In-Service Performance Evaluation (ISPE) for G4 (1S) Type of Strong-Post W-Beam Guardrail System and Cable Median Barrier: Volume I

Final Report

Contract No. BDK80 977-19

December 2012

Prepared by:
Lehman Center for Transportation Research
Florida International University

Prepared for:
Research Center
Florida Department of Transportation

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Research Center
State of Florida Department of Transportation
605 Suwannee Street, M.S. 30
Tallahassee, FL 32399-0450

December 2012

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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 CHART

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle In-Service Performance Evaluation (ISPE) for G4 (1S) Type of Strong-Post W-Beam Guardrail System and Cable Median Barrier: Volume I		5. Report Date December 2012 6. Performing Organization Code
7. Author(s) Priyanka Alluri, Kirolos Haleem, and Albert Gan		8. Performing Organization Report No.
9. Performing Organization Name and Address Lehman Center for Transportation Research Florida International University 10555 West Flagler Street, EC 3680, Miami, FL 33174		10. Work Unit No. (TRAIS) 11. Contract or Grant No. BDK80 977-19
12. Sponsoring Agency Name and Address Research Center State of Florida Department of Transportation 605 Suwannee Street, M.S. 30, Tallahassee, FL 32399-0450		13. Type of Report and Period Covered Final Report June 2011 – December 2012 14. Sponsoring Agency Code 99700-3596-119
15. Supplementary Notes Mr. John Mauthner, P.E., of the Roadway Design Office at the Florida Department of Transportation served as the Project Manager for this project.		

16. Abstract

This report (Volume I) presents a study to evaluate the safety performance of G4 (1S) strong-post W-beam guardrails on both limited and non-limited access facilities in Florida. A companion report (i.e., Volume II) focuses on the performance of cable median barriers in Florida. In total, 685.2 miles of limited access facilities and 341.5 miles of non-limited access facilities were identified to have G4 (1S) strong-post W-beam guardrails. A total of 40,738 crashes from the years 2006-2010 at these locations were identified and their police reports were reviewed to obtain detailed crash information. Of these 40,738 crashes, 8,674 crashes were determined to be guardrail-related (i.e., involving vehicles hitting a guardrail). These crashes were reviewed in further detail to identify crossover crashes and the manner in which the vehicles crossed the guardrails, i.e., either by over-riding, under-riding, or penetrating the guardrails.

The 685.2 miles of limited access facilities experienced 7,290 guardrail-related crashes. Overall, 95.3% of guardrail-related crashes were prevented from crossing the guardrail. Compared to roadside guardrails, median guardrails had a slightly higher percentage of guardrail non-crossovers. A relatively high 98.3% of crashes involving vehicles hitting the median guardrail were prevented from crossing the median. A special evaluation was performed based on 156.0 miles of median guardrail locations installed with rub-rail. The results showed that these locations did not perform differently when compared to all median guardrail locations (with and without rub-rail).

The 341.5 miles of non-limited access facilities experienced a total of 1,384 guardrail-related crashes. Overall, 92.6% of guardrail-related crashes were prevented from crossing the guardrail. Median guardrails had a higher percentage of guardrail non-crossovers at 93.8%. Roadside guardrails prevented 90.6% of crashes from crossing over the guardrail. Further, as expected, guardrail crossover crashes were more severe compared to guardrail non-crossover crashes. Among the crossovers, over-rides were more severe than penetrations.

As part of this project, the existing guardrail inventory methods currently being used in other states were reviewed, and a set of guardrail inventory features was proposed for Florida's application. A Web-based database application, named the Florida Guardrail Inventory (FGI), that incorporates these features was developed. The system allows FDOT to record and maintain inventory and repair records for guardrails on Florida's state roads.

17. Key Word In-Service Performance Evaluation, G4 (1S) Strong-Post W-Beam Guardrails, Crossover Crashes, Rub-rails, Safety Analysis		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 106	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

This research was funded by the Research Center of the Florida Department of Transportation (FDOT) under the direction of Mr. Darryll Dockstader. We are particularly grateful to our Project Manager, Mr. John Mauthner, P.E., of the FDOT Roadway Design Office for his guidance and support throughout the project. We are also grateful to the following members of the project review panel for their insightful review and comments on this report:

- Mr. Benjamin Gerrell, P.E., Roadway Design Office, FDOT
- Ms. Stefanie Maxwell, P.E., State Construction Office, FDOT
- Mr. Joseph Santos, P.E., State Safety Office, FDOT
- Mr. Daniel Strickland, P.E., Office of Maintenance, FDOT
- Mr. Frank Sullivan, P.E., Roadway Design Office, FDOT

The authors are grateful to the following graduate research assistants at the FIU Lehman Center for Transportation Research (LCTR) for their assistance in data preparation:

- Mr. Andres Diaz
- Ms. Shanghong Ding
- Mr. Erik Echezabal
- Ms. Mariadelcarmen Guevara
- Ms. Katrina Meneses
- Ms. Stephanie Miranda
- Ms. Anita Pourji

We would also like to extend a special thanks to Dr. Kaiyu Liu of LCTR who developed the Visual Roadway Inventory Collection System (VRICS), and Mr. Haifeng Wang, also of LCTR, who developed the Florida Guardrail Inventory (FGI) application.

Last but certainly not the least, we would like to thank Ms. Vicki Morrison of the FDOT Research Center for her editing of this report.

EXECUTIVE SUMMARY

The main objective of this project is to evaluate the safety performance of G4 (1S) strong-post W-beam guardrail systems installed on both limited and non-limited access facilities in Florida. In this study, the effectiveness of guardrails is measured by the percentages of errant vehicles prevented from crossing the guardrail, i.e., guardrail crossover crashes. Guardrails installed in the medians are also evaluated based on median crossover crashes. A crash in which an errant vehicle crosses the guardrail at any point during the crash is categorized as a guardrail crossover crash. If the errant vehicle reaches the opposite travel lane after crossing the guardrail in the median, it is a median crossover crash. A guardrail can be crossed over by under-riding, over-riding, or penetrating the guardrail. A crash is categorized as non-crossover when an errant vehicle does not cross the guardrail at any point during the crash.

For this study, two Web-based applications were developed: the Visual Roadway Inventory Collection System (VRICS) to collect and verify roadway characteristics data, and the Florida Guardrail Inventory (FGI) application to record and maintain guardrail inventory data on all state roads in Florida. As part of data processing, the VRICS application was used to identify state roads with G4 (1S) strong-post W-beam guardrails. The application was later customized to identify locations on limited access facilities where the guardrails were fitted with rub-rails.

In total, 685.2 miles of limited access facilities and 341.5 miles of non-limited access facilities were identified to have G4 (1S) strong-post W-beam guardrails. A majority of strong-post W-beam guardrails along medians on limited access facilities were fitted with rub-rails. However, these rub-rails were often along shorter segments and not continuous. Only the freeway sections longer than three miles and with continuous sections of rub-rails were analyzed. A total of 156.0 miles of limited access facilities were identified and used to evaluate the safety performance of rub-rails.

For the years 2006-2010, the limited and non-limited access facilities that were installed with strong-post W-beam guardrails experienced a total of 33,513 and 7,225 crashes, respectively. The police reports of all the 40,738 crashes were downloaded from the Hummingbird web system hosted on FDOT's Intranet and reviewed in detail. The review focused on identifying crash consequences of vehicles hitting the guardrail.

During the five-year analysis period, the 685.2 miles of limited access facilities experienced 7,290 guardrail-related crashes. In other words, 7,290 crashes involved vehicles hitting the guardrail at any point during the crash. Overall, 95.3% of guardrail-related crashes were prevented from crossing the guardrail. Of all the cars that hit the guardrail, 97.5% were prevented from crossing over. Likewise, 91.6% of light trucks were non-crossover crashes. As expected, medium and heavy trucks were found to have a lower non-crossover rate as the guardrail has not been designed for these vehicle types. Further, as expected, guardrail crossover crashes resulted in more severe crashes compared to guardrail non-crossover crashes. Also, among the guardrail crossover crashes, over-rides were more severe.

Of all the crashes that involved vehicles hitting the roadside guardrail, 94.5% did not cross over the guardrail. Compared to roadside, guardrails installed in the medians had a slightly higher guardrail non-crossover percentage of 95.5%. Median crossover crashes resulted in a greater proportion of severe injury crashes compared to median non-crossover crashes. Further, among the median crossovers, over-rides were more severe than penetrations.

A special evaluation was performed based on 156.0 miles of median guardrail locations installed with rub-rail. A total of 884 crashes involved vehicles leaving the roadway and striking the median guardrail with rub-rail. Of the 884 crashes, 41 (4.6%) resulted in vehicles crossing over the guardrail. Overall, 95.4% of median-guardrail-related crashes were non-crossover crashes. Also, only 15 (1.7%) of the 884 crashes crossed the median guardrail, cleared the median, and went into the opposite travel lanes. In other words, 98.3% of crashes involving vehicles hitting the guardrail in the median were prevented from crossing over the median (i.e., median non-crossover crashes). Further, 11 (73.3%) of these 15 median crossover crashes were due to over-rides; and 9 (81.8%) of these 11 over-rides were either cars or light trucks. The results showed that these locations did not perform differently when compared to all median guardrail locations (with and without rub-rail).

From 2006-2010, the 347.5 miles of non-limited access facilities experienced a total of 1,384 guardrail-related crashes. Overall, 92.6% of guardrail-related crashes were prevented from crossing over the guardrail. Guardrails installed in the median had a higher percentage of guardrail non-crossovers at 93.8%. Roadside guardrails prevented 90.6% of crashes from crossing over the guardrail.

As part of this project, the existing guardrail inventory methods currently being used in other states were reviewed and a set of guardrail inventory features was proposed for Florida's application. A Web-based database application, named the Florida Guardrail Inventory (FGI), that incorporates these features was developed. The system allows FDOT to collect and maintain inventory and repair records for guardrails on Florida's state roads.

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LIST OF ACRONYMS/ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
BCT	Breakaway Cable Terminal
CAR	Crash Analysis Reporting
DOT	Department of Transportation
FDOT	Florida Department of Transportation
FGI	Florida Guardrail Inventory
FHWA	Federal Highway Administration
FIU	Florida International University
GIS	Geographic Information System
GPS	Global Positioning System
ISPE	In-Service Performance Evaluation
ITD	Idaho Transportation Department
LCTR	Lehman Center for Transportation Research
MASH	Manual for Assessing Safety Hardware
MELT	Modified Eccentric Loader Terminal
MGS	Midwest Guardrail System
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
PDO	Property Damage Only
RCI	Roadway Characteristics Inventory
SCDOT	South Carolina Department of Transportation
SUV	Sport Utility Vehicle
TOU	Through, Over, or Under
VRICS	Visual Roadway Inventory Collection System
WSDOT	Washington State Department of Transportation

CHAPTER 1
INTRODUCTION

1.1 Background

The Federal Highway Administration (FHWA) Office of Safety Design has issued a new guidance to states that standard 27 in. guardrail does not satisfy National Cooperative Highway Research Program (NCHRP) Level 3 test criteria and calls for a guardrail height of at least 27-3/4 in. to the top of the rail, including construction tolerance. The basis for increasing the guardrail height is to accommodate full-size standard cab pickup trucks (representing the 2000P crash test vehicle for NCHRP Report 350 Test Level 3).

The Florida Department of Transportation's (FDOT) current standard for strong-post W-beam guardrail system is detailed in FDOT Design Standard Index 400 (FDOT 2011) and is based on the G4 (1S) system. Florida has used a G4 (1S) type system with a standard guardrail height of 27-1/8 in. since the 1960s, which is 5/8 in. less than FHWA's new revised minimum height guideline.

