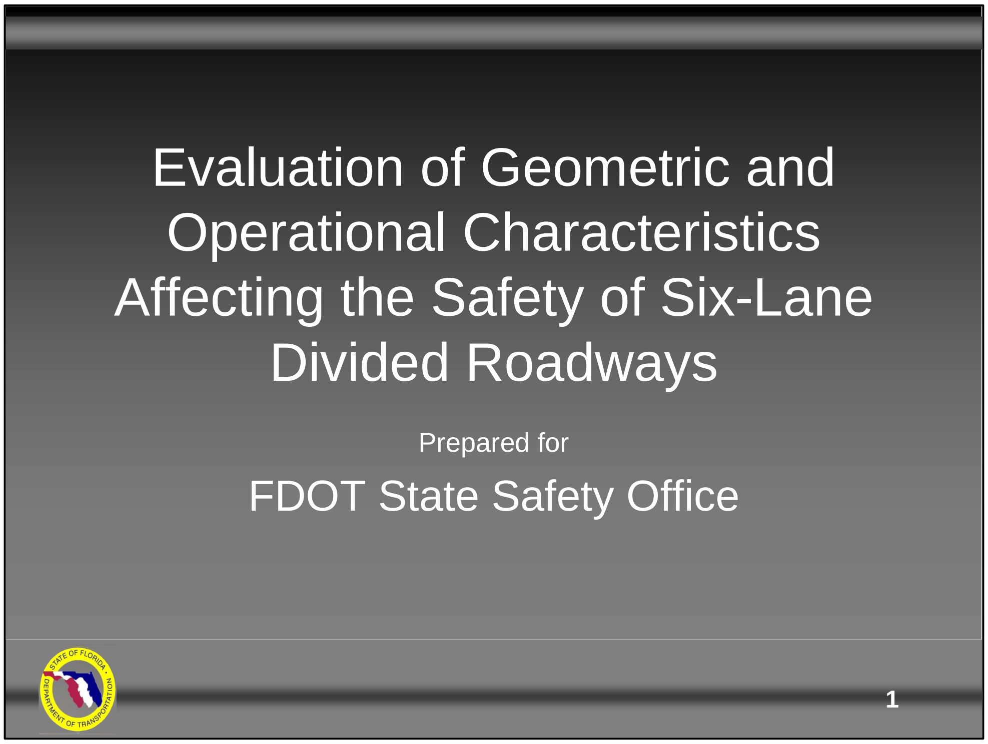
Non-incapacitating (B) and Possible Injury (C)	0.00	0.00	
PDO (O)	0.00	0.00	

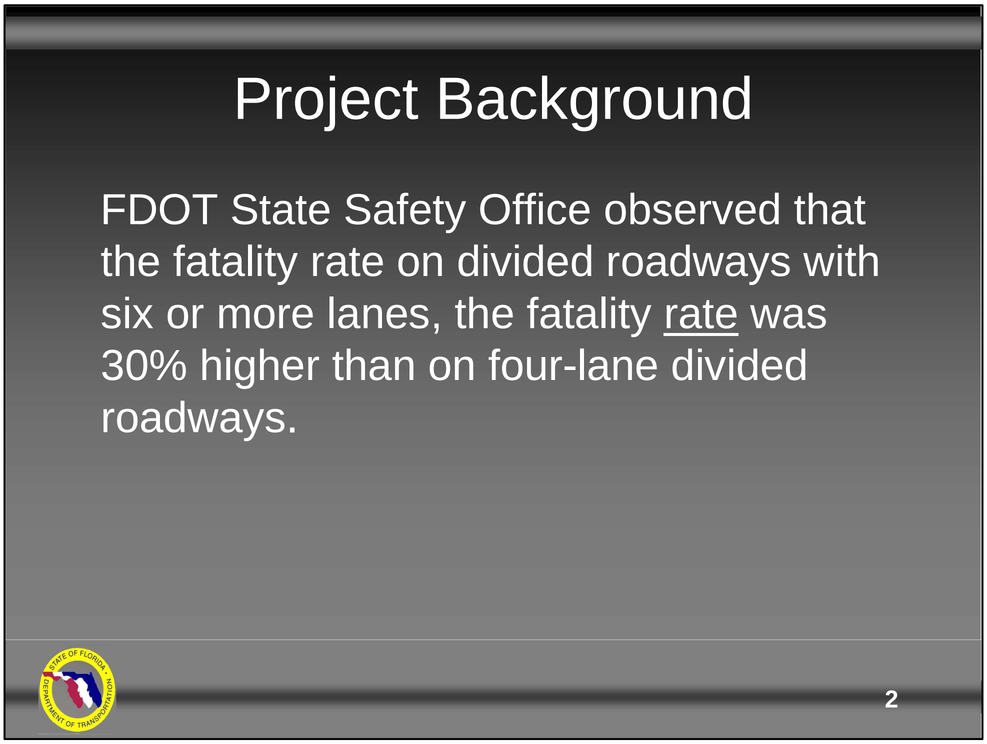
Projected Number of Crashes over Lifetime of Project	**Standard Values**	**Proposed Values**	**Difference**
Fatal (K) and Severe (A)	0.00	0.00	0.00
Non-incapacitating (B) and Possible Injury (C)	0.00	0.00	0.00
PDO (O)	0.00	0.00	0.00

Cost per Crash	
Fatal (K) and Severe (A)	
Non-incapacitating (B) and Possible Injury (C)	
PDO (O)	

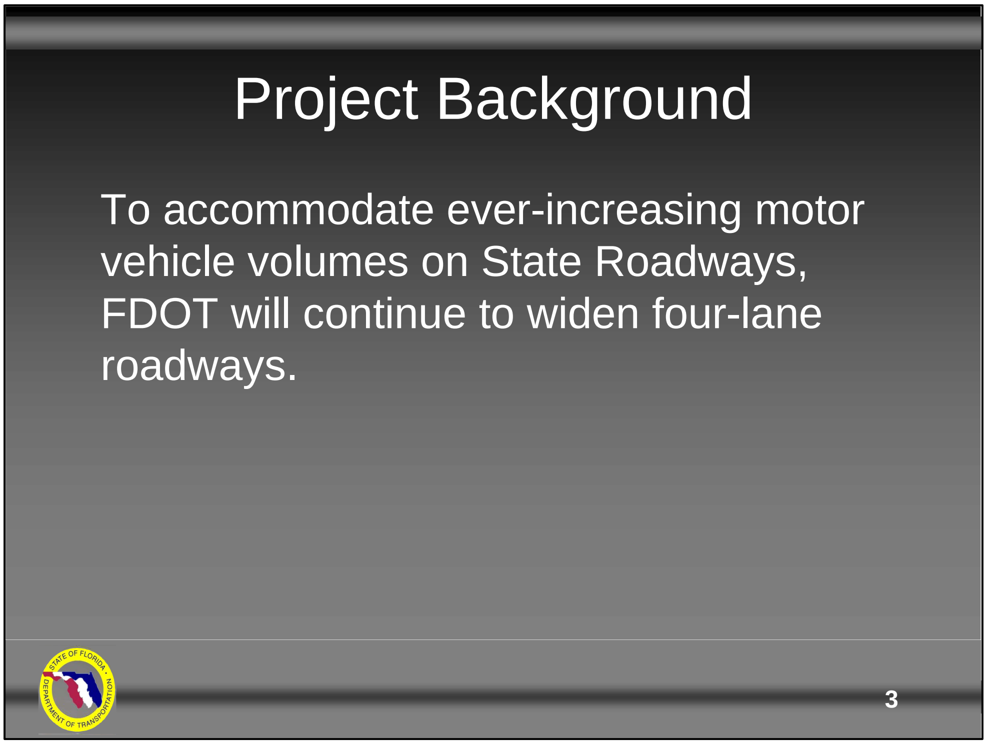
Projected Crash Costs over Lifetime of Project	**Standard Values**	**Proposed Values**	**Savings**
Fatal (K) and Severe (A)	$0	$0	$0
Non-incapacitating (B) and Possible Injury (C)	$0	$0	$0
PDO (O)	$0	$0	$0

APPENDIX G ANNOTATED POWERPOINT PRESENTATION





In an effort to determine those factors influencing the crash rates on Florida's roadways, the FDOT State Safety Office reviews and analyzes the crash trends on the State System. One such review revealed that six- or more lane, non-limited access roadways have the highest fatality rate (fatalities/million vehicle miles traveled) of all FDOT roadways. In 1998, six- or more lane divided highways had a 25% higher fatality rate than four-lane divided highways. By 2001, six-lane sections had 32% to 48% higher fatality rates than four-lane divided highways, depending on urban, suburban, or rural location. This difference in the crash rate is hypothesized to be caused by differences in geometrics and traffic characteristics between six- and four-lane highways.

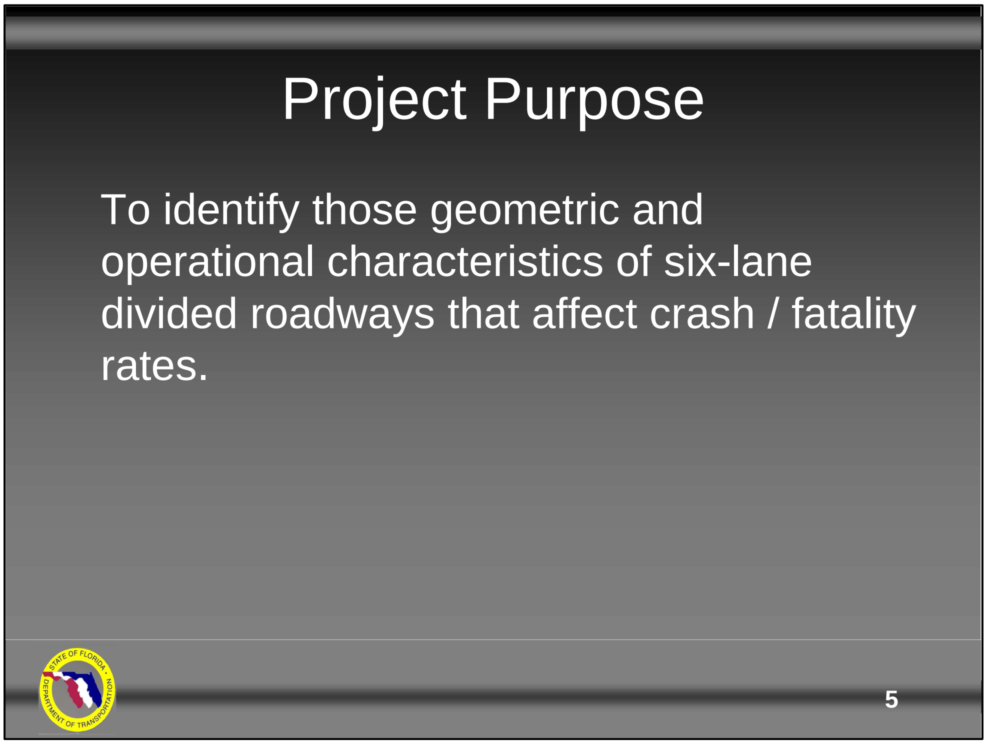


Florida is one of the fastest growing states in the nation. As the population grows, so does the number of motor vehicles.