The new guidance has not given consideration to In-Service Performance Evaluation (ISPE). The lack of ISPE is of particular concern as the importance of ISPEs has been well documented in NCHRP Report 350 and American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) report (FHWA 2011). Both documents state that "the safety performance of a highway feature cannot be measured by a series of crash tests only." A comprehensive ISPE that compares the collision performance of the existing G4 strong-post W-beam guardrail design as it relates to passenger cars and pickup/light trucks is especially critical when evaluating the implementation of FHWA guidelines that exceed FDOT's established design standards.

1.2 Objectives

This project has two main objectives:

1. Perform an ISPE of both median and roadside G4 (1S) strong-post W-beam guardrail system on both limited access and non-limited access facilities on the State Highway System in Florida.

2. Establish a procedure and develop a system for the collection and continued maintenance of guardrail inventory data.

1.3 Study Approach

The primary purpose of a guardrail is to prevent errant vehicles from leaving the travel way and striking a roadside obstacle, traversing a rough terrain, or colliding with traffic in the opposite lane. Steel rails, known as rub-rails, are sometimes added below the W-beam guardrails to mainly avoid snagging of the vehicle on the posts (Maine DOT 2004; Zhu and Li 2009; South

Dakota DOT 2012) and to increase the barrier stiffness (Bullard et al. 2010). Figures 1-1 and 1-2 show G4 (1S) W-beam guardrails without and with rub-rail, respectively.

Figure 1-1: G4 (1S) Strong-post W-beam Guardrail without a Rub-rail on Florida Turnpike in Miami-Dade County

Figure 1-2: G4 (1S) Strong-post W-beam Guardrail with a Rub-rail on I-95 in St. Johns County

The safety effectiveness of guardrails is measured by the percentages of errant vehicles prevented from crossing the guardrail, i.e., guardrail crossover crashes. A crash in which an errant vehicle crosses the guardrail at any point during the crash is categorized as a guardrail crossover crash. If after crossing the guardrail installed in the median, the errant vehicle clears the median and onto the opposite travel lanes, it is categorized as a median crossover crash. A crash is categorized as non-crossover when the errant vehicle does not cross over the guardrail at any point during the crash.

A guardrail can be crossed over in three manners: by under-riding, over-riding, or penetrating the guardrail. By definition:

- An under-ride crossover crash is classified as a crash which involves an errant vehicle crossing the guardrail by sliding under the W-beam.
- An over-ride crossover crash is classified as a crash which involves an errant vehicle crossing the guardrail by riding on top of the W-beam.

- A penetration (or through-ride) crossover crash is classified as a crash which involves an errant vehicle crossing the guardrail by going through the W-beam.

Detailed analysis of guardrail-related crashes at locations with strong post W-beam guardrails is required to accurately evaluate their safety performance. This information is unavailable in the crash summary statistics. Detailed crash-specific information, such as; crashes directly related to guardrail, crossover crash classification, type of vehicle that hit the guardrail, crash severity, etc., can be more accurately determined from a detailed review of police crash reports. As such, a major effort of this project was to identify and review police reports to acquire data for analysis.

1.4 Report Organization

The rest of the report is organized as follows:

- Chapter 2 describes the In-Service Performance Evaluation (ISPE) methods and summarizes results from existing ISPE studies on guardrails.
- Chapter 3 summarizes the data collection and preparation effort for the identification of study locations and detailed review of police reports.
- Chapter 4 focuses on the safety performance evaluation of guardrails on limited access facilities in Florida.
- Chapter 5 focuses on the safety performance evaluation of guardrails on non-limited access facilities in Florida.
- Chapter 6 lists the proposed guardrail inventory features to be collected and discusses the developed Florida Guardrail Inventory (FGI) application.
- Chapter 7 provides a summary of this project effort and the relevant conclusions.

CHAPTER 2
LITERATURE REVIEW

This chapter includes a comprehensive review of literature on conducting In-Service Performance Evaluation (ISPE) of roadside safety features. Specific ISPE procedures applicable to this project are then discussed. A review of recent literature pertaining to the safety performance of guardrails is included. The current practices of state DOTs on maintaining an inventory of roadside safety hardware is provided. A review of existing guardrail inventory methods currently being used in other states is also provided.

2.1 Safety Performance Evaluation

Safety performance evaluation of roadside safety hardware prior to their extensive installation started as early as 1962 with the release of a one-page standard - Highway Research Correlation Services Circular 482. Following Circular 482, the National Cooperative Highway Research Program (NCHRP) Report 230 – "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances" and NCHRP Report 350 – "Recommended Procedures for the Safety Performance Evaluation of Highway Features" were released in 1981 and 1993, respectively (Michie 1981; Ross et al. 1993). Until recently, NCHRP Report 350 was considered the standard for roadside barrier testing procedures. An update to the currently available NCHRP Report 350 was recommended by Ando (2002) due to the following three main reasons:

1. Technological advances that have occurred.
2. Changes in specifications.
3. Changes in vehicle fleet.

In 2009, NCHRP Report 350 was replaced by the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH). Table 2-1 identifies the main differences between NCHRP Report 350 and MASH.

Table 2-1: Significant Changes Between NCHRP Report 350 and MASH (FHWA 2011)

Topic	NCHRP Report 350	MASH
Small car test vehicle	820C vehicle (1,800 lbs.)	1100C vehicle (2,420 lbs.)
Small car impact angle	20°	25°
Light truck test vehicle	2000P vehicle (4,400 lbs.)	2270P vehicle (5,000 lbs.)
Gating terminals and crash cushion impact angle	15°	5°
Variable message signs and arrow board trailers	No mention	Added to the TMA (Truck Mounted Attenuators) crash test matrix
Support structure and work zone traffic control device testing	Tested only small car	Tested both small car and light truck
Windshield damage criteria	Subjective/Qualitative	Objective/Quantitative
Vehicle rebound in crash cushion tests	None	Required

As per the transition from NCHRP Report 350 to MASH, roadside safety hardware accepted under NCHRP Report 350 is appropriate for replacement and new installation, and retesting is not required. Also, as of January 1, 2011, all new products must be crash tested using MASH crash test criteria to be eligible for use on the National Highway System (FHWA 2011).

NCHRP Report 350 extensively describes both on-field vehicle crash testing procedures and in-service performance evaluation of roadside safety features to promote uniform testing approaches across agencies. Even though standard procedures for vehicle crash testing are available, Ross et al. (1993) considers knowledge and expertise on ISPE to be limited.

NCHRP Report 118 regards in-service evaluation as an essential component of road safety research. Michie and Bronstad (1971) stated that "after the system has been carefully monitored and evaluated in service and its effectiveness has been established, the system is judged to be operational". Even though roadside safety features are designed and crash tested per NCHRP Report 350, it is impossible to determine their actual performance in field without effective in-service evaluations (Ross et al. 1993; Ray et al. 2003). The main difference between ISPE and crash tests is that the former measures the observed typical performance of a roadside feature while the latter documents the expected practical worst-case scenario. NCHRP Report 490 compared ISPE with full-scale crash testing to understand the pros and cons of each approach. Table 2-2 explains the major differences between ISPE and full-scale crash tests.

Table 2-2: Comparison of ISPE and Full-Scale Crash Testing (Ray et al. 2003)

In-Service Performance Evaluations	Full-Scale Crash Tests
Advantages	
• Typical conditions are observed • Injury results are known • Costs are known • Actual service conditions are evaluated	• Expected worst-case conditions are evaluated • Impact conditions are known • Vehicle types are known • Behavior is observed
Disadvantages	
• Impact conditions are unknown • Behavior cannot be observed • Vehicle types are unknown	• Injury severity is unknown • Costs are unknown • Factors of safety are unknown

In addition to the aforementioned advantages, ISPEs are the best source of information relative to installation, maintenance and repair costs, and collision rates and injury distributions, resulting in reliable cost-benefit analyses. These evaluations also "provide an independent check on test and evaluation procedures to ensure that crash test research efforts are solving appropriate real-world problems" (Ray and Hopp 2000; Ray et al. 2003).

According to Mak and Sicking (2002), the differences between field performance and crash test results are due to the following reasons:

- Field impact conditions such as non-tracking and side impacts are not included in crash test guidelines.
- Site conditions which adversely affect vehicle kinematics before, during, or after impact with the safety device, such as roadside slopes and ditches are not considered in crash tests.
- Performance of hardware is sensitive to installation details, such as soil resistance or barrier flare configuration.

Acknowledging the differences between ISPE and crash tests, the authors of NCHRP Report 490 consider both measures to be valuable. Crash tests tend to assess the worst case scenarios while an ISPE results in "maximized benefit for most typical collisions". Therefore, both approaches improve roadside safety.

2.2 In-Service Performance Evaluation (ISPE)

Fitzpatrick et al. (1999) defined ISPE as the process of assessing the performance of roadside safety hardware under real-world service conditions. The objective of an ISPE is "to observe, measure, and record the performance of the hardware in a wide variety of circumstances" (Ray et al. 2003). The main purpose of ISPE of roadside safety features is to determine (Ray et al. 2003; Schalkwyk et al. 2006):

- if roadside safety features are performing as expected;
- potential installation and maintenance problems;
- collision, installation, and repair costs associated with features;
- whether the vehicle crash performances (in real world conditions) are consistent with the expected performance of full-scale crash test procedures as discussed in NCHRP Report 350, or whether the performance is degraded by weather, age, climate, etc.; and
- if modification or change in the design is recommended for producing better and more cost-effective safety features.

Ray et al. (2003) intends an ISPE to be "simple, straightforward, routine, and easily implementable", and does not consider "in-depth collision reconstruction activities". Even with extensive documentation of the benefits of ISPE, very few states are actually performing ISPE on their safety hardware. The following are considered to be the main reasons for not performing ISPE on a regular basis:

- no "formal process" has been established to conduct the evaluation (Ray et al. 2003; Schalkwyk et al. 2006),
- collecting and analyzing the data require a significant commitment of manpower (Ray et al. 2003; Mak and Sicking 2002; Schalkwyk et al. 2006),
- lack of good and sustainable working relationships among police agencies, area engineers, and maintenance personnel (Mak and Sicking 2002; Schalkwyk et al. 2006), and
- agencies did not perceive a benefit from performing in-service evaluations (Ray et al. 2003).

2.2.1 Data Requirements for an ISPE

For an ISPE, data quality and quantity are equally important. With data quality being as good as it exists, quantity plays a significant role in determining the success of an ISPE. Lesser data are always an issue (Cooner et al. 2009; Ray et al. 2003; Mak and Sicking 2002). Ray and Hopp (2000) consider larger sample sizes to result in better estimations and increase the confidence in precision of the estimates. As in the case of several research projects on ISPE, data quantity becomes an issue when inadequate number of study sites over a short span of 1-3 years were analyzed. This is because collisions involving roadside safety hardware are rare, and those requiring filing a police report are exceptionally rare (Ray and Hopp 2000; Ray and Weir 2003).

Until recently, for any type of crash data analysis, only reported crashes (crashes reported to police or Department of Transportation) were considered. However, for a more comprehensive ISPE, in addition to the reported crashes, information on frequency and severity of unreported crashes, inventory and maintenance information of roadside features, roadway characteristics, and traffic data are required along with a detailed manual review of hard copies of police reports and maintenance records. These extensive data requirements often make ISPE more labor intensive and less appealing to the states (Ray et al. 2003; Mak and Sicking 2002).