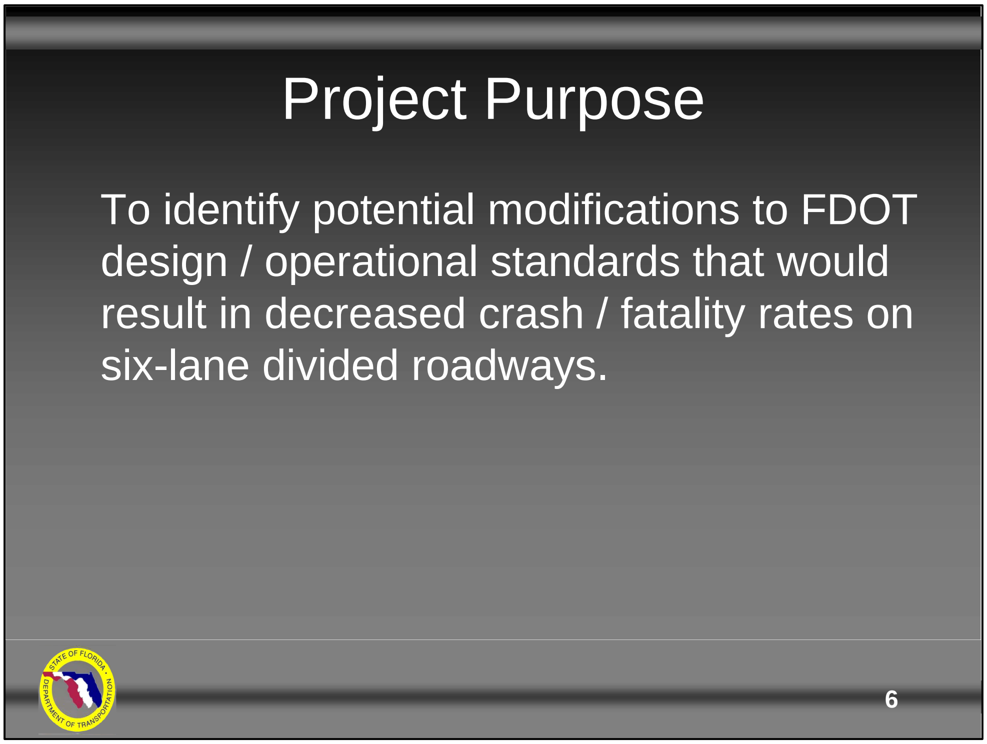
Project Background

To decrease crash / fatality rates, FDOT needs to know what factors result in higher crash rates on six-lane roadways.

4



The main goal of this project was to improve the safety of six-lane divided roadways in the State of Florida by mitigating the high crash rates on these roadways as compared to four-lane divided roadways. To attain this goal, the overall objective of this project was to evaluate roadway and operational factors influencing the high injury and fatality rates on six-lane divided roadways.

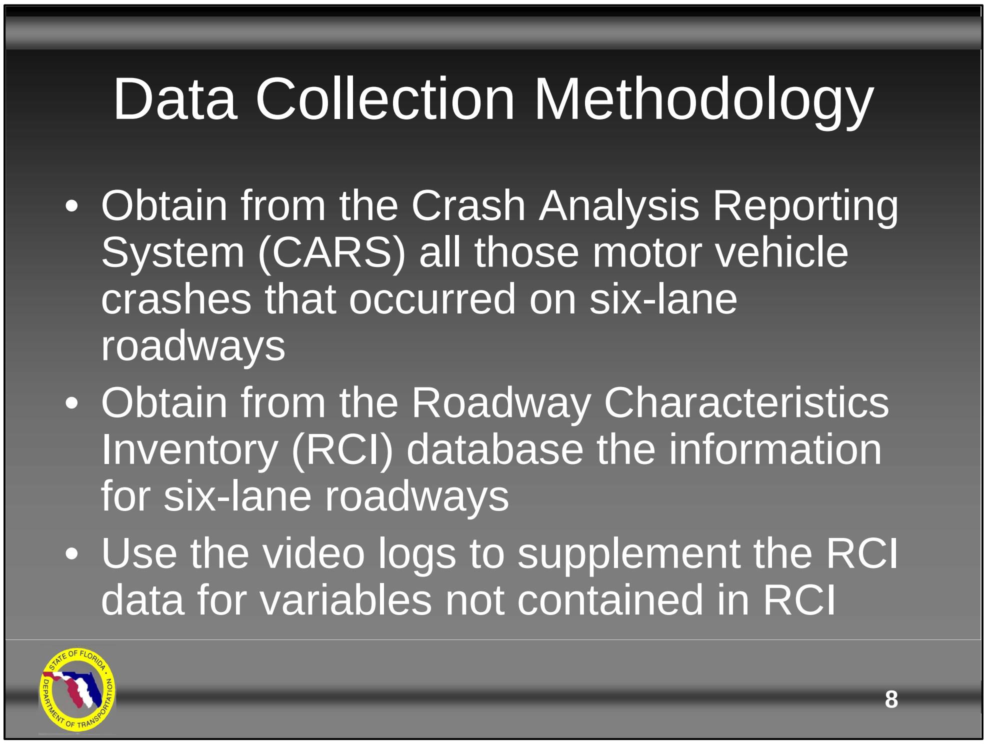


The major outcome of this research project was expected to be the development of roadway safety models that can be used by planners, designers, and engineers to improve highway design and maintenance in order to promote safety of six-lane divided roadways.

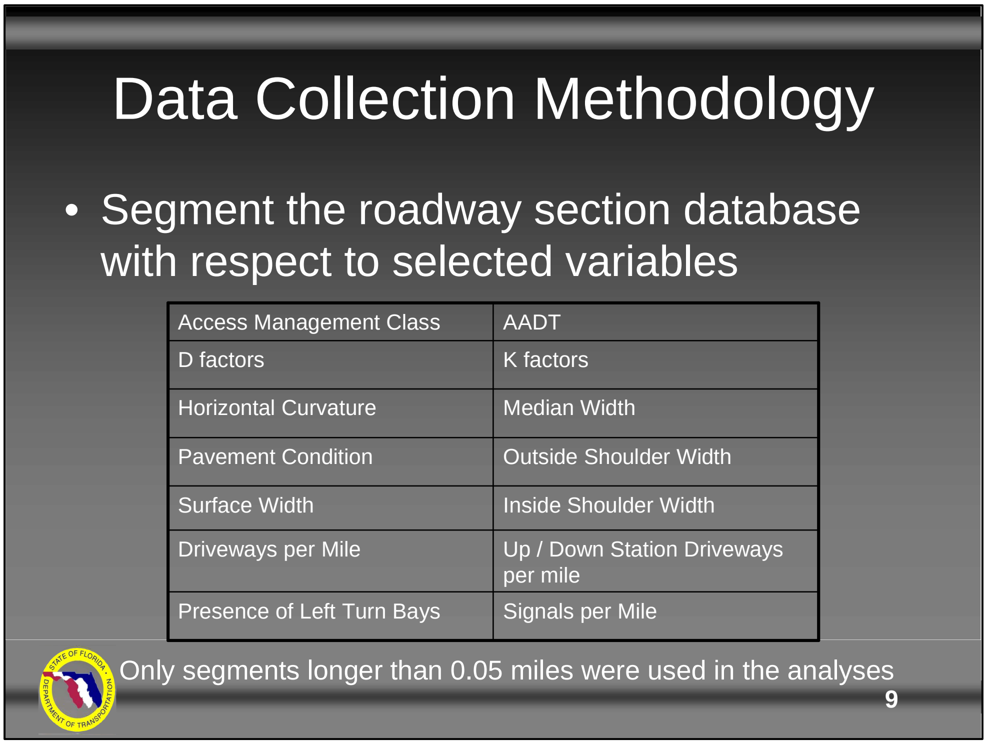
Hypothesis Confirmation

Crash patterns on six-lane divided roadways are different than those on four-lane divided roadways.

7



The data came from several sources:
•FDOT crash databases - Crash data for the State Highway System (SHS) during the year 2001 was obtained from the FDOT crash database. This dataset contains all crashes, each with an individual identifying number, and all the information coded on the Florida Motor Vehicle Crash Report form. Each crash record includes many crash- and vehicle-level variables. Examples include first harmful event for each vehicle, injury severity, alcohol/drug use, etc. Additionally, some roadway data have been linked to the crash details in the Crash Analysis Reporting System (CARS). While it contains a wealth of information, the CARS data alone were not adequate to perform the analyses needed for this project. Many roadway variables suspected as being significant are not included within this database. For instance, the CARS does not distinguish between roadways with six lanes and those with more than six lanes. Consequently, the crash data had to be linked to a more comprehensive roadway characteristics data file.
•Roadway Characteristics Inventory (RCI) file - The Roadway Characteristics Inventory (RCI) contains information on many geometric and operational variables for state-maintained roadways throughout Florida. Examples include shoulder type, pavement surface width, posted speed limit, horizontal degree of curvature, pavement condition, etc. The RCI file was obtained from Florida DOT and was dated 2004. More information about the RCI can be found online at http://www.dot.state.fl.us/planning/statistics/rci/default.htm.
•FDOT videologs - Although the RCI contains a wealth of geometric information, some variables which were thought to be important are not included in the RCI. More specifically, the research team thought that the following non-included variables are important in understanding crashes along six-lane roadways: (1) Number of driveways on each side, per mile; (2) Number of median openings per mile; (3) Presence of left turn bays (1=yes, 0=no); and (4) Number of signalized intersections per mile. Fortunately, FDOT maintains videologs of state-maintained roadways throughout Florida. The videologs contain snapshots of roadways at 0.01-mile intervals and are organized according to the roadway ID number. Depending on the roadway, the videologs were filmed from 2001 to 2004. Each of the segments identified using the RCI database was "driven" using the videologs. The values for these variables were entered into a separate database and then were merged with the segmented RCI file.
•Local traffic operations offices - Signal timing had to be obtained from operating agencies. Signal timing plans were obtained from counties and cities and linked to the segmented RCI database. Because of the time required to obtain this data, this data collection effort was limited to FDOT's District 7.



Data Collection Methodology

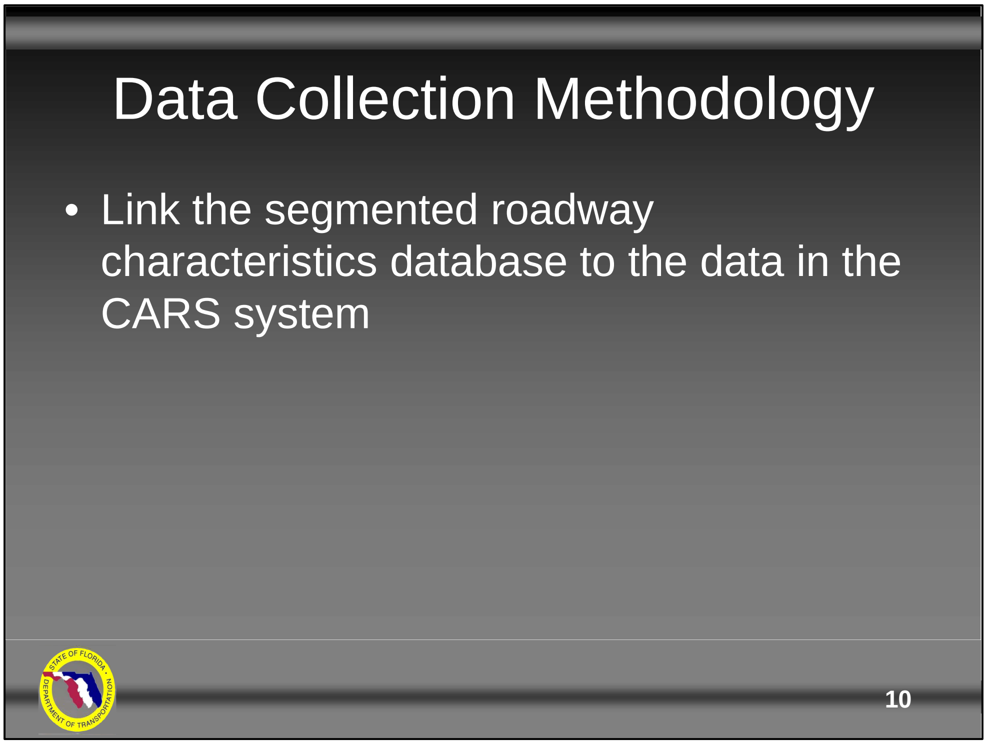
- Segment the roadway section database with respect to selected variables

Access Management Class	AADT
D factors	K factors
Horizontal Curvature	Median Width
Pavement Condition	Outside Shoulder Width
Surface Width	Inside Shoulder Width
Driveways per Mile	Up / Down Station Driveways per mile
Presence of Left Turn Bays	Signals per Mile