Mak and Sicking (2002) consider unreported crashes to be very critical in an ISPE as they represent the undocumented success of the roadside safety hardware. This is because "unreported crashes result in neither injury to occupants nor serious damage to the vehicles" (Ray and Hopp 2000; Ray et al. 2003). Therefore, as discussed by Mak and Sicking (2002), unbiased results from an ISPE could be expected only by analyzing both reported and unreported crashes. Data from a research study by Ray and Hopp (2000) found that in Iowa, 90% of the collisions with guardrail terminals go unreported. Nevertheless, with no official source of information, estimating the number of unreported collisions is very difficult as the researchers need to rely on maintenance records and periodic site visits (Ray and Hopp 2000; Mak and Sicking 2002; Ray and Weir 2001). Fitzpatrick et al. (1999) used video logs to capture unreported crashes and near misses as they appeared to be a feasible alternative to on-site inspection. Later, Ray et al. (2003) proved video logging to be cost-prohibitive and impractical due to logistic issues. Ray and Weir (2001) recommended against the use of periodic site visits to identify unreported crashes as this type of data collection is time consuming, cost prohibitive, and sensitive to methodology and human error. Instead, Ray and Hopp (2000) recommended "the use of rates of injury-producing collisions per million vehicle kilometers traveled past the guardrail or other hardware, which can be determined from data on reported injury collisions, hardware inventory, and traffic volumes".

2.2.2 The Procedure for Performing an ISPE

There is no formal process set in place for conducting an in-service performance evaluation (Ray et al. 2003; Schalkwyk et al. 2006). Appendix D of NCHRP Report 490 aimed at addressing this issue. Figure 2-1 shows the flowchart of the entire ISPE process broken down into three sub phases: planning and preparation, data collection, and analysis. The following sections discuss each of the three sub-phases in detail:

(a) Planning and Preparation Phase

The planning and preparation phase consists of eight steps which are briefly discussed in the following paragraphs:

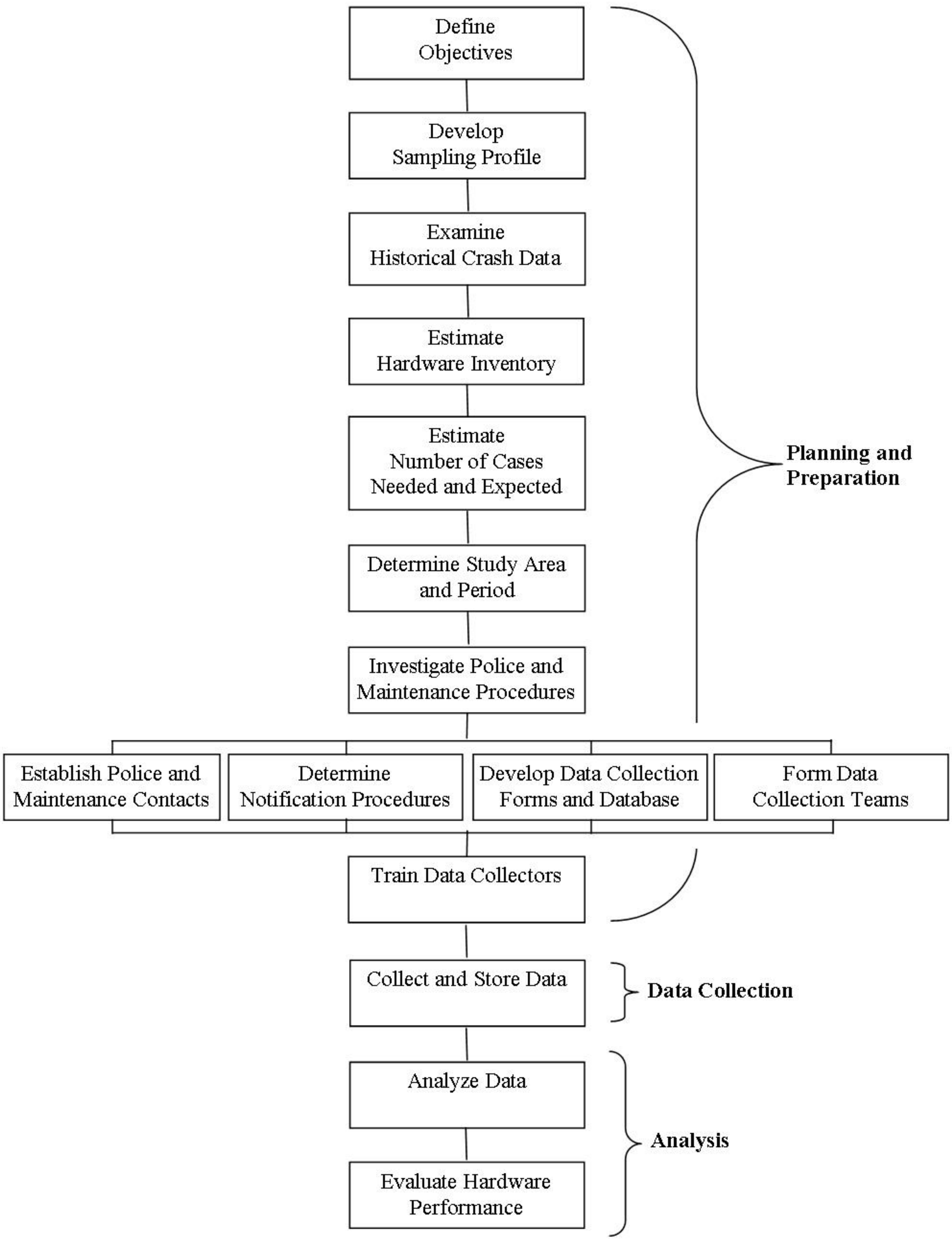


Figure 2-1: Flow Chart of the ISPE Process (Ray et al. 2003)

1. *Define Objectives:* Unlike conventional evaluations, ISPE process depends on specific study objectives - both quantitative and qualitative. Quantifiable objectives include collision rates; average installation, maintenance, and repair costs; etc. Non-quantifiable objectives include problems with maintenance and repairs of safety hardware, etc. Identification of each specific objective along with the required data and their source in the early stages is recommended. Pre-identified objectives and performance measures often drive data collection and analysis procedures, and therefore considered to be the first step in conducting a successful ISPE.

2. *Develop Sample Profile:* Detailed analysis of each section of the entire state's roadway safety hardware is impossible. Therefore, a sample representative of the overall safety performance of the hardware has to be queried. Predefined criteria for crashes and roadway sections as per the objectives of the ISPE are recommended to maintain consistency and to avoid unintentional bias in the analyses.

3. *Examine Historical Crash Data:* The next step in the process would be to obtain crash data for the past years. Care should be taken that the data fits the sample profile as closely as possible. Also, traffic data need to be obtained. Using this information, quantitative analyses like calculation of exposure, collision rates, injury rates, etc. could be performed.

4. *Estimate Hardware Inventory:* Estimating the quantity of hardware being studied is vital in assessing the exposure of traffic, and therefore, in evaluating the safety performance of the hardware. Comparison of the safety performance of two types of safety hardware could yield meaningless results when the hardware's exposure is not taken into account. This is because the number of opportunities for a collision is a function of the amount of roadside hardware in place and the traffic volume passing the hardware.

5. *Estimate Number of Cases Needed and Expected:* Determining the amount of crash data (or exposure) required to yield meaningful conclusions is the next major step in the planning process. The expected injury collision rate would be calculated as:

   $$\text{Injury Collision Rate} = (\#\text{ of injury collisions})/(\text{AADT}\times 365\times\text{study years}\times\text{length}) \quad (2\text{-}1)$$

   The confidence interval for the injury collision rate, p, can be calculated as follows:

   $$[(\rho - w) \leq p \leq (\rho + w)] = (1 - \alpha) \times 100\% \quad (2\text{-}2)$$

   where,

   $(1-\alpha)$ = the confidence level,
   $2w$ = the desired interval width (i.e., precision), and
   $\dot{p}$ = a point estimate of the actual injury collision rate, p.

   Assuming normal approximation to the binomial distribution, the half-width w can be expressed as a function of sample size, N:

$$w = \sqrt{Z^2_{(1-\frac{\alpha}{2})} \times \frac{\rho\dot{\rho}(1-\rho\dot{\rho})}{N}} \tag{2-3}$$

where Z $_{(1-\alpha/2)}$ is the percentile of the two-sided standard normal distribution for the given confidence interval.

From the above expression,

$$N = \frac{Z^2_{(1-\frac{\alpha}{2})} \times \rho\dot{\rho}(1-\rho\dot{\rho})}{w^2} \tag{2-4}$$

Using the above equation, when the point estimate of actual collision rate (ṗ) is calculated using historical data, the required sample size could be determined for a specific confidence interval.

6. *Determine Study Period and Area:* For an ISPE, the study period and area should be selected such that the sample is unbiased, and is dependent on the amount of exposure required for drawing meaningful conclusions. As discussed earlier, average traffic volumes and hardware inventory will play an influential role in determining the study period and study area.

7. *Investigate Police and Maintenance Procedures:* Detailed police reports and maintenance records of all target crashes within the study region should be obtained from the responsible personnel. Privacy issues should be carefully considered while reproducing and analyzing the reports.

8. *Train Data Collectors:* Area-wise field data collection teams have to be formed and trained to be able to accurately collect the required data variables. One person in each data collection team should be designated as the lead field collector and this person will serve as the main point of contact.

(b) Data Collection Phase

1. *Collect and Store Data:* This stage consists of collecting and storing data. Regular site visits, periodic interviews with police officers and maintenance personnel, and review of video logs are considered to be the most common data collection procedures. Following data collection, data storage is also very important. Data are recommended to be stored in two formats: paper and electronic. Electronic data are used for analysis purposes while data on paper files could be used to verify information in case of discrepancies.

(c) Analysis Phase

1. *Analyze Data:* Using data on reported crashes, gross crash rates (for example, crashes per mile per year, crashes per year by device type, crash rates per million passing vehicles, etc.) could be easily calculated with traffic, crash, and roadway characteristics

information. Crash rates and frequencies stratified by crash severity, crash types, etc. could also be included in the analysis.

2. *Evaluate Hardware Performance:* Safety performance of two or more types of road safety hardware could be compared using the base collision injury rates which are calculated on a standard cross section of a highway.

$$C_h = \frac{\sum_{j=1}^{n} C_j}{\sum_{j=1}^{n} (AADT \times 365 \times L_h \times \prod_{i=1}^{m} CMF_i)} \tag{2-5}$$

where,

C_h	=	base injury collision rate for hardware *h* on a road section made up of *n* segments,
C_j	=	number of injury collisions on segment *j*,
AADT	=	annual average daily traffic (vehicles/day) on segment *j*,
L_h	=	length of hardware *h* on segment *j*, and
CMF_i	=	m crash modification factors for segment *j*.

2.2.3 Outline of the ISPE Process Specific to this Project

This section discusses how the ISPE process was tailored to achieve the project objectives. Note that the steps shown are based on the process outlined in NCHRP Project 22-13 (Ray et al. 2003):

1. *Identify Study Objectives:* Each ISPE is geared toward a specific goal and therefore, identifying study objectives is a prerequisite to formulating a plan of action. The main objective of this study is to assess the safety performance of G4 (1S) type strong-post W-beam guardrail systems on both limited access and non-limited access roadways on the State Highway System in Florida.

2. *Mark the Study Area:* Locations with G4 (1S) W-beam guardrails were identified on both limited access and non-limited access facilities in Florida.