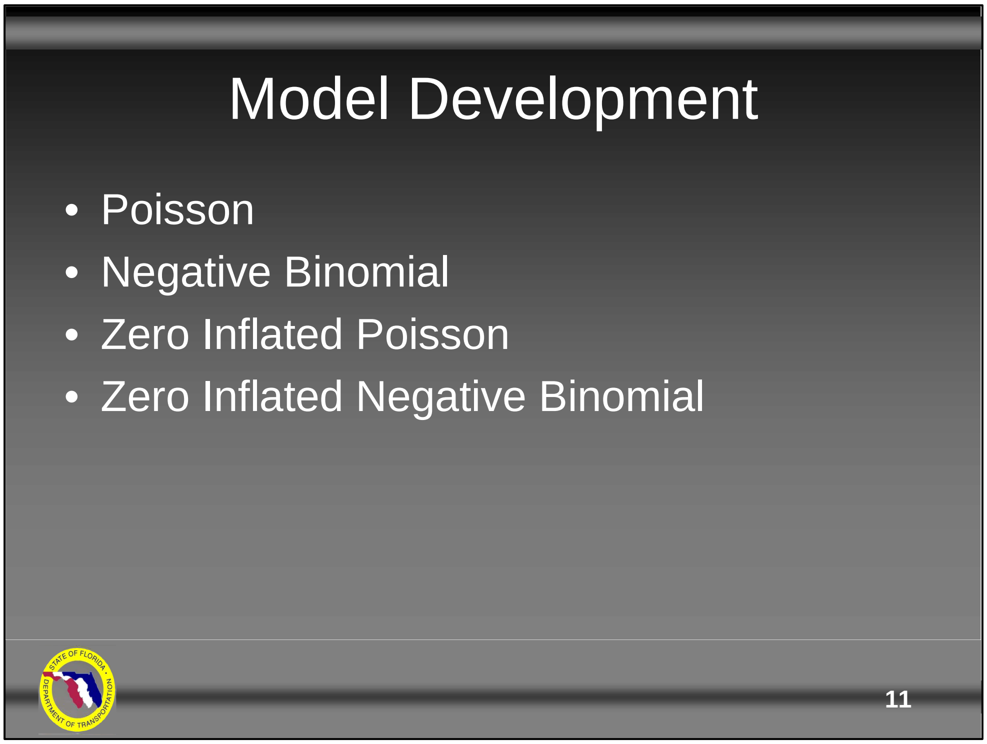
Only segments longer than 0.05 miles were used in the analyses

9

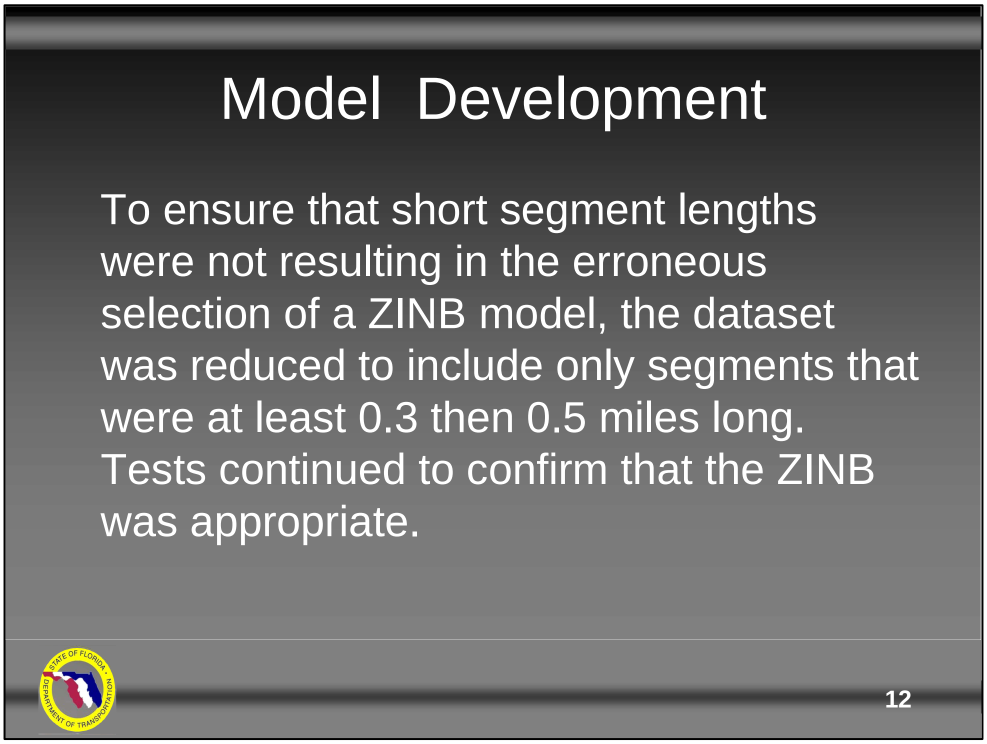
To make the data useful, the six-lane roadways needed to be obtained from the dataset and segmented. As the RCI has a field identifying the number of lanes the first step was simple. However, the RCI does not have an overall segmentation; rather, each item in the RCI is coded for a begin and end milepost. To create an overall segmentation for this project, the researchers identified a set of key variables which they thought influenced crash rates (Appendix A of the report). A spreadsheet was then programmed to determine at what mileposts any key variable changed. Then the researchers created new segmentation based upon these break points. The segments that were used had a minimum length of 0.05 mile. The resulting roadway characteristics file contained nearly 2000 roadway segments.



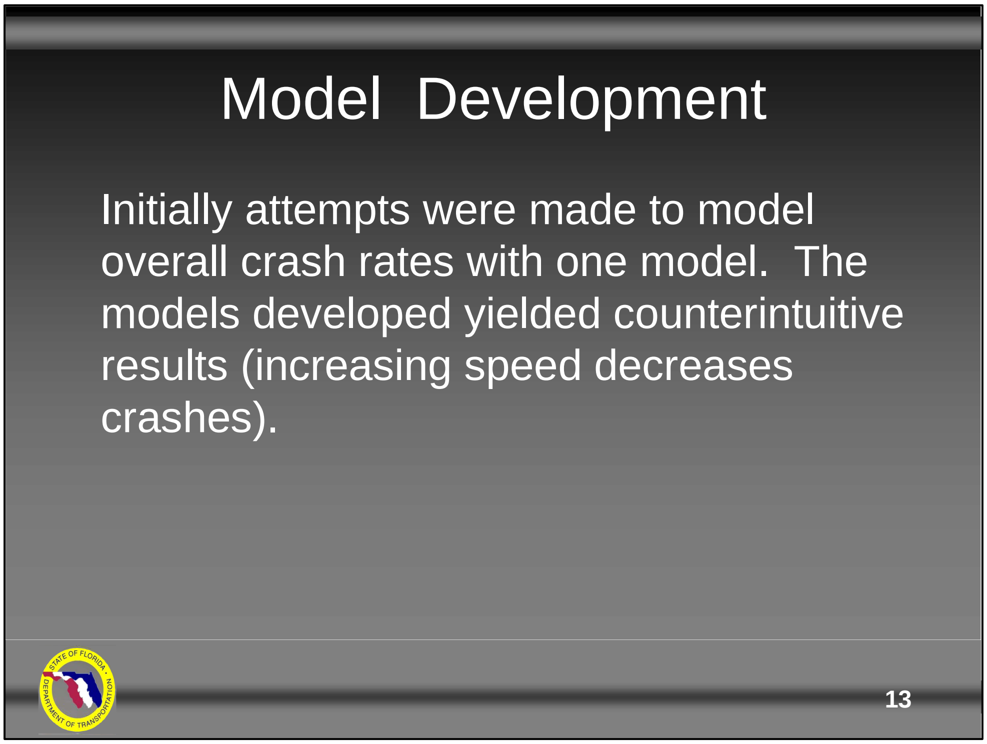
Since each crash record had a roadway segment associated with it, the crashes were linked to the RCI variables. Consequently, each crash record contained fields for all the crash, RCI, and median and driveway data, and, in some cases, signal timing information. This effort created a massive and robust dataset. Testing could now be performed based upon any RCI / crash detail field.



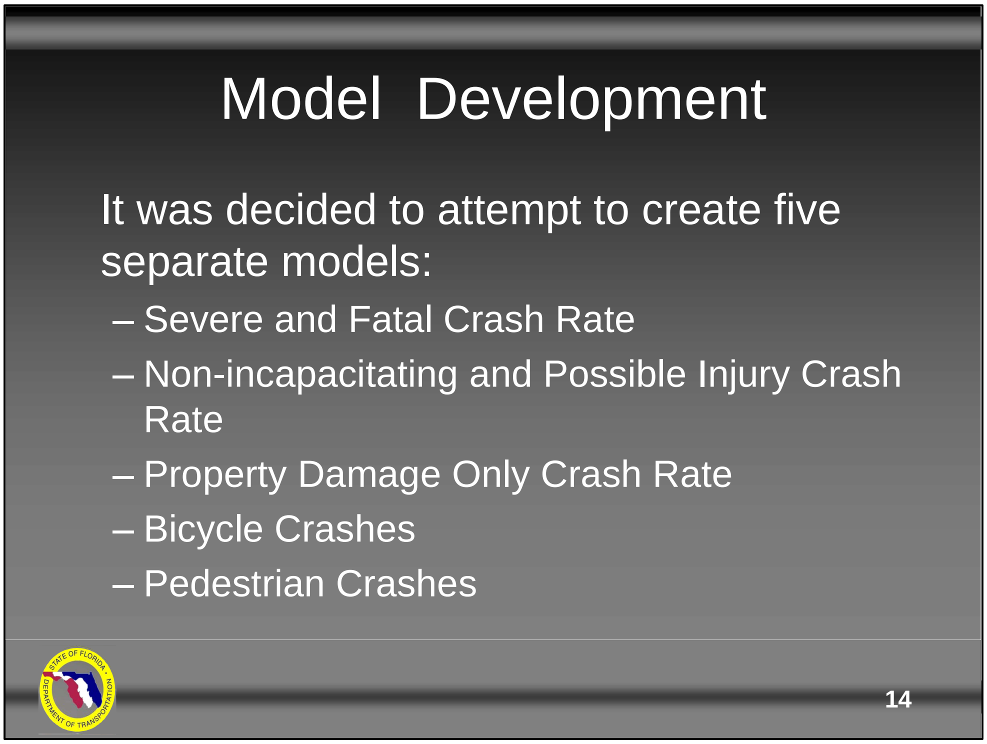
Both zero-inflated negative binomial models and zero-inflated Poisson models were considered. Because there is significant over dispersion in the data set, a Poisson model was not considered to be appropriate. The zero-inflated negative binomial model was selected as the appropriate model form.
A large percentage of the roadway segments in the database had no crashes during 2001 and therefore had a crash rate equal to zero. The researchers tested for the presence of a dual state and found zero-inflated models to be the best fit.



The researchers were concerned that the short length of many segments could have led to a false conclusion that the zero-inflated negative binomial model was appropriate. Consequently, the researchers also checked to see if segment length had an influence in the large percentage of segments with zero crashes. Models were tested on segments with lengths >0.5 miles, >0.3 miles, and >0.05 miles and zero-inflated models were found to be the most appropriate.



Initially, the researchers tried to develop one model that pertained to all crashes, but the resulting model suggested that a series of three models – one for each level of crash severity – would be more appropriate. For example, horizontal degree of curvature increased the rate of severe/fatal crashes but decreased the rates of non-incapacitating/possible injury and property damage only crashes. Hence, separate models for each level of crash severity were fitted.



However, as described on the next slide, modeling bicycle and pedestrian crashes was deemed to be impractical. Therefore, this presentation and Chapter 6 of our report focus on three models, one for each level of crash severity.

Model Development

Bicycle and Pedestrian Crash Models

The development of these models was deemed impractical. The characteristics found to be associated with crashes were likely to represent and increased incidence of walking and cycling. Without exposure data, it was not possible to obtain true crash rates.

15

The researchers attempted to create models for pedestrian crashes and bicyclist crashes. While models could have been developed, the form of those models is inconsistent with reasonable explanations. For example, more crashes occurred on roadway segments with sidewalks than on segments without sidewalks. The researchers believe that this finding is the result of increased exposure on segments with sidewalks (*i.e.*, more people walking on segments with sidewalks than on segments without sidewalks).
Because there is no measure of exposure for pedestrians and bicyclists, the models appear to be predicting where walking and bicycling are occurring rather than the relative risks associated with the roadways.