3. *Collect Inventory Data:* A comprehensive ISPE requires an inventory of the entire roadside safety hardware. With data and resource constraints, only the inventory of the safety hardware installed on the study locations was collected. This could be done either by going into the field, or using video logging, or using spatial maps. For this project, a Web-based application, called Visual Roadway Inventory Collection System (VRICS), was developed to obtain the inventory information.

4. *Obtain Historic Crash Data:* Multiple years of crash data within the study area are required. Crashes that occurred on segments where strong-post W-beam guardrails were operational were used for the analysis. In-depth analysis of crashes using police reports gave more detailed information on several features such as crash location, type of

vehicles involved, crash severity, and crash causation. All this information was considered in evaluating the safety performance of guardrails.

5. *Obtain Maintenance Records:* As discussed in the literature review, in addition to the reported crashes, analysis of unreported crashes play a significant role in gauging the success of safety hardware. Maintenance records are the best source of information for analyzing unreported crashes. However, maintenance records were not reviewed for this project due to time constraints.

6. *Obtain Roadway Characteristics and Traffic Data:* Roadway characteristics information was obtained from the FDOT Roadway Characteristics Inventory (RCI) database. This information was required to perform in-depth statistical analyses to evaluate the guardrail system's safety performance.

7. *Perform Analyses:* Detailed descriptive analyses on the type of collisions; types of vehicles involved; crash severity; frequency, type, and severity of crossover crashes, etc. were conducted.

8. *Present Results and Findings:* The results and findings of the in-service safety performance evaluation of G4 (1S) strong-post W-beam guardrail systems in Florida were presented.

2.3 Results from Past Studies

Since the early 1970s, state Departments of Transportation (DOTs) have been performing in-service performance evaluations for several roadside safety hardware. A detailed review of literature revealed that data requirements, analysis methods, and the results depend considerably on the objective for performing an ISPE. In this context, selected past studies relevant to the present research project are reviewed and summarized in the following paragraphs:

a) Through, Over, or Under Guardrail Penetration by Guardrail Height (Manchas and Olson 2009)

The objective of this study was to evaluate whether a correlation exists between guardrail height and penetration of the guardrail in Washington State. Analysis was performed to determine if guardrail heights of 27 in. or lower experience more through, over, or under penetrations (TOU) than guardrails of height greater than 27 in.

Collision data for 10.25 years were analyzed, and 1,806 collisions were evaluated. Of the 1,806 collisions, 1,518 struck the guardrail face, 198 struck the leading end, and 90 were of the TOU collision type (i.e. guardrail penetrations). The miles of guardrails stratified by guardrail height were compared to the collisions. It was found that "the greatest number of miles exposed to traffic within this study had the greatest number of collisions".

Figure 2-2 shows the percentage of total collisions that penetrated the guardrail by guardrail height. The percentages of penetrations were consistent across the 6 in. range and it could be concluded that there was no indication of clear benefit of guardrail at heights above 27 in. in reducing TOU penetrations. The percentages of property damage only (PDO) crashes were consistent across the 6 in. height range. However, similar trend was not observed with serious injury and fatal crashes.

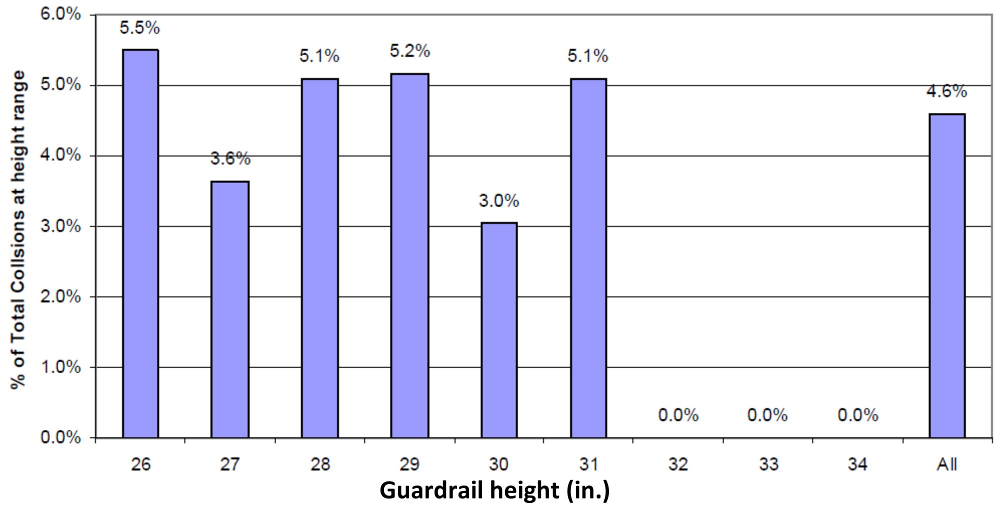


Figure 2-2: Percent of TOU Collisions by Guardrail Height (26 to 34 in.)

b) Evaluation of Rail Height Effects on the Safety Performance of W-beam Barriers (Marzougui et al. 2007)

The main goal of this project was to investigate the effect of rail height on the safety performance of G4 (1S) W-beam guardrail systems. The adequacy of rail height in redirecting the striking vehicle was studied. The work plan for this project included the following three steps:

1. develop and validate a detailed finite element model of G4 (1S) W-beam guardrail system,
2. evaluate the performance of four additional in lower barriers, and
3. consideration of basic installation tolerances (±3 models of G4 (1S) W-beam guardrail with varying rail heights (1.5 in. and 3 in. higher and lower than the standard height), and
4. perform full-scale crash tests with a guardrail of standard height and 2.5 in. lower.

The effect of guardrail height has become critical in recent years due to the following reasons:

- change in vehicle fleet with increasing use of sport utility vehicles (SUVs) and pickup trucks,
- increased frequency of resurfacing pavements resulting in.) as acceptable for barrier height.

Simulation results showed that guardrails with standard height and guardrails with increased heights have satisfactorily redirected the vehicles, thus meeting the standards set by NCHRP

Report 350. From the results, it could be concluded that guardrails with lower height would fail to redirect large SUVs and pickup trucks.

c) *Performance of Steel-post W-beam Guardrail Systems (Faller et al. 2007)*

As a part of this research, the modified G4 (1S) W-beam guardrail system and the Midwest Guardrail System (MGS) were evaluated and compared using five full-scale crash tests, as per the NCHRP Report 350 Crash Test Level 3 requirements. The evaluation criteria included structural adequacy, occupant risk, and vehicle trajectory after the collision.

As per the relevance of this research to the current project, the top rail height for the W-beam was 706 mm (27.8 in.) while that of MGS was 813 mm (32 in.), and the height of the pickup truck used was 691 mm (27.2 in.).

The modified G4 (1S) W-beam guardrail system provided an unacceptable safety performance when hit by a ¾ ton two door pickup truck. However, the performance was acceptable when hit by a ½ ton four door pickup truck. In the two similar scenarios, the MGS with a rail height of 787 mm (31 in.) performed acceptably. The MGS with a rail height of 813 mm (32 in.) performed acceptably when struck by a 1100C small-car test vehicle.

Based on the results from this study, the MGS was recommended over the Steel post W-beam guardrail system in future installations. The MGS was proven to contain and redirect pickup trucks which have their center of gravity above the normal passenger cars.

d) *Opportunities for Reduction of Fatalities in Vehicle-Guardrail Collisions (Gabler and Gabauer 2007)*

The objective of this paper was to determine the opportunities for reducing fatalities in vehicle-guardrail collisions. Six-year data (2000-2005) from FARS (Fatality Analysis Reporting System) and GES (General Estimates System) were used in the analysis. The following are the major relevant findings of the study:

- Motorcycles were involved in less than 1% of all guardrail crashes, but accounted for over 30% of all guardrail crash fatalities in 2000-2005.
- Guardrail collisions involving rollover comprised 27% of all passenger vehicle fatalities.
- Guardrail end treatments are a particular hazard in side impacts and as a rollover tripping mechanism.

With the changing vehicle fleet from passenger cars to large SUVs, frequency of rollover crashes are on an increasing trend. Large SUVs and pickup trucks have their center of gravity often above the guardrail, forcing a roll over when struck. This theory is backed by data which indicates that the rollover crashes are three times more frequent in SUVs than in passenger cars. To address this issue, the guardrail height is recommended to be increased as in the case of the Midwest Guardrail System which has raised the rail height from 27 in. to 31 in. (Faller et al. 2004).

e) Median Barriers in North Carolina - Long Term Evaluation (Murphy 2006)

In 1998, North Carolina started a project to prevent and reduce the severity of cross median crashes on freeways. The project was divided into the following three phases:

1. add median protection to freeways with historic crash history,
2. systematically protect all freeways with median widths ≤ 70 ft, and
3. revise the design policy to protect all future freeways with median widths ≤ 70 ft.

As part of the project, over 400 miles of median barriers were installed in a six-year period and long term median barrier evaluation was conducted. Table 2-3 summarizes the results.

Table 2-3: Long-Term Median Barrier Evaluation (Murphy 2006)

	All Barrier Types			W-beam		
	Before	After	% Change	Before	After	% Change
Mileage (miles)	428			132		
Average ADT (veh/day)	26,600	34,300	29%	28,800	36,700	27%
Total Crashes	2,048	3,718	82%	695	1,044	50%
Severe Injury Crashes (K and A)	120	98	-18%	38	28	-25%
Moderate and Minor Injury Crashes (B and C)	696	1,103	58%	242	347	43%
PDO	1,232	2,517	104%	414	668	61%
Cross Median Crashes	152	30	-80%	41	3	-94%
Fatal Cross Median Crashes	13	2	-80%	3	1	-82%
Severe Injury Cross Median Crashes (K and A)	20	3	-87%	7	1	-91%
Crashes Involving Median Barrier	-	1,218	-	-	309	-
% of Crashes Involving Median Barrier	-	33.0 %	-	-	30.0%	-
Breach Rate	-	2.4%	-	-	0.9%	-

f) In-Service Performance of Guardrail Terminals in Washington State (Igharo et al. 2004)

The main objective of this project was to perform an ISPE of exiting guardrail end treatments and unrestrained precast concrete barriers in Washington State. Inventory, incident, and accident data were collected and maintained in a relational database with online capabilities for data entry as per the guidelines set forth in NCHRP Project 22-13. Extensive data of over 2,300 targeted guardrail terminal systems' installations were collected. Information on device type, route, direction, mile post, cross-sectional placement, and orientation was recorded. Roadway curvature, traffic volume, shoulder type, device type, correctness of the installed configuration, angle and point of impact, lateral offset distance, vehicle type and weight, and collision scenarios were obtained from Washington State DOT (WSDOT) Traffic Data Office and included in the performance evaluation. Maintenance and police reports were used for identifying and analyzing thirty crashes during the one-year study period.

The results from this study show that there was no significant difference between breakaway cable terminals and slotted rail terminals in their injury related performances. As part of data analysis, the installations' quality, a critical parameter in assessing the performance of breakaway cable terminal, was evaluated; it was found that breakaway cable terminal when installed properly could be a valid end treatment.

g) Midwest Guardrail System for Standard and Special Applications (Faller et al. 2004)

The main objective of this study was to evaluate the performance of the Midwest Guardrail System. W-beam guardrail systems, the most common type in the country, might not be capable of containing and redirecting SUVs (and vehicles with higher center-of-gravity) during high speed and high angle collisions. Addressing this issue, the Midwest guardrail is proven to increase safety of light trucks and SUVs by preventing rollover crashes and by stopping the vehicles closer to the guardrail after a collision, thus preventing secondary collisions.

A guardrail system with a 31 in. mounting height, reduced post embedment depth, a block-out depth of 12 in., and repositioning of guardrail splice from a post to a midspan location is recommended. However, further evaluations (including an ISPE) are required for extensive installation of the Midwest guardrail system.

h) In-Service Performance Evaluation of Bullnose Median Barriers in Iowa (Ray and Weir 2003)

The main goal of this project was to perform an ISPE of the guardrail envelope, also known as the bullnose median barrier, in Iowa. Bullnose median barrier, introduced by AASHTO in 1977, has atypical design. The middle portion of the bullnose is a W-beam guardrail installed in the median, and the ends of the bullnose are specially designed to safely stop errant vehicles that strike the installation end-on.

The ISPE process consisted of data collection and performance evaluation on the basis of collision characteristics, occupant injury, and barrier damage. Two-year data were collected through police reports, maintenance cost-recovery reports, and regular site visits. A total of 42 collisions were categorized as impact with the nose (9), impact near the nose (12), impact with the bullnose transition (17), and impact at midspan (4). Of these, only 67% were reported to the police while the rest were obtained from maintenance personnel.

For identifying unreported target crashes, a 38.5 km stretch of Interstate, termed as "control section", was monitored. The data collection team flagged 40 bullnose collisions while only a total of two crashes were reported to police and maintenance personnel. Most of the unreported crashes at the control site were assumed to be property-damage-only as the police and maintenance staff were not notified. Of the 42 reported crashes, only 5 were fatal or severe injury, and about 50% resulted in no occupant injury. A detailed analysis of the sequence of events leading to each crash indicated one or more design flaws with the bull nose system and more research needs to be done to come to concrete conclusions. Assessment of damage to guardrail installations was performed for 34 (of 42) crashes. It was observed that the end generally experienced more damage than the midspan sections.

In summary, the ISPE of bullnose median barriers revealed possible design flaws. The bullnose was ineffective in nose and near-nose collisions, suggesting a need to develop median treatments.

i) Continuous Evaluation of In-Service Highway Safety Feature Performance (Mak and Sicking 2002)

The main objective of this research project was to develop a program for the Arizona Department of Transportation (ADOT) to conduct continuous in-service evaluation of highway safety features.

The proposed ISPE program for ADOT has four components:

1. Level I - continuous monitoring subsystem.
2. Level II - supplemental data collection subsystem.
3. Level III - in-depth investigation subsystem.
4. New product evaluation subsystem.

Level I module is a continuous element and considered as the backbone of ISPE. It consists of a relational database developed by merging several data files (roadway, maintenance, roadside feature inventory, crash, and traffic). General trend analysis could be performed using this database. Level II module is similar to several ad hoc ISPEs aimed at assessing the performance of roadside safety features. Analyzing police accident reports, maintenance records, and on-site inspections are a part of this component. This component is used to supplement the data in level I subsystem. Level III module deals with in-depth investigation allowing for crash reconstructions to assess the performance of safety features. This module is recommended for fatal or severe injury crashes. Incidents of device failure also need to be investigated in detail. New product evaluation module evaluates new programs documenting the construction/installation problems of safety devices. In summary, establishment of a continuous ISPE program is recommended to supplement ongoing and future ad hoc ISPE projects.

j) Unreported Collisions with Post-and-Beam Guardrails in Connecticut, Iowa, and North Carolina (Ray and Weir 2001)

The main goal of this project was to conduct an in-service performance evaluation of four guardrail systems: the G1 cable guardrail, the G2 Weak-post W-beam guardrail, and the G4 (1S) and G4 (1W) strong-post W-beam guardrails by focusing primarily on unreported crashes and distribution of vehicle occupant injuries. All target collisions in 24-month study period (both reported and unreported) were analyzed based on collision characteristics, occupant injuries, and barrier damage. Data on reported crashes were collected from police reports, maintenance records, and information on unreported crashes was documented by conducting periodic site visits. In total, there were 127 G1 collisions, 126 G2 collisions, 201 G4 (1S) collisions, and 15 G4 (1W) collisions.

Sections of Interstate in Connecticut, Iowa, and North Carolina were identified as control segments, and monitored for unreported crashes. Rail mounting height of guardrails was found to affect the performance of cable guardrails, in terms of vehicle containment and occupant injury, and analyzed in this study.

The study results show that almost 75% of all police-reported guardrail collisions and 80% of police-reported collisions on the control sections resulted in PDO. On the control sections, 90% of the guardrail collisions were either unreported or PDO. There was no statistically significant difference between the performance of guardrails in the three states and among the four systems. However, occupant injuries were less common in collisions with the G1 guardrail than in collisions with the G4 (1S) or both G4 types combined.

From this study, the researchers concluded that data collection of unreported crashes by site visits was both time consuming and sensitive to methodology and human error. Therefore, its use was not recommended for future ISPEs. A more generalized and comparable process of ISPE using data on reported crashes, roadside hardware inventory, and average annual daily traffic (AADT) was suggested. Rates of injury collisions per million vehicle miles travelled past a guardrail were considered to be easier to calculate and more comparable to ISPE of other hardware systems and other states.

k) Comparison of the Impact Performance of the G4 (1W) and G4 (2W) Guardrail Systems under NCHRP Report 350 Test 3-11 Conditions (Plaxico et al. 2000)

The main goal of this project was to compare the impact performance of two guardrails: G4 (2W) which uses a 150x200 mm wood post and the G4 (1W) which uses a 200x200 mm wood post. Even though the performance of the two types of guardrails was assumed to be similar, only one full-scale crash test was conducted on a G4 (1W) guardrail. The two guardrails were compared using a validated finite element analysis model based on deflection, vehicle redirection, and occupant risk factors. The results from the simulations indicated that the two guardrail systems result in very similar performance under NCHRP Report 350 Test 3-11 conditions (a 2000-kg pickup striking the guardrail at 100 km/hr at an angle of 25°).

l) Performance of Breakaway Cable and Modified Eccentric Loader Terminals in Iowa and North Carolina: In-Service Evaluation (Ray and Hopp 2000)

The main goal of this project was to conduct an in-service performance evaluation of breakaway cable terminal (BCT) and modified eccentric loader terminal (MELT) in Iowa and North Carolina. All target collisions in the 24-month study period were analyzed based on collision characteristics, occupant injuries, and barrier damage.

Similar to several other ISPE studies, police accident reports, maintenance cost-recovery reports, and regular site visits were used to obtain relevant data for 102 BCT and 42 MELT collisions. Guardrail terminal impacts were found to be generally single-vehicle single-event collisions with acceptable vehicle response. Besides reported crashes, the number of unreported crashes was expected to be higher than the initial estimates. A 35.8 km stretch of Iowa interstate (with 24 BCT installations) was identified as a control segment and monitored for a 12-month period. At least 69 target collisions were estimated to have occurred within the control section. Of the 69 collisions, 62 were unreported.

The results from this study indicated that reported collisions occur for every 34 million vehicles passing the BCT installations. However, the frequency and severity of target crashes depend on several other factors, and therefore, these figures should not be directly transferred to other locations and scenarios. When the occupant injuries were compared between BCT and MELT terminals, and between Iowa and North Carolina, no statistical difference was found. However, with additional data, the size of the ranges could be reduced and the confidence in the precision estimates could be increased. Analyzing the damage to barriers, BCTs and MELTs were found to have similar types of damages. Further research might reveal potential design problems with the guardrails.

m) The Safety Value of Guardrails and Crash Cushions: A Meta-Analysis of Evidence from Evaluation Studies (Elvik 1995)

This paper reported the meta-analysis of 32 relevant studies (containing about 232 numerical estimates of safety effects) and quantified the safety performance of guardrails, cable barriers, and crash cushions. Both the frequency and severity of crashes were evaluated. The performance measure, net safety index is calculated as the product of the change in probability of crashes and the change in severity of the crashes.

The following are the four potential sources of variation in study results: publication bias, random variation in crash frequency, variation related to the design and quality of data of each evaluation study, and systematic variation in the effect of the countermeasures. Of the four biases, random variation in crash occurrences contributed to most of the variations and needed to be addressed. The results of the study show that median barriers increase crash rate but reduce crash severity. Guardrails and crash cushions decrease both crash rate and crash severity.

2.4 Inventory of Roadside Safety Hardware

Complete and accurate inventory of the roadside safety hardware is required to conduct an ISPE. However, collecting data and maintaining the inventory database is labor intensive and is therefore one of the major reasons for states to not adopt ISPE procedures. Currently, states with inventories are an exception. Nevertheless, with many states shifting toward comprehensive and multi-dimensional safety management systems, Ray et al. (2003) saw a greater probability of witnessing more states using inventories to manage their roadside hardware. A survey conducted under NCHRP Project 22-13 by Mak and Sicking (2002) revealed that eighteen of the 45 responding states have some type of existing roadside hardware inventory, although a few inventories are outdated. Even though the survey is a decade old, it gives an idea of the lack of states' interest in maintaining a comprehensive inventory database.

A cost-effective way of collecting inventory data is to incorporate data collection into routine maintenance and repair procedures. With an ongoing data collection process, Ray et al. (2003) envisions ISPE to be a long-term part of the safety management system. This process, once in place and fully functional, could help in continuous evaluation and assessment of the state's safety hardware.

One of the deliverables of this project is to identify features for guardrail inventory and to develop a Web-based interface for data entry and maintenance. Similar to these deliverables, Igharo et al. (2004) developed an inventory database for WSDOT with online capabilities for data entry. Data collection forms with suggestions from NCHRP Project 22-13 were developed and revised based on discussions with the maintenance personnel. The research team believes that similar data collection forms customized to Florida would be beneficial.

In NCHRP Report 490, Ray explained the process of data collection, storage, and quality checks. The report recommended storing data in two formats: hard copy and electronic formats. Also, care should be taken that the specific personal information is excluded from the reports. For electronic formats, as shown in Figure 2-3, a relational database is recommended with the basic database structure. Further, quality checks should be considered an integral part of the procedure and should be performed continuously based on data consistency and applicable data ranges.

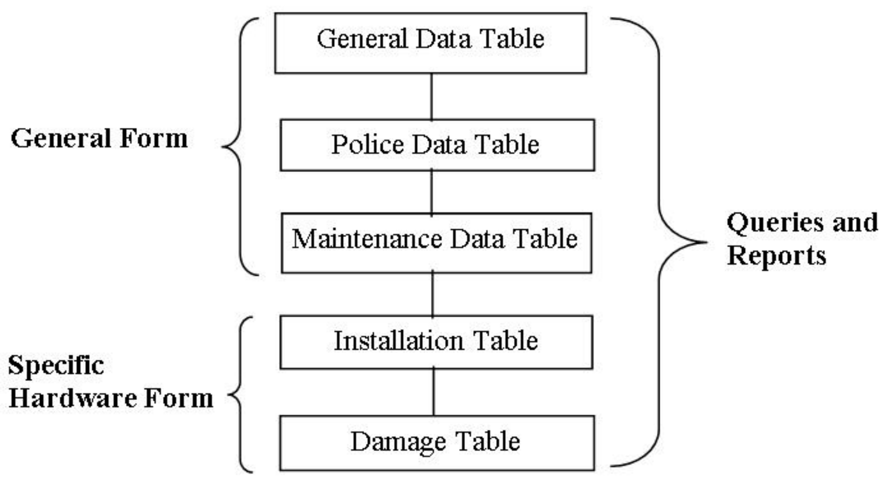


Figure 2-3: Database Structure (Ray et al. 2003)

2.4.1 Existing Guardrail Inventory Studies

FDOT does not currently have an inventory database for guardrails, which makes it difficult for their proper maintenance and evaluation. This section reviews the existing guardrail inventory methods currently being used in other states. Based on the literature review, the essential features to be included in Florida's inventory system will be identified and discussed in Chapter 5.

a) State of Washington

Igharo et al. (2004) evaluated the in-service performance of existing guardrail end treatments and unrestricted precast concrete barrier in Washington State. They created an inventory database for evaluating each type of barrier. The database mainly included a pre-collision data collection form and a damage data collection form. For guardrail end treatments, the following are some of the gathered pre-collision features:

- Rail height from ground line
- Type of post
- Downstream spacing to next post
- Is block-out used?
- Is backup plate used?
- Type of shoulder
- Type of foundation

The gathered damage data features for guardrail end treatments included:

- Maximum rail deflection
- Total rail length damaged
- Total rail length extruded
- Total number of secondary impacts
- Distance from post #1 to point of impact (POI)
- Was soil tube at post #1 pulled out?
- Was soil tube at post #2 pulled out?
- Did cable release mechanism detach from rail?