Severe and Fatal Crash Model

Table 6.1 Severe and Fatal Crashes – Model Coefficients and Statistics

Variable	Coefficient	Standard Error	b/St.Er.	P[Z]>z	Mean of X
Constant	3.90259462	.07922201	49.261	.0000	
HCURDEG	.03082006	.02606036	1.183	.2370	.47368285
SIGPM	.02859905	.00535165	5.344	.0000	4.30435599
ISLDWIDT	-.02161111	.00796378	-2.714	.0067	3.56957929
SLDWIDTH	-.01558822	.01328139	-1.174	.2405	3.16796117
MEDWID	-.00170746	.00289369	-.590	.5551	23.5799353
Alpha	.37816326	.03671053	10.301	.0000	
Tau	.03664763	.01233541	2.971	.0030	

Alpha is the dispersion parameter and tau is a parameter for the zero inflation model.

16

The severe and fatal crash model was developed based on 1,545 segments and is as follows:

Severe and Fatal Crash Rate = 3.9026 + 0.0308 HCURDEG + 0.286 SIGPM – 0.0216 ISLDWIDT – 0.0156 SLDWIDTH – 0.0017 MEDWID

These variables were found to be statistically significant:

- Signals per mile (SIGPM)
- Inside shoulder width (ISLDWIDT), in feet

This model includes three additional variables that are not statistically significant:

- Horizontal degree of curvature (HCURDEG), in degrees
- Outside shoulder width (SLDWIDTH), in feet
- Median width (MEDWIDTH), in feet

These three variables were included because they were strongly correlated with the crash rates.

Non-Incapacitating and Possible Injury Crash Model

Table 6.2 Non-incapacitating and Possible Injury Crashes – Model Coefficients and Statistics

Variable	Coefficient	Standard Error	b/St.Er.	P[Z]>z	Mean of X
Constant	5.06651355	.04727706	107.166	.0000	
HCURDEG	-.04474767	.01802106	-2.483	.0130	.48989089
TOTDRIPM	.00163933	.00054235	3.023	.0025	29.7987356
SIGPM	.05090045	.00335587	15.168	.0000	4.21589859
ISLDWIDT	- .02450391	.00665571	-3.682	.0002	3.63607189
SLDWIDTH	- .04838232	.00783622	-6.174	.0000	3.17329910
Alpha	.52978498	.01919589	27.599	.0000	
Tau	- .15341166	.00801502	-19.141	.0000	

Alpha is the dispersion parameter and tau is a parameter for the zero inflation model.

17

The non-incapacitating and possible injury model was developed based on 1,558 segments and is as follows:

Non-incapacitating and Possible Injury Crash Rate = 5.0665 – 0.0447 HCURDEG + 0.0016 TOTDRIPM + 0.0509 SIGPM – 0.0245 ISLDWIDT – 0.0484 SLDWIDTH

These variables were found to be significant:

- Horizontal degree of curvature (HCURDEG), in degrees
- Total driveways per mile (TOTDRIPM)
- Signals per mile (SIGPM)
- Inside shoulder width (ISLDWIDT)
- Shoulder width (SLDWIDTH)

Property Damage Only Crash Model

Table 6.3 Property Damage Only Crashes – Model Coefficients and Statistics

Variable	Coefficient	Standard Error	b/St.Er.	P[Z]>z	Mean of X
Constant	7.46746992	.49098425	15.209	.0000	
TOTDRIPM	.00166889	.00076008	2.196	.0281	29.1482935
HCURDEG	- .05211821	.01792429	- 2.908	.0036	.50313413
SIGPM	.04924155	.00500854	9.832	.0000	4.17300797
ISLDWIDT	- .01963261	.00772817	- 2.540	.0111	3.59694555
SLDWIDTH	- .02338018	.00869786	- 2.688	.0072	3.20385126
MEDWID	- .00630954	.00187049	- 3.373	.0007	23.7343958
SURWIDTH	- .06820171	.01394311	- 4.891	.0000	35.0876494
Alpha	.64758585	.02723195	23.780	.0000	
Tau	- .11493519	.00812804	-14.141	.0000	

Alpha is the dispersion parameter and tau is a parameter for the zero inflation model.

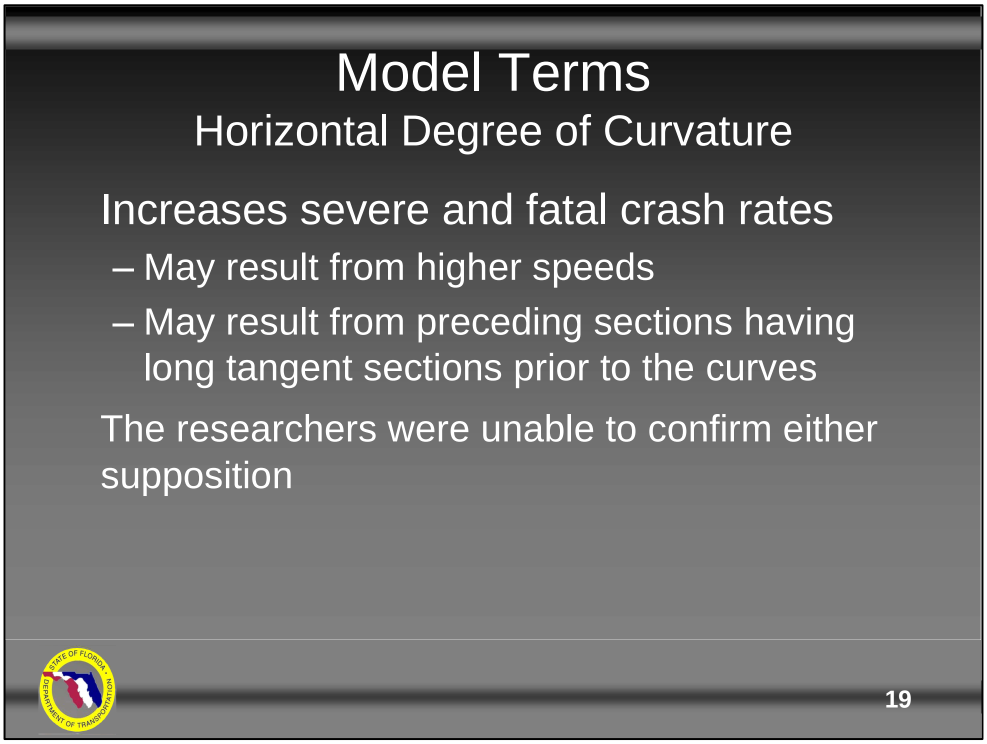
18

The property damage only crash model was developed based on 1,506 segments and is as follows:

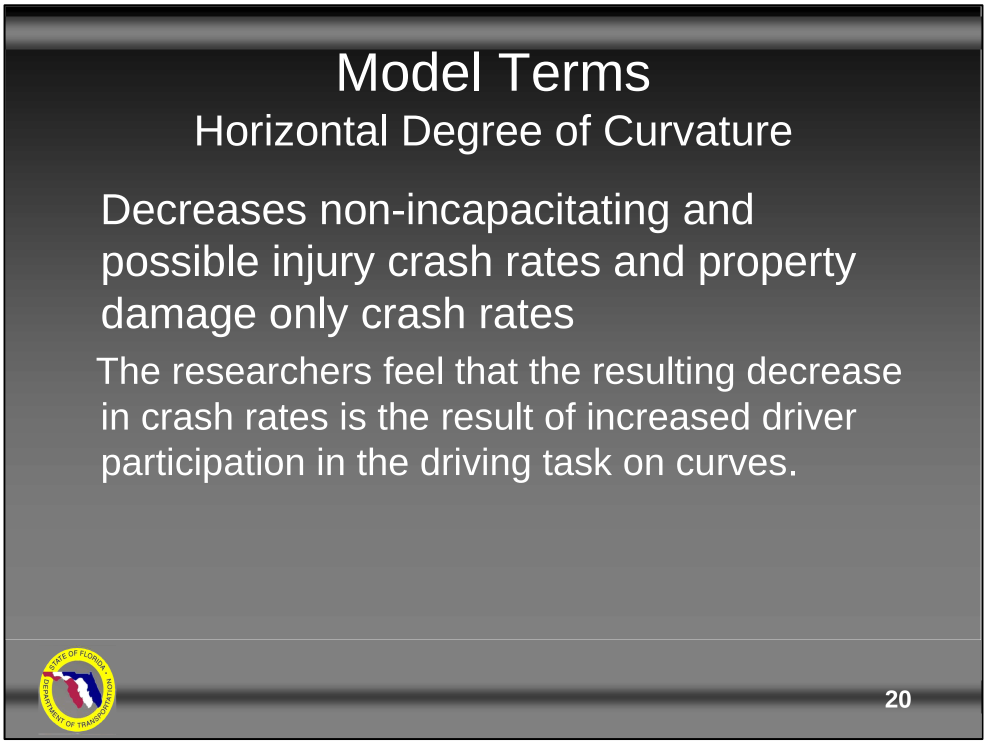
Property Damage Only Crash Rate = 7.4675 + 0.0017 TOTDRIPM – 0.0521 HCURDEG + 0.0492 SIGPM – 0.0196 ISLDWIDT – 0.0234 SLDWIDTH – 0.0063 MEDWID – 0.0682 SURWIDTH

These variables were found to be significant:

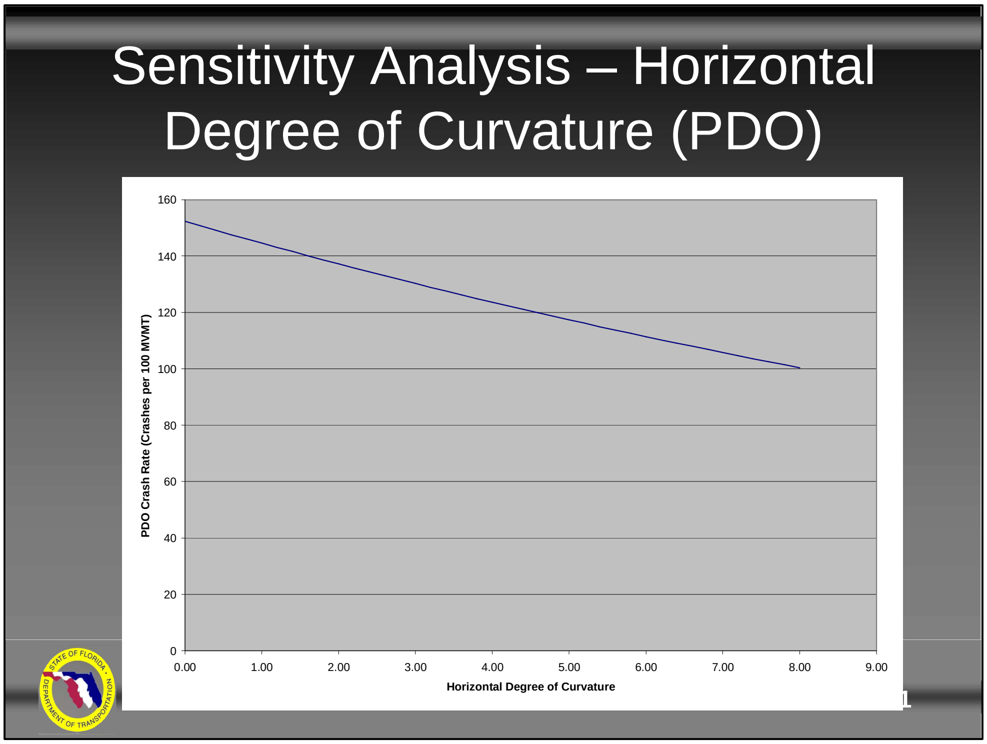
- Total driveways per mile (TOTDRIPM)
- Horizontal degree of curvature (HCURDEG), in degrees
- Signals per mile (SIGPM)
- Inside shoulder width (ISLDWIDT), in feet
- Shoulder width (SLDWIDTH), in feet
- Median width (MEDWIDTH), in feet
- Surface width (SURWIDTH), in feet