Dye Management Group, Inc. (2004) suggested that posts, bolts, rails, and extenders are essential parts of a guardrail inventory system. Further, the authors suggested that the inventory system has to be capable of continuously tracking guardrail system components and proactively maintaining all part levels to reduce freight charges and meet minimum buy levels.

b) State of Idaho

The study "Transportation Asset Management System for Roadway Safety: Idaho's Guardrail Management System Saves Lives, Time, and Money", published in 2005, discussed Idaho Transportation Department's (ITD) inventory of roadway assets such as bridges and guardrails (FHWA 2005). ITD implemented an inventory system named GRail using a video logging technique and state-of-the-art digital photo imaging data. This approach is believed to improve accuracy and also reduce resource maintenance. GRail allows managers to effectively address locations where damaged guardrails may compromise highway safety. Note that the inventory includes all of Idaho's Interstate and National Highway System routes.

The video logging survey system is set up in a vehicle with equipment capable of collecting high quality images, Global Positioning System (GPS) location data, and distance traveled for use in the GRail system. Using the distance and sensor data collected, location fields, such as milepost, offset, road name, direction, latitude, and longitude are automatically filled in by the system. Digital images and curvature data are also collected for use in traffic engineering applications and the collected GPS latitude and longitude for mapping with ITD's Geographic Information System (GIS) database. The collected data are then downloaded to file servers located in each ITD District Office.

c) State of Minnesota

Hennen et al. (1998) developed a synthesis and action plan for guardrail maintenance and repair through consultation with engineering professionals and other public officials representing the cities, counties, and the State of Minnesota. The authors recommended the following specific items to be considered when developing a guardrail maintenance and repair work plan:

- Inspection frequency and standards
- Criteria for determining repair and maintenance needs
- Method by which guardrail repair is prioritized against other maintenance responsibilities
- Budgetary constraints
- Correct repair and maintenance procedures
- Personnel responsible for each duty
- Training needs/plan
- Work zone safety
- Weather and climatic changes
- Supplies and equipment needs
- Record-keeping requirements.

The following three guardrail inventory samples also provided the in-place guardrail evaluation form, the guardrail inventory form, and the guardrail evaluation checklist. The in-place guardrail evaluation form included the following features:

- Is there adequate distance for guardrail deflection?
- Is there proper location behind the curb?
- Is there proper post spacing?
- Does guardrail completely protect the hazard area?
- Is rail height within $\pm$ 3 in. of standard height?
- Is proper end treatment required?
- Is guardrail attachment to bridge required?
- Is rub-rail required?
- Is guardrail damaged?

The guardrail inventory form included the following:

- Guardrail ID
- Roadway speed limit
- Side of road
- Guardrail type
- Guardrail length
- Post spacing
- Distance from pavement edge
- Installation year
- Guardrail condition.

The guardrail evaluation checklist form included:

- Guardrail location
- Date of inspection
- Municipality
- Roadway characteristics (e.g., shoulder width, horizontal curvature, and AADT)
- Crash experience (e.g., PDO guardrail crashes, and injury and fatal guardrail crashes).

d) State of South Carolina

SCDOT (2010) discussed guidelines for the inspection and repair of guardrails, cable barriers, and crash attenuators. The sample guardrail inspection form included the following details:

- General Information
  - Date of inspection
  - District and county names
  - Roadway type.

- Guardrail Segment Information
  - Guardrail ID
  - Guardrail segment length
  - Direction of travel
  - End treatment (type and quantity)
  - Shoulder condition (good or poor)
  - Guardrail Condition
  - Height to top of rail
  - Number of rotten posts
  - Is the guardrail damaged? (Yes or No)

- Damaged Guardrail Information
  - Type of damage (severe, moderate, or minor)
  - Length of damage
  - Is the end terminal damaged? (Yes or No)
  - Number of damaged terminals
  - Number of damaged posts.

- Notes and Comments

Additionally, as shown in Table 2-4, an inspection calendar was proposed for guardrails, cable barriers, and crash attenuators.

Table 2-4: Proposed Inspection Calendar for Guardrails, Cable Barriers, and Crash Attenuators (SCDOT 2010)

Item	Guardrails	Cable Barriers	Crash Attenuators
Type of inspection	Formal walking, hands-on inspection	Formal walking, hands-on inspection	Formal walking, hands-on inspection
Duration of inspection	Every three years for interstate routes and every five years for non-interstate routes	Annually	Annually
Duration of inspection for damage	During drive-by inspections	Two or three times a week (drive-by inspection)	During roadway inspections (drive-by inspection)

e) State of Michigan

Council et al. (2001) provided a Highway Safety Information System (HSIS) guidebook for the State of Michigan. As part of the guidebook, a guardrail inventory was prepared. Examples of the listed variables in the guardrail inventory included:

- Guardrail length.
- Rail height.
- Rail material.
- Guardrail location.
- Guardrail type.
- Date of inspection.
- Reason for inspection.
- Installation date.
- Lateral distance.
- Reason for maintenance.
- Number of posts.
- Post treatment type.
- Post type.
- Shoulder type.
- Type of the wood used.

f) State of California

Ravani et al. (2009) developed a system named GVIZ, Google Earth Visualization, for inspection and inventory of a wide variety of infrastructure assets, such as culverts and guardrails. GVIZ combines data from multiple sources (e.g., MS Access and csv files) and produces Keyhole Markup Language (KML) reports to represent three-dimensional relationships between roadside inventory features.

As part of the project, a questionnaire was prepared and sent out to state DOTs and few counties and cities to identify inventoried roadside features and the methods used for maintaining the inventory. The proposed methods for inventory in the questionnaire included a variety of choices, such as GPS, video log, photo log, field inventory, or other. Further, the following steps were recommended to effectively inventory the roadside features:

- Prioritize the items for inventory in terms of importance, cost, and difficulty to collect data.
- Perform a base line inventory cost analysis.
- Develop a baseline inventory data using the remote methods in Google Earth.
- Use GPS data collection method for areas where remote methods prove to be inapplicable.
- Sample a few locations to check the remote method against the GPS method to determine the error rate.

g) State of Oregon

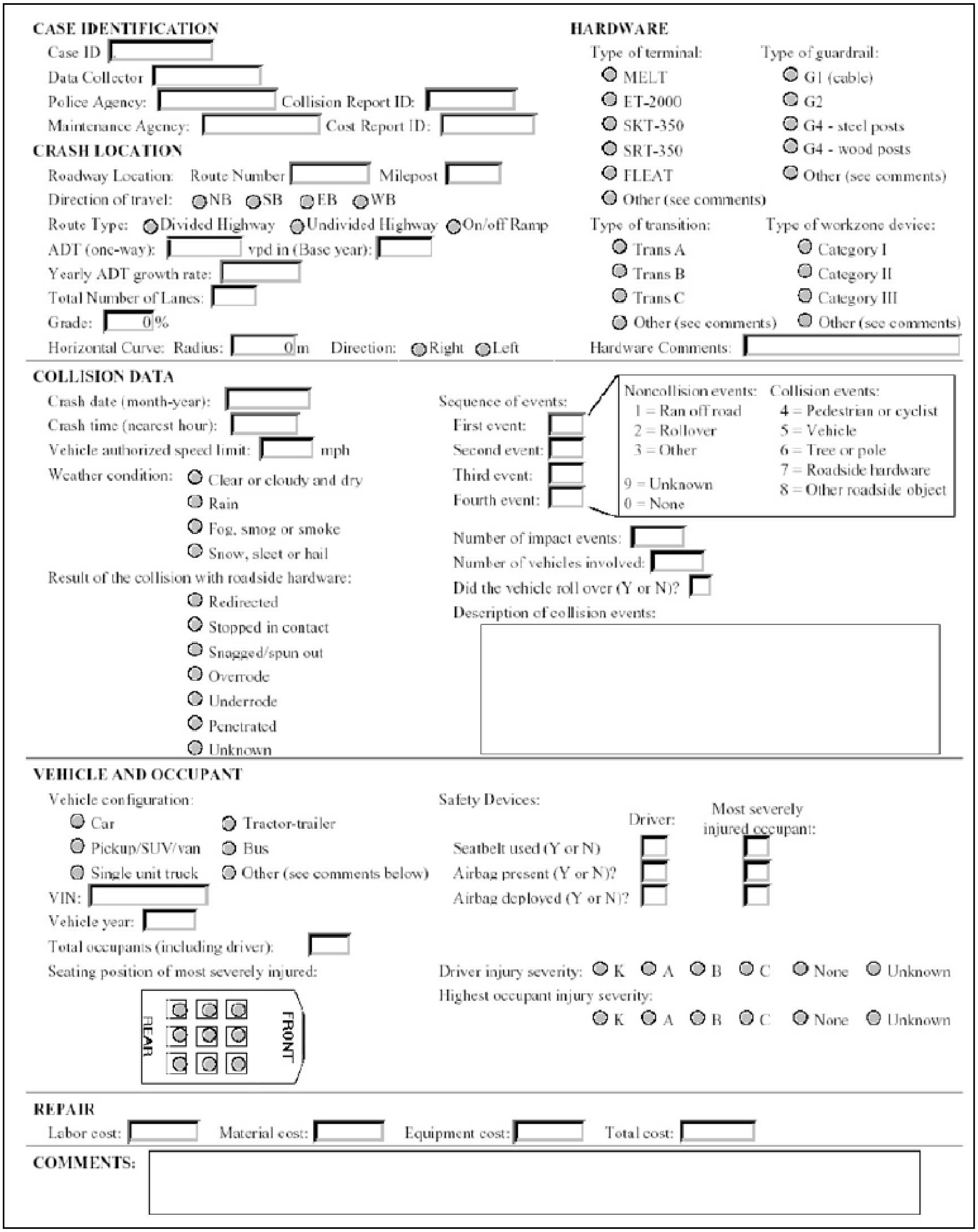
In 2004, the Roadway Engineering Services in Oregon implemented an inventory system for guardrails, concrete barriers, cable barriers, guardrail terminals, and crash attenuators (ODOT 2005). Video logging provided by Oregon DOT's Roadway Inventory Classification System (RICS) Unit was used to inventory the roadside safety features. The identified features were located by highway and mile point. Additionally, field trips were conducted to further identify the type and general characteristics of each feature.

h) NCHRP Report 490: Appendix D

Appendix D of the NCHRP Report 490 by Ray et al. (2003) covered guardrail inventory forms. For example, Figure 2-4 shows an in-service performance evaluation form. Further, the report covered the equipment that could be used for collecting inventory data, including measuring wheel, tape measure, camera, etc. Detailed data of guardrail components were also incorporated for several types of guardrails, e.g., W-beams and concrete barriers. Figures 2-5 and 2-6 respectively show two snapshots of the W-beam and concrete barrier data inventory forms.