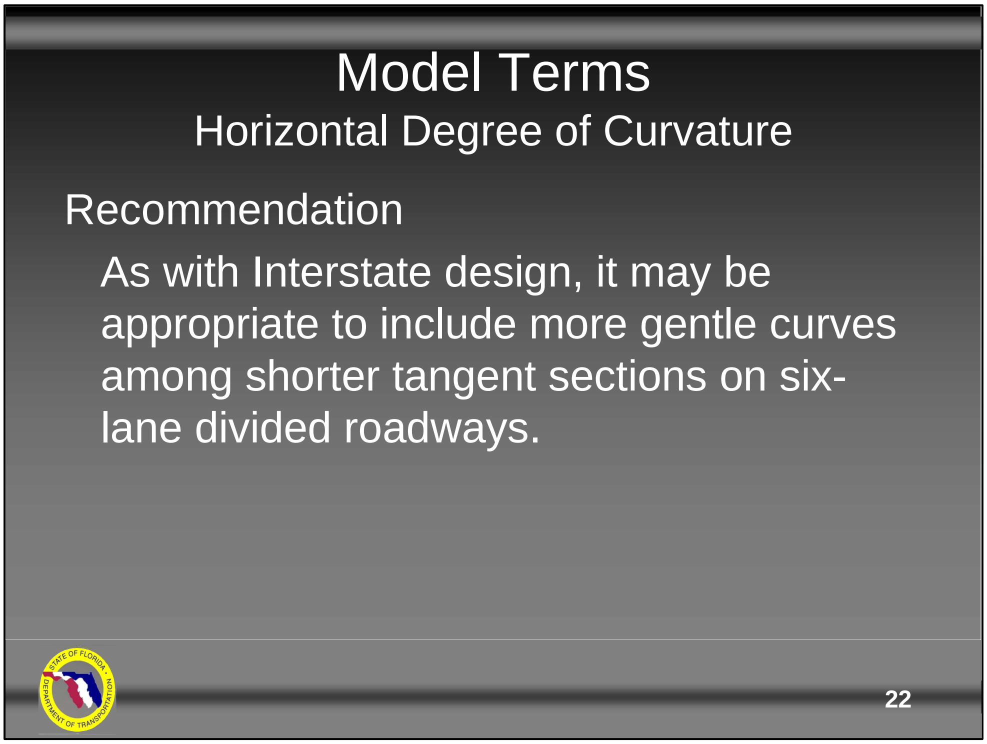
Although increasing the horizontal degree of curvature increased fatal and severe crash rates, this variable was not statistically significant.



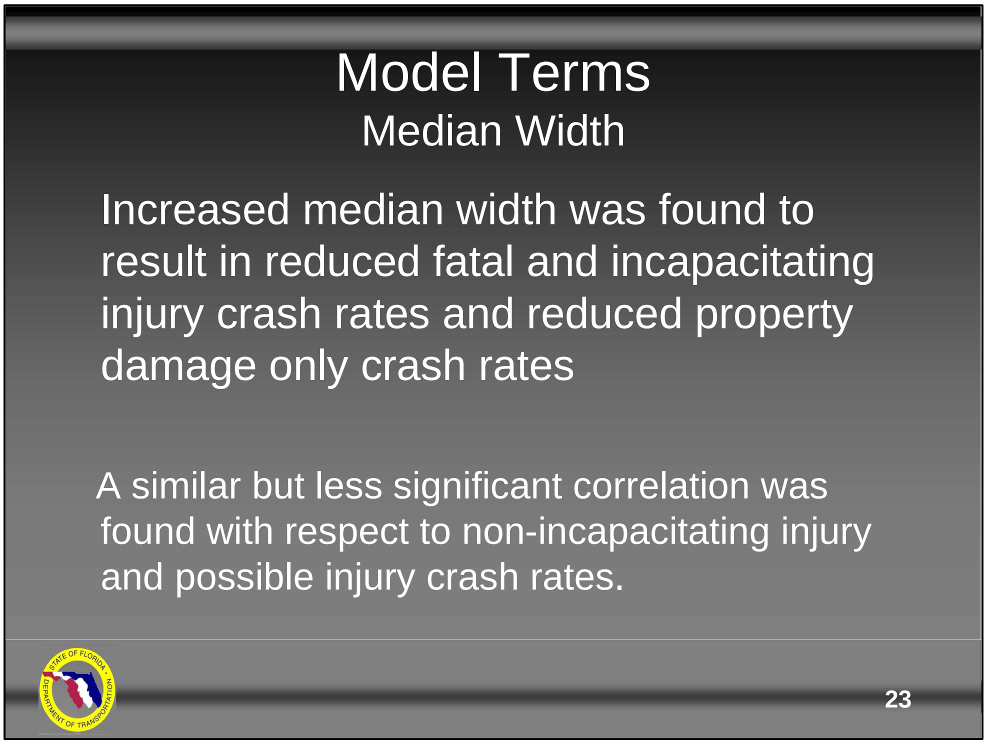
The model results indicate that increasing the horizontal degree of curvature reduces the rates of non-incapacitating and property damage only crashes. The researchers believe this is attributable to a higher level of driver awareness when driving on curves.



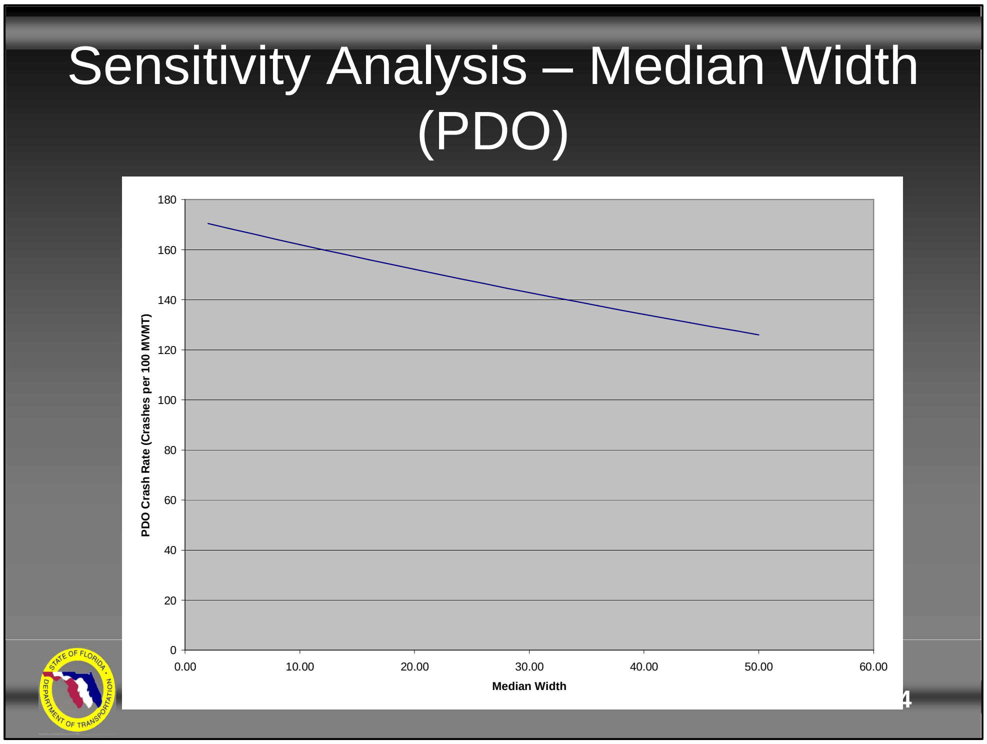
Sensitivity analyses for severe/fatal crashes (Figure C-5), non-incapacitating/possible injury crashes (Figure D-5), and PDO crashes (Figure E-1) are shown in the Appendices of the report. This graph (Figure E-1) shows that increasing the degree of curvature from 2^{o} to 4^{o} would reduce the PDO crash rate from about 138 to about 123 per MVMT.



For freeways, AASHTO recommends a proper combination of flat curvature, shorter tangents, gentle grades, variable median widths, and separate roadway elevations to enhance the safety and aesthetic aspects of freeways. This might hold true in the case of six-lane highways in Florida. The FDOT Plans Preparation Manual recommends a maximum horizontal degree of curvature of 10^{o} 15' for a rural environment and 8^{o} 15' for an urban environment on a 45 mph roadway. The observed horizontal degree of curvature on the majority of six-lane roadway segments is well below these values. The observed effect of horizontal degree of curvature on reducing crash rates suggests that, where possible, the addition of gentle curves in the design of arterial roadways may reduce the observed crash rates on six-lane highways in Florida. Based on these study results, the researchers also recommend that FDOT should not "straighten out" roadway segments that are well within the maximum degree of curvature. This is not to suggest that curves should be maintained on roadways where it can be shown that the curvature is associated with a documented crash problem; rather that a general policy of flattening curves may not be appropriate.



The models indicate that increasing the median width reduces crash rates.



Sensitivity analyses for severe/fatal crashes (Figure C-3) and for PDO crashes (Figure E-4) are shown in the Appendices of the report. This graph (Figure E-4) shows that increasing the median width from 20 ft to 40 ft would reduce the PDO crash rate from just over 150 to about 135 crashes per 100 MVMT.