The report also identified the following details to be collected to record the hardware damage data:

- Groundline post deflection.
- Rail height post deflection.
- Damaged components inventory (i.e., rail, posts, splices, block-out, and bolts).
- Damaged rail length.



CASE IDENTIFICATION

Case ID
Data Collector
Police Agency: Collision Report ID:
Maintenance Agency: Cost Report ID:

CRASH LOCATION

Roadway Location: Route Number Milepost
Direction of travel: NB SB EB WB
Route Type: Divided Highway Undivided Highway On/off Ramp
ADT (one-way): vpd in (Base year):
Yearly ADT growth rate:
Total Number of Lanes:
Grade: 0%
Horizontal Curve: Radius: 0 m Direction: Right Left

HARDWARE

Type of terminal: MELT; ET-2000; SKT-350; SRT-350; FLEAT; Other (see comments)
Type of guardrail: G1 (cable); G2; G4 - steel posts; G4 - wood posts; Other (see comments)
Type of transition: Trans A; Trans B; Trans C; Other (see comments)
Type of workzone device: Category I; Category II; Category III; Other (see comments)
Hardware Comments:

COLLISION DATA

Crash date (month-year):
Crash time (nearest hour):
Vehicle authorized speed limit: mph
Weather condition: Clear or cloudy and dry; Rain; Fog, smog or smoke; Snow, sleet or hail
Result of the collision with roadside hardware: Redirected; Stopped in contact; Snagged/spun out; Overrode; Underrode; Penetrated; Unknown

Sequence of events:
First event:
Second event:
Third event:
Fourth event:

Noncollision events:	Collision events:
1 = Ran off road	4 = Pedestrian or cyclist
2 = Rollover	5 = Vehicle
3 = Other	6 = Tree or pole
	7 = Roadside hardware
9 = Unknown	8 = Other roadside object
0 = None	

Number of impact events:
Number of vehicles involved:
Did the vehicle roll over (Y or N)?
Description of collision events:

VEHICLE AND OCCUPANT

Vehicle configuration: Car; Tractor-trailer; Pickup/SUV/van; Bus; Single unit truck; Other (see comments below)
VIN:
Vehicle year:
Total occupants (including driver):
Seating position of most severely injured:
REAR FRONT

Safety Devices:	Driver:	Most severely injured occupant:
Seatbelt used (Y or N)		
Airbag present (Y or N)?		
Airbag deployed (Y or N)?		

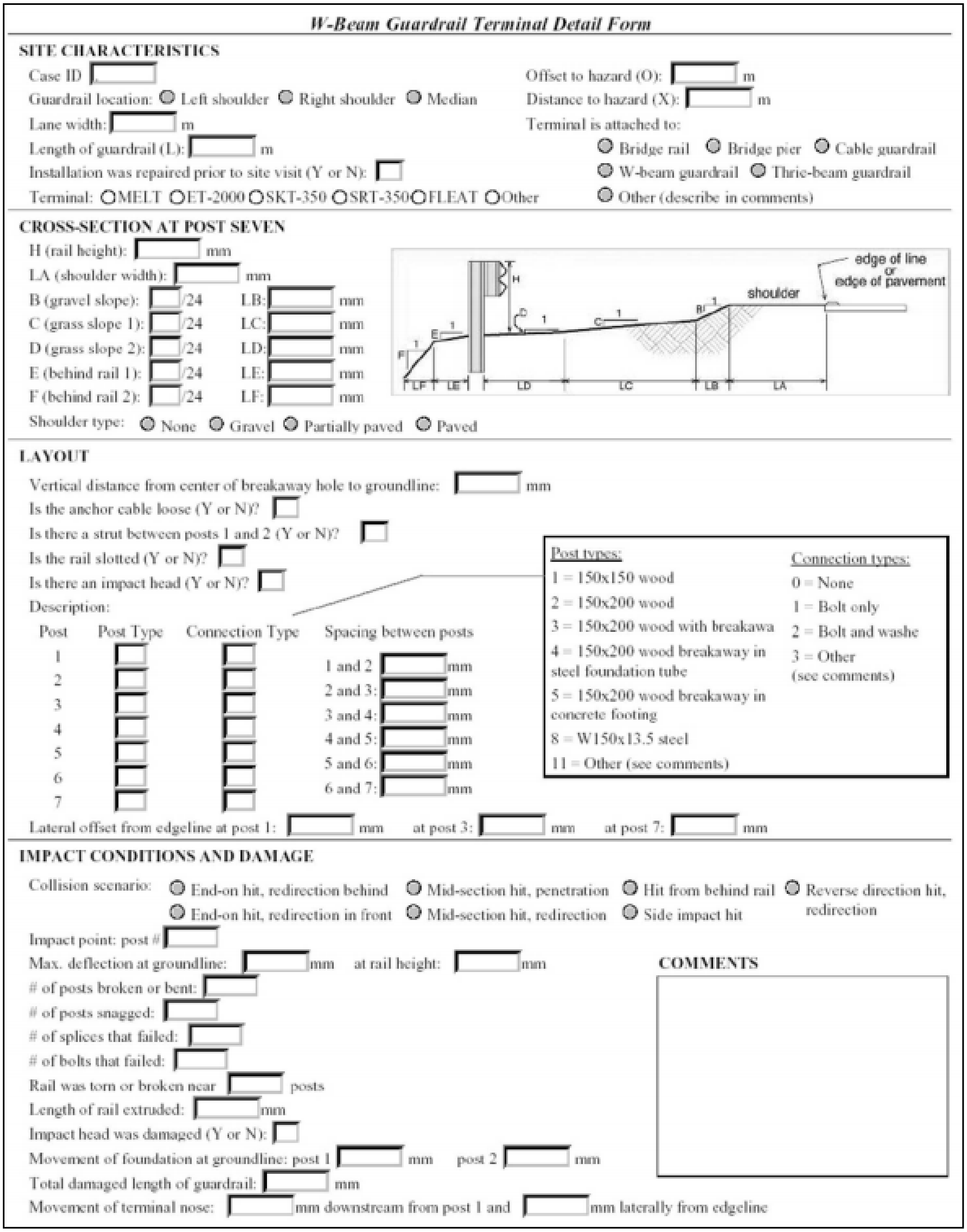
Driver injury severity: K A B C None Unknown
Highest occupant injury severity: K A B C None Unknown

REPAIR

Labor cost: Material cost: Equipment cost: Total cost:

COMMENTS:

Figure 2-4: Sample In-Service Performance Evaluation Form (Ray et al. 2003)



W-Beam Guardrail Terminal Detail Form

SITE CHARACTERISTICS

Case ID [ ]
Guardrail location: ○ Left shoulder ○ Right shoulder ○ Median
Lane width: [ ] m
Length of guardrail (L): [ ] m
Installation was repaired prior to site visit (Y or N): [ ]
Terminal: ○MELT ○ET-2000 ○SKT-350 ○SRT-350 ○FLEAT ○Other

Offset to hazard (O): [ ] m
Distance to hazard (X): [ ] m
Terminal is attached to:
○ Bridge rail ○ Bridge pier ○ Cable guardrail
○ W-beam guardrail ○ Thrie-beam guardrail
○ Other (describe in comments)

CROSS-SECTION AT POST SEVEN

H (rail height): [ ] mm
LA (shoulder width): [ ] mm
B (gravel slope): [ ] /24 LB: [ ] mm
C (grass slope 1): [ ] /24 LC: [ ] mm
D (grass slope 2): [ ] /24 LD: [ ] mm
E (behind rail 1): [ ] /24 LE: [ ] mm
F (behind rail 2): [ ] /24 LF: [ ] mm
Shoulder type: ○ None ○ Gravel ○ Partially paved ○ Paved

LAYOUT

Vertical distance from center of breakaway hole to groundline: [ ] mm
Is the anchor cable loose (Y or N)? [ ]
Is there a strut between posts 1 and 2 (Y or N)? [ ]
Is the rail slotted (Y or N)? [ ]
Is there an impact head (Y or N)? [ ]
Description:

Post	Post Type	Connection Type
1	[ ]	[ ]
2	[ ]	[ ]
3	[ ]	[ ]
4	[ ]	[ ]
5	[ ]	[ ]
6	[ ]	[ ]
7	[ ]	[ ]

Spacing between posts
1 and 2: [ ] mm
2 and 3: [ ] mm
3 and 4: [ ] mm
4 and 5: [ ] mm
5 and 6: [ ] mm
6 and 7: [ ] mm

Post types:
1 = 150x150 wood
2 = 150x200 wood
3 = 150x200 wood with breakawa
4 = 150x200 wood breakaway in steel foundation tube
5 = 150x200 wood breakaway in concrete footing
8 = W150x13.5 steel
11 = Other (see comments)

Connection types:
0 = None
1 = Bolt only
2 = Bolt and washe
3 = Other (see comments)

Lateral offset from edgeline at post 1: [ ] mm at post 3: [ ] mm at post 7: [ ] mm

IMPACT CONDITIONS AND DAMAGE

Collision scenario: ○ End-on hit, redirection behind ○ Mid-section hit, penetration ○ Hit from behind rail ○ Reverse direction hit, redirection ○ End-on hit, redirection in front ○ Mid-section hit, redirection ○ Side impact hit

Impact point: post # [ ]
Max. deflection at groundline: [ ] mm at rail height: [ ] mm
# of posts broken or bent: [ ]
# of posts snagged: [ ]
# of splices that failed: [ ]
# of bolts that failed: [ ]
Rail was torn or broken near [ ] posts
Length of rail extruded: [ ] mm
Impact head was damaged (Y or N): [ ]
Movement of foundation at groundline: post 1 [ ] mm post 2 [ ] mm
Total damaged length of guardrail: [ ] mm
Movement of terminal nose: [ ] mm downstream from post 1 and [ ] mm laterally from edgeline

COMMENTS

Figure 2-5: Sample W-beam Guardrail Inventory Form (Ray et al. 2003)

Concrete Barrier Detail Form

SITE CHARACTERISTICS

Case ID: [ ]

Installation was repaired prior to site visit (Y or N): [ ]

Barrier location: ○ Left shoulder ○ Right shoulder ○ Median

Lane width: [ ] m

Barrier Purpose: ○ Fixed object
○ Steep slope
○ Median crossover
○ Other (describe in comments)

LAYOUT

Barrier type: ○ New Jersey shape
○ F shape
○ Constant slope
○ Other (describe in comments)

Support type: ○ Poured foundation
○ Grouted/ epoxied/ bolted down
○ No connection to pavement surface
○ Other (describe in comments)

Connection between segments:
○ Monolithic
○ Pin and loop
○ Pin and rebar
○ Other (describe in comments)

Length of segment: [ ] mm

Length of barrier installation (L): [ ] m

Offset to hazard (O): [ ] m

Distance to hazard (X): [ ] m

TYPICAL CROSS-SECTION

Shoulder type: ○ None ○ Gravel ○ Partially paved ○ Paved

H (rail height): [ ] mm

V (vertical curb height): [ ] mm

LA (shoulder width): [ ] mm

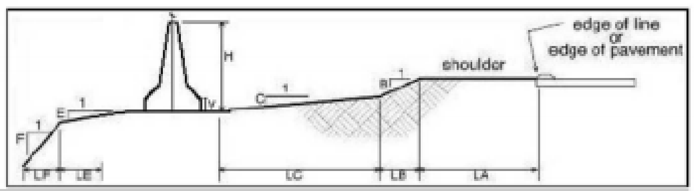
B (gravel slope): [ ]/24 LB: [ ] mm

C (grass slope 1): [ ]/24 LC: [ ] mm

D (grass slope 2): [ ]/24 LD: [ ] mm

E (behind rail 1): [ ]/24 LE: [ ] mm

F (behind rail 2): [ ]/24 LF: [ ] mm



IMPACT CONDITIONS AND DAMAGE

Impact point: segment # [ ]

Distance to end of first barrier segment: [ ] mm

Maximum deflection at groundline: [ ] mm

Number of damaged connections: [ ]

Total damaged length of barrier: [ ] mm

Damage is less than 6m from the end of a bridge rail (Y or N): [ ]

COMMENTS

[ ]

Figure 2-6: Sample Concrete Barrier Inventory Form (Ray et al., 2003)

2.5 Summary

In-Service Performance Evaluation (ISPE) of roadside safety hardware is of paramount importance to assess their safety performance in real-world conditions. Until recently, NCHRP Report 350 was the basis for performance evaluation of roadside features. Released in 2009, MASH replaced NCHRP Report 350. In addition to crash test results, several reports, including NCHRP Report 350 recommend the ISPE for assessing the hardware's safety performance. While crash tests measure the performance of safety hardware in worst-case scenario, ISPEs quantify the observed typical performance of the roadside feature, making benefit-cost analysis more feasible.