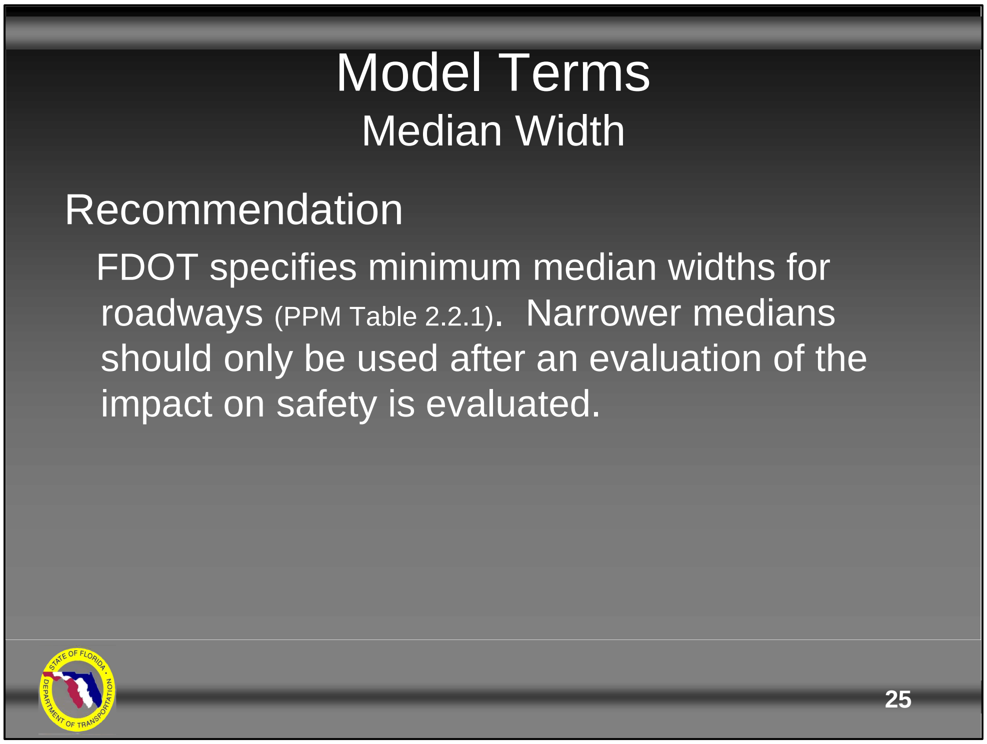
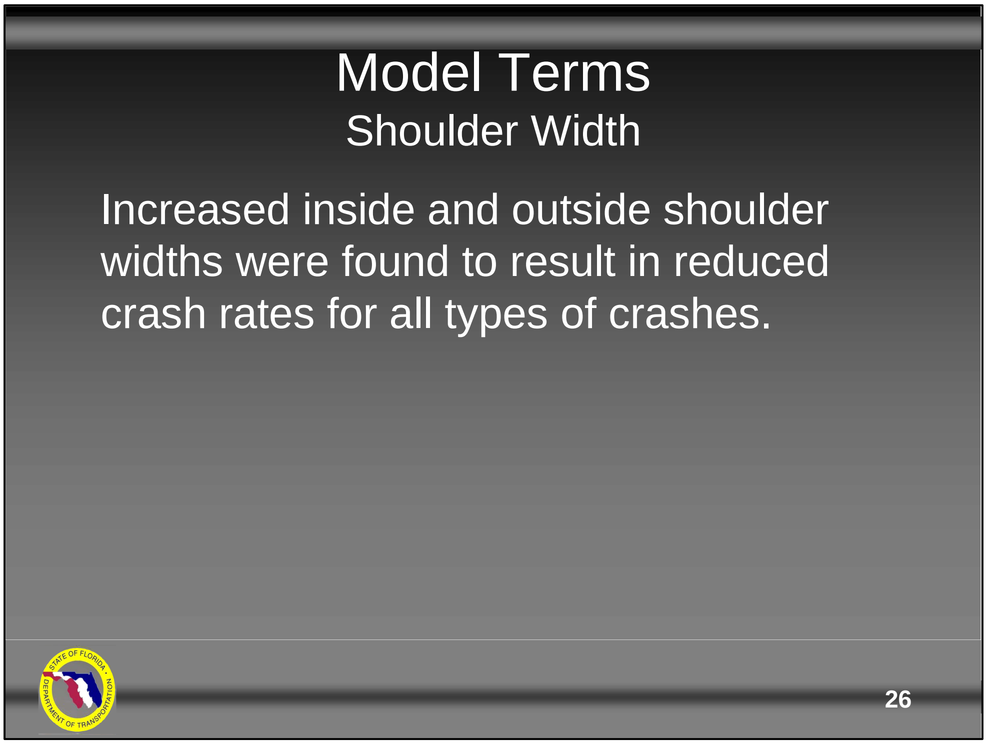
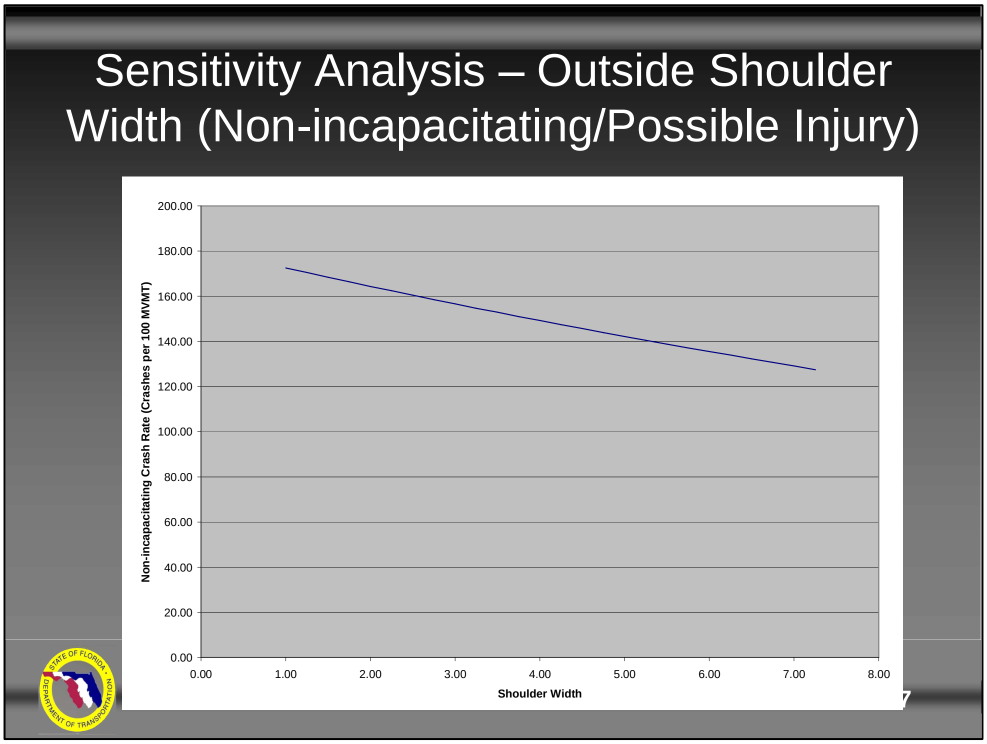


Table 2.2.1 of the FDOT Plans Preparation Manual requires a median width of at least 40 feet on arterial roadways with design speeds in excess of 45 mph, and at least 22 feet on arterial roads with design speeds of 45 mph or less. The minimums may be reduced to either 15.5 ft or 19.5 ft, depending on design speed, on reconstruction projects with severe right-of-way constraints. The results support FDOT's median width policy. The researchers strongly endorse FDOT's efforts to implement the median width requirements on all new roadways. Moreover, where right-of-way is available, deficient median widths should be widened during projects on existing roadways.



Wider shoulder widths reduce crash rates and hence a wider shoulder width is recommended to reduce crash rates on six-lane highways in Florida.



Sensitivity analyses for outside and inside shoulder width are shown in in the Appendices of the report - Figures C-1 and C-4 (severe/fatal crashes), D-2 and D-4 (non-incapacitating/possible injury crashes), and E-5 and E-6 (PDO crashes). This graph (Figure D-2) shows that increasing outside shoulder width from 2 ft to 4 ft would reduce the non-incapacitating/possible injury crash rate from about 165 to 150 per 100 MVMT.

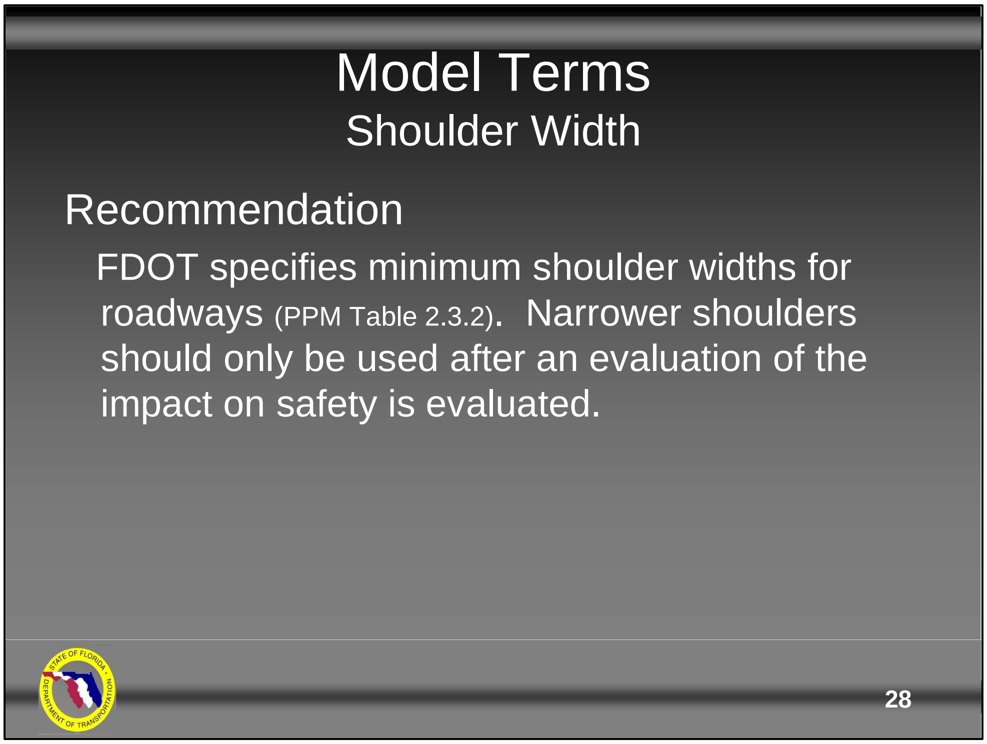
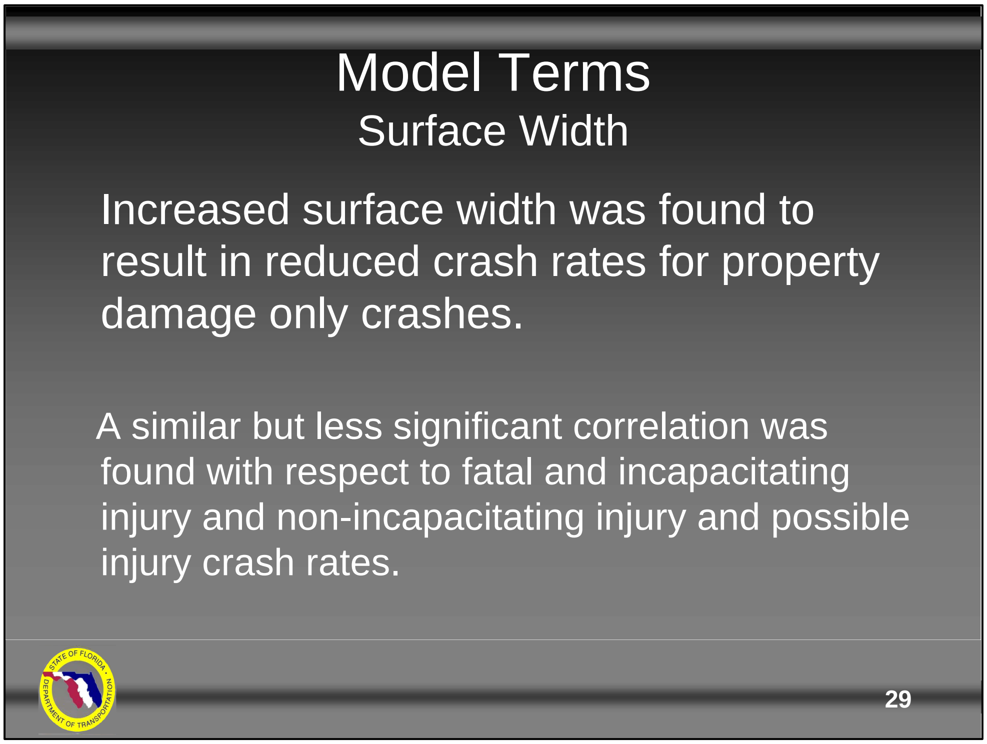
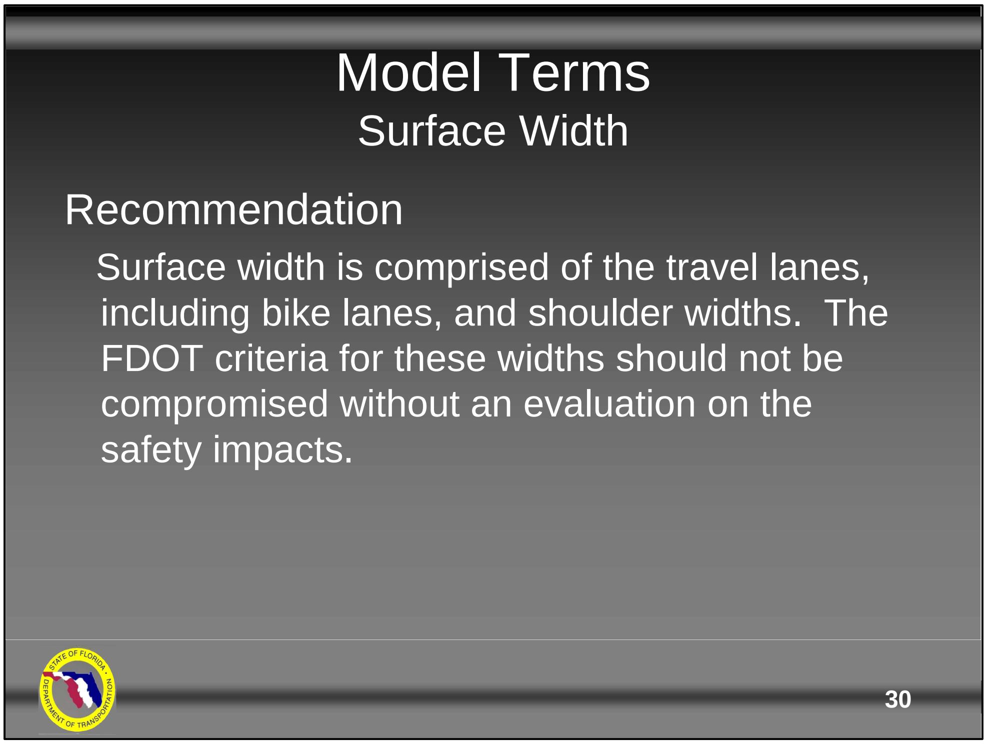


Table 2.3.2 of the FDOT Plans Preparation Manual requires outside shoulder widths of 8, 10, or 12 ft, depending on low, normal, or high volume, for divided six-lane arterials.

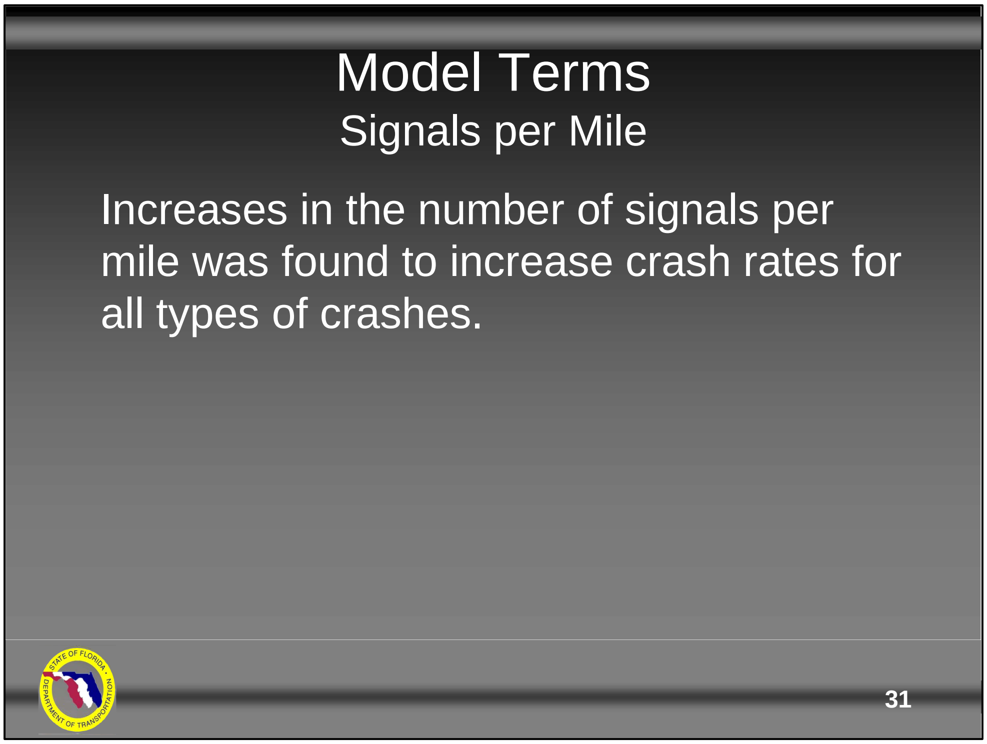
The results of this study support FDOT's shoulder width policy. The researchers strongly endorse FDOT's efforts to implement the shoulder width requirements on all new roadways. Moreover, where right-of-way is available, deficient shoulder widths should be widened during reconstruction projects on existing roadways.



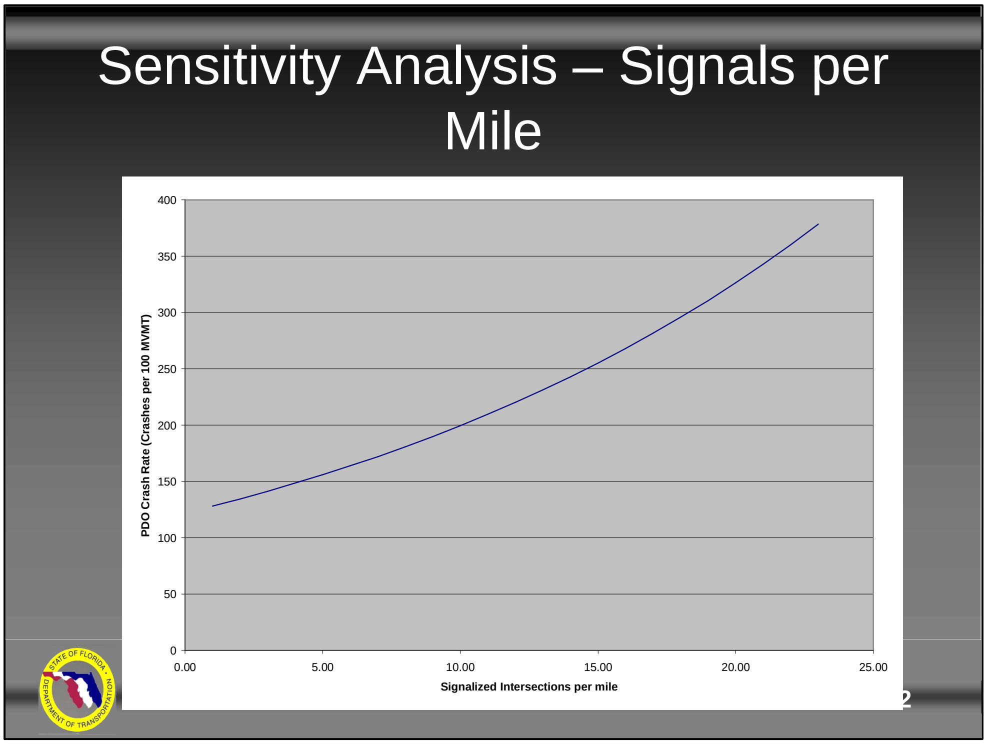
An increased surface width was found to reduce PDO crash rates.



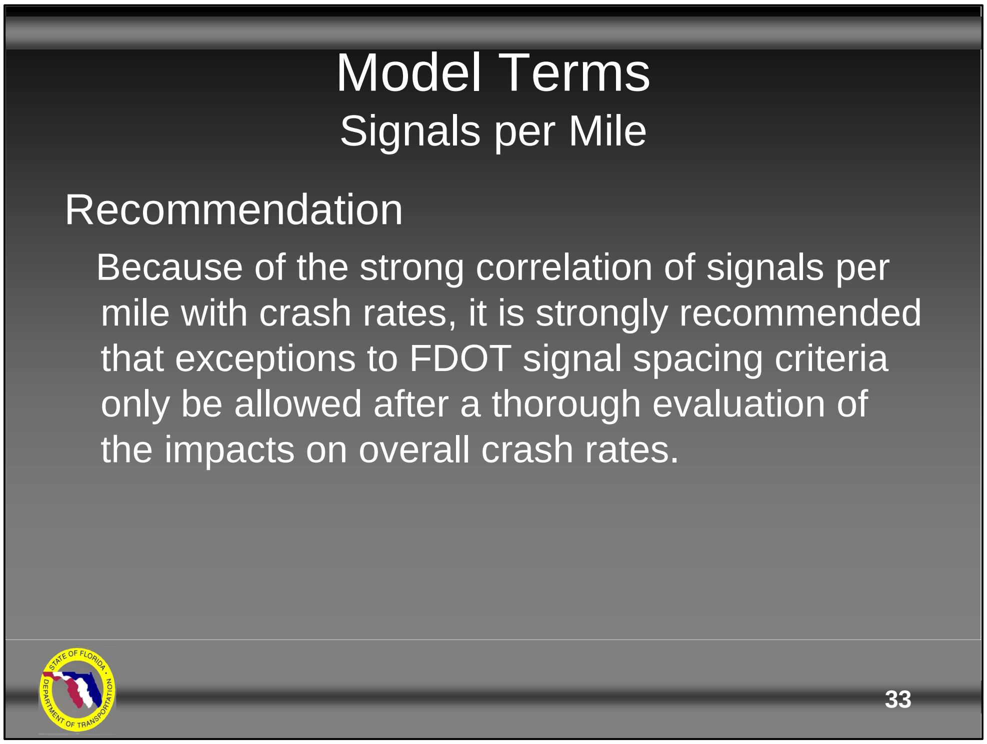
The Roadway Characteristics Inventory defines surface width as the total width of all through lanes in a single direction. That is, surface width depends on both the number of through lanes and the lane widths. The Plans Preparation Manual states that the standard practice is to provide lane widths as wide as practical, up to 12 ft (Section 2.1.1). The results of the present research support FDOT's current practice (versus narrower lane widths), as wider lane widths mean wider surface widths, which would reduce crash rates and hence result in safer driving conditions.



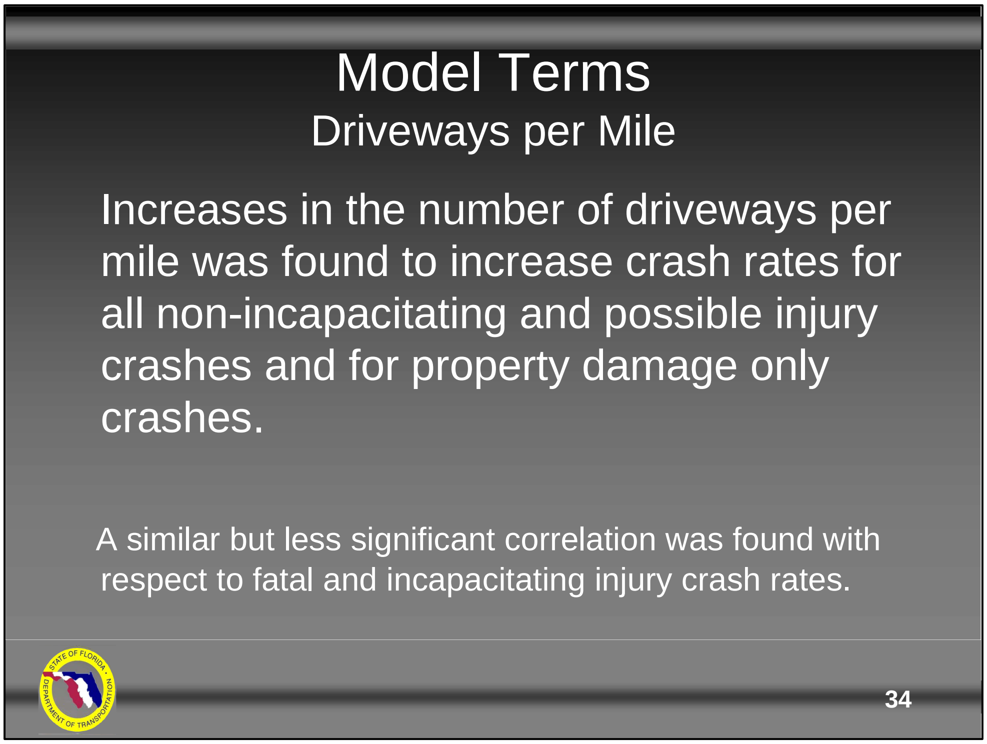
For the roadway segments included in this study, the number of signals per mile ranged from 0 to 51.
Roughly 80 percent of the roadway segments included in this study have Access Management Class 3 or 5. FDOT's State Highway Access Management Classification System and Standards require for a minimum signal spacing of 0.5 mile on Class 3 roadways. On Class 5 roadways, the minimum signal spacing is 0.25 mile (posted speed limit 45 mph or less) and 0.5 mile (higher speed limits). The standards are contained within Section 1.8 of the Plans Preparation Manual (the entire rule is available online at http://www.dot.state.fl.us/planning/systems/sm/accman/pdfs/1497.pdf).



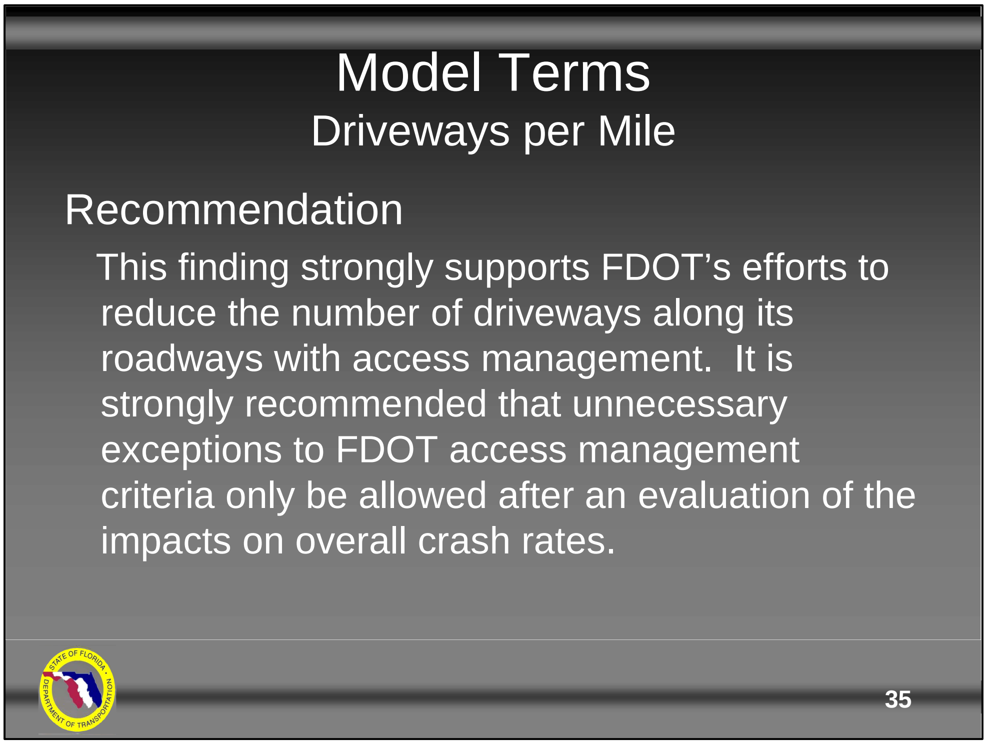
Sensitivity analyses for non-incapacitating/possible injury crashes (Figure D-3) and PDO crashes (Figure E-3) are shown in the Appendices of the report. This graph (Figure D-3) shows, for example, that reducing the number of signals per mile from 10 to 5 would reduce the PDO crash rate from about 200 to 150 per 100 MVMT.



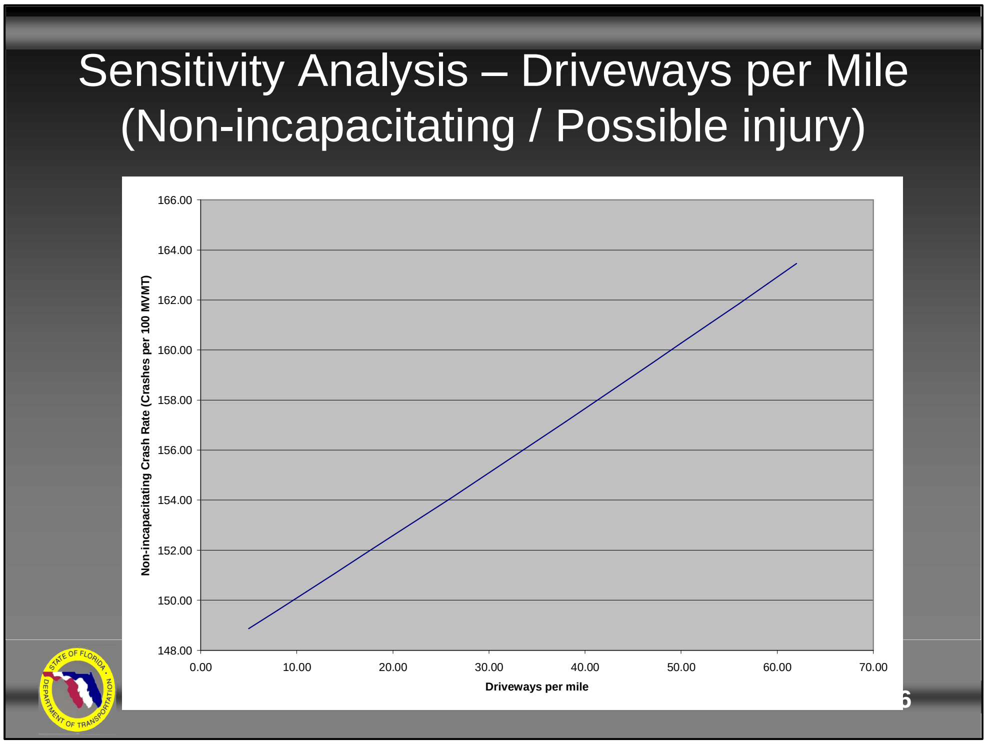
The results support FDOT's access management policies. The researchers acknowledge that FDOT must balance safety with the access needs of residents and businesses. Nevertheless, we strongly endorse FDOT's efforts to enforce its access management policies when considering applications for new driveway connections and signalized intersections.



For the roadway segments included in this study, the number of driveways per mile ranged from 0 to 600 and includes both sides of the roadway. Roughly 80 percent of the roadway segments included in this study have Access Management Class 3 or 5. FDOT's State Highway Access Management Classification System and Standards provide for minimum driveway spacing of 440 feet (Class 3) and 245 feet (Class 5), when the posted speed limit is 45 mph or less. On higher-speed roads, the spacings increase to 660 feet and 440 feet, respectively. The standards are contained within Section 1.8 of the Plans Preparation Manual (the entire rule is available online at http://www.dot.state.fl.us/planning/systems/sm/accman/pdfs/1497.pdf).



The results support FDOT's access management policies. The researchers acknowledge that FDOT must balance safety with the access needs of residents and businesses. Nevertheless, we strongly endorse FDOT's efforts to enforce its access management policies when considering applications for new driveway connections and signalized intersections.



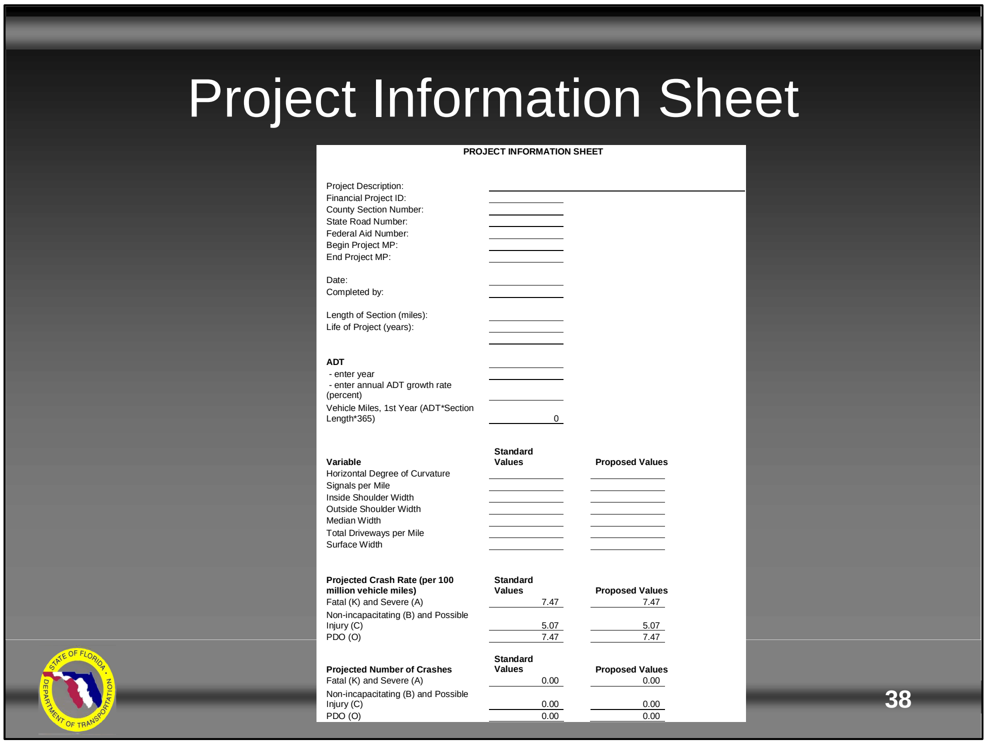
Sensitivity analyses for non-incapacitating/possible injury crashes (Figure D-1) and PDO crashes (Figure E-2) are shown in the Appendices of the report. This graph (Figure D-1) shows, for example, that reducing the number of driveways per mile from 40 to 20 would reduce the non-incapacitating/possible injury crash rate from about 157 to 152 per 100 MVMT.

Study Conclusions

FDOT has excellent standards for roadway design. This research confirms the need to adhere to those standards unless there are compelling reasons to vary from them.

37

The results of this research strongly support FDOT’s standards, as stated in the Plans Preparation Manual and the State Highway Access Management Classification System and Standards. The information obtained by this research will help designers make decisions on what roadway treatments may be appropriate and under what conditions. By implementing the results of this research, FDOT will be able to continue to provide for the roadway capacity needs of Florida while maintaining or improving the safety of its roadways. Although FDOT has comprehensive design and operational standards, these standards provide some flexibility to individual designers / engineers. In some cases, this flexibility is required to address right-of-way or environmental constraints. At other times, the flexibility allows for the accommodation of local community preferences. Additionally, various designers / engineers may apply the standards differently from each other. However, the researchers strongly recommend that FDOT weigh the advantages of granting exceptions to the standards against the potential for reduced safety.



PROJECT INFORMATION SHEET

Project Description:	
Financial Project ID:	
County Section Number:	
State Road Number:	
Federal Aid Number:	
Begin Project MP:	
End Project MP:	
Date:	
Completed by:	
Length of Section (miles):	
Life of Project (years):	
ADT	
- enter year	
- enter annual ADT growth rate (percent)	
Vehicle Miles, 1st Year (ADT*Section Length*365)	0

Variable	**Standard Values**	**Proposed Values**
Horizontal Degree of Curvature		
Signals per Mile		
Inside Shoulder Width		
Outside Shoulder Width		
Median Width		
Total Driveways per Mile		
Surface Width		

Projected Crash Rate (per 100 million vehicle miles)	**Standard Values**	**Proposed Values**
Fatal (K) and Severe (A)	7.47	7.47
Non-incapacitating (B) and Possible Injury (C)	5.07	5.07
PDO (O)	7.47	7.47

Projected Number of Crashes	**Standard Values**	**Proposed Values**
Fatal (K) and Severe (A)	0.00	0.00
Non-incapacitating (B) and Possible Injury (C)	0.00	0.00
PDO (O)	0.00	0.00

It is important to realize that the models developed in this research are not intended to be used in "what-if" analyses (such as "What if we had a 14-foot lane, instead of the 12 feet required by the PPM?"). Rather, the models can assist the engineer in a comparative analysis of roadway safety in accordance with a standards vs. designed type of analysis. This analysis would analyze the safety impacts of designs implemented with one or more exceptions granted.

An example of how this analysis could be implemented is through a Project Information Sheet (Appendix F of the report, also available as a Microsoft Excel spreadsheet). Such a calculation sheet could be incorporated into the PPM to address the requirements of Chapter 23 (Section 23.2.2.4).

The user inputs information such as section length, ADT, horizontal degree of curvature, cost per crash, etc. The spreadsheet calculates the following:

Projected Crash Rate (per 100 million vehicle miles) – These are calculated for (1) fatal and severe crashes, (2) non-incapacitating and possible injury crashes, and (3) PDO crashes, using the respective models and either the standard or the proposed values. As these cells contain formulas, initially various values appear as "placeholders." Once Horizontal Degree of Curvature, Signals per Mile, etc., have been entered, the projected crash rates will appear in these cells.

Projected Number of Crashes – These are annual numbers of crashes for each level of crash severity and for standard vs. proposed. The volume used to calculate the projected number of crashes is an average volume over the life of the project. Initially, various values appear as "placeholders."

Projected Number of Crashes over Lifetime of Project – These are the projected total number of crashes for each level of crash severity and for standard vs. proposed. Again, the volume used for this calculation is the average volume over the life of the project. Initially, various values appear as "placeholders."

Difference – A positive difference indicates that constructing the roadway using the proposed values for Horizontal Degree of Curvature, Signals per Mile, etc., would result in more crashes for that level of crash severity, compared to using the standard values from the PPM. That is, the exceptions would <u>worsen</u> safety. A negative difference indicates that constructing the roadway using the proposed values would result in fewer crashes, compared to using the standard values from the PPM. In that case, the exceptions would <u>improve</u> safety. Initially, zeroes appear as "placeholders."

Cost per Crash – These are the average costs per crash for each level of crash severity.

Projected Crash Costs over Lifetime of Project – These are the projected total costs for crashes with each level of severity, over the lifetime of the project, and for standard vs. proposed. The inflation rate is assumed to be zero. Initially, zeroes appear as "placeholders."

Savings – A positive savings indicates that constructing the roadway using the exceptions would reduce crash costs (because of fewer crashes). A negative savings indicates that constructing the roadway using the exceptions would increase crash costs (because of more crashes). Initially, zeroes appear as "placeholders."

By completing the Project Information Sheet, the engineer can easily see the safety and cost effects of applying the