A comprehensive ISPE requires exhaustive data including inventory of roadside safety hardware and roadway characteristics, traffic, and detailed information of both reported and unreported crashes. Estimates of unreported crashes are crucial as they measure the success of safety features. While information on reported crashes could be easily obtained from crash database and police reports, unreported crash frequencies could be estimated from maintenance records and physical examination of the safety features during regular site visits.

CHAPTER 3
DATA PREPARATION

This chapter describes the data collection and preparation efforts undertaken to identify locations with G4 (1S) strong-post W-beam guardrail systems on both limited access and non-limited access facilities on the State Highway System in Florida. It also discusses the police reports' review process used to identify guardrail-related crashes and crossover crash types.

3.1 Identify Locations with Guardrail

The FDOT's Roadway Inventory Characteristics (RCI) database does not provide adequate information on the specific type of roadside safety feature inventoried. Therefore, other options to collect this information were investigated. The 2010 RCI was used to extract segments based on the existing roadside safety feature and median type. Segments with the following roadside safety features (GUARDRAIL) and median type (RDMEDIAN) were extracted:

- *GUARDRAIL* variables:
    - DBLGRAIL – Double Face Guardrail Length
    - SPCGRAIL – Miscellaneous Guardrail Length
    - STDGRAIL – Standard Guardrail Length
- *RDMEDIAN* types:
    - 04 – Guardrail
    - 12 – Paved with Guardrail
    - 13 – Paved with Barrier other than Guardrail
    - 14 – Curb ≤ 6” & Guardrail
    - 18 – Curb > 6” and Guardrail
    - 23 – Lawn with Guardrail
    - 25 – Lawn with Barrier
    - 31 – Lawn with Double Guardrail

The extracted segments were imported into the Visual Roadway Inventory Collection System (VRICS) to identify locations installed specifically with G4 (1S) strong-post W-beam guardrail systems. The VRICS application was developed as a Web-based system to facilitate the process of collecting roadway data using Google Street View. Figure 3-1 shows a screen capture of the main interface of the system. The system reads a linear-referenced roadway segment, converts its coordinates to the Google Maps projection, and then displays the segment on the Street View starting from its begin milepost. The user can then let the system run the Street View through the roadway segment continuously just like in a typical videolog system, but with higher-quality pictures and 360 degree view of the roadway.

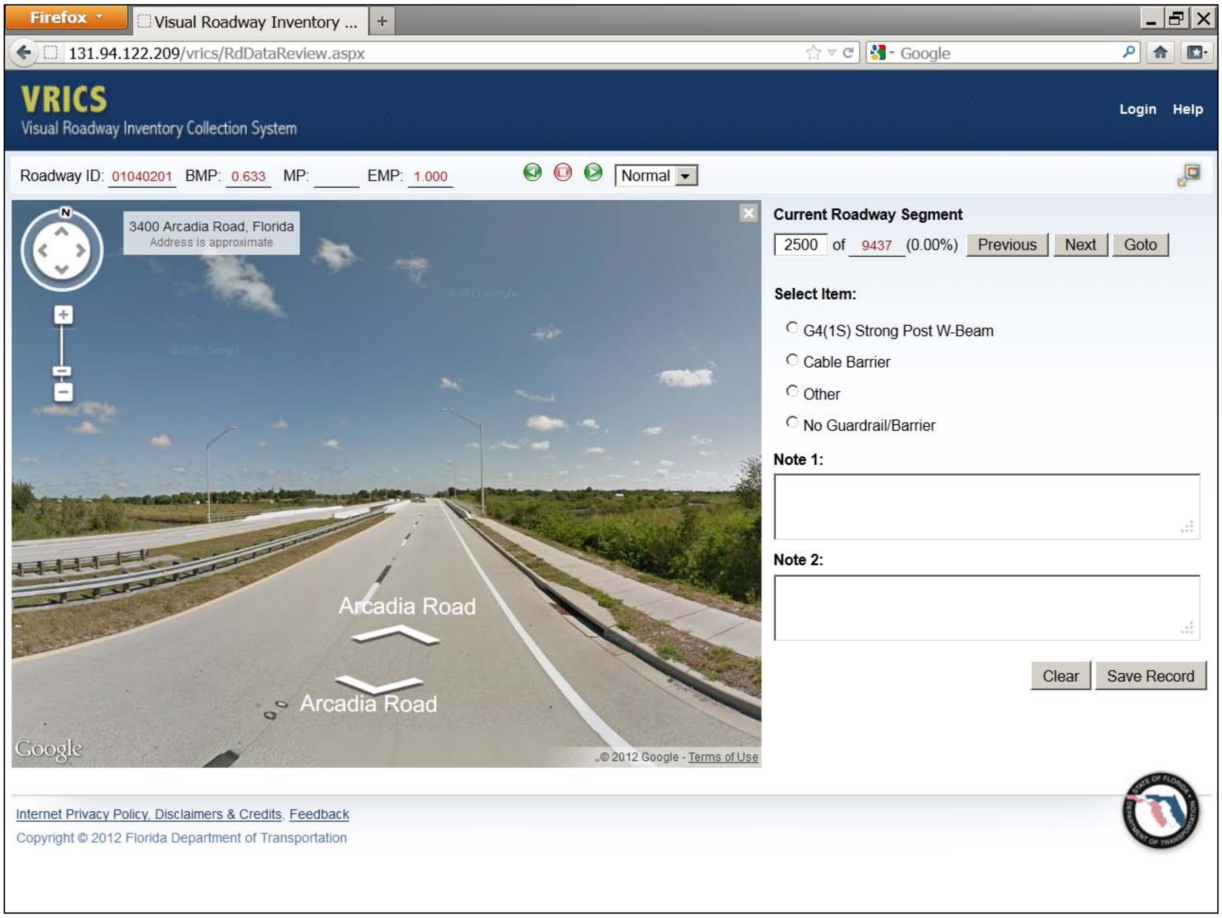


Figure 3-1: VRICS Main Screen

This system was used to identify locations installed specifically with G4 (1S) strong-post W-beam guardrail systems. The segments list extracted from the RCI database include locations with all types of guardrails, such as strong-post W-beam guardrail, weak-post W-beam guardrail, concrete barrier, cable barrier, etc. However, the present study focuses on only locations with strong-post W-beam guardrails. The segment list extracted from the RCI was imported into the VRICS tool and each segment was visually reviewed to verify if it was installed with G4 (1S) strong-post W-beam guardrails. After a segment is identified, the user can click on one of the radio buttons to select the type identified and then click on the **Save Record** button to save the selection. The system allows the user to quickly move from one segment to another by clicking the **Previous** and **Next** navigation button. The user can also jump to a specific segment by entering a segment record number and click the **Goto** button. The system also allows the user to traverse an entire segment by using the **Forward** and **Backward** buttons, similar to those in a typical videolog system.

3.2 Identify Locations with Rub-rails

The VRICS system was used to identify locations on limited access facilities where guardrails were fitted with rub-rails. A majority of guardrails along medians had rub-rails. However, these rub-rails were often along shorter segments and not continuous. These short segments and longer segments with discontinuous sections of rub-rails were excluded to minimize the negative impact from freeway crash mileposts that are known to be imprecise. Only the freeway sections longer than three miles and with continuous sections of rub-rails were identified. A total of 156.0 miles of limited access facilities were identified and used to evaluate the safety performance of rub-rails.

In total, 685.22 miles of limited access facilities and 341.47 miles of non-limited access facilities were identified to have G4 (1S) strong-post W-beam guardrails. Table A-1 in Appendix A lists all the study locations on limited access facilities. Table A-2 lists the locations with rub-rails that were included in the analysis, and Table A-3 lists all the study locations on non-limited access facilities.

3.3 Review Police Reports

The safety evaluation focused on crashes involving vehicles hitting the guardrails. The FDOT's Crash Analysis Reporting (CAR) system was used to identify crashes that occurred at the study locations. For the years 2006-2010, the limited and non-limited access facilities that were installed with strong-post W-beam guardrails experienced a total of 33,513 and 7,225 crashes, respectively.

The police reports of all the 40,738 crashes were downloaded from the Hummingbird web system hosted on FDOT's Intranet and reviewed in detail. The review focused on identifying crash consequences of vehicles hitting the guardrail. The following information was collected from the police reports:

- Did the vehicle hit the guardrail? Yes / No / Not Sure
  If yes,
  - Which side did the vehicle hit? Roadside / Median / Not sure
  - Did the vehicle cross the guardrail? Yes / No / Not Sure
    If yes:
    - What is the crossover type? Over-ride / Under-ride / Penetration / Not Sure
    - Did the vehicle go into the opposite lane? Yes / No / Not Sure
  - What is the type of the vehicle that hit the guardrail? Car / Light Truck / Medium Truck / Heavy Truck / Motorcycle / Other / Unknown / Not Sure
  - What is the crash severity? Fatal Injury / Incapacitating Injury / Non-incapacitating Injury / Possible Injury / Property Damage Only / Unknown / Not Sure

As defined in Chapter 1, a crash in which an errant vehicle crosses the guardrail at any point during the crash is categorized as a guardrail crossover crash. A guardrail crossover crash could be the result of an errant vehicle under-riding, over-riding, or penetrating the guardrail. A guardrail crossover crash is categorized as a median crossover crash when an errant vehicle traverses the opposite travel lanes by crossing over the guardrail located in the median. A crash is categorized as non-crossover when an errant vehicle never crosses the guardrail during the crash. Figures 3-2 through 3-5 provide examples of the four different crash classifications (i.e., penetration, over-ride, under-ride, and non-crossover crash types).

V-1 was northbound in the right lane of State Road 93 (I-75). For unknown reasons, V-1's left front tire blew out and caused D-1 to loose control of V-1. V-1 then started to travel in a northwesterly direction across all three northbound lanes of State Road 93. At this time V-1, entered into the median and struck the guardrail. V-1 continued through the guardrail and into the left southbound lane of traffic. D-1 then took evasive actions by braking and veering V-1 to the right with an attempt to gain control and avoid a head on collision with oncoming traffic. Upon my arrival V-1 was at final rest in the grassy median on the southbound side of state Road 93 facing north.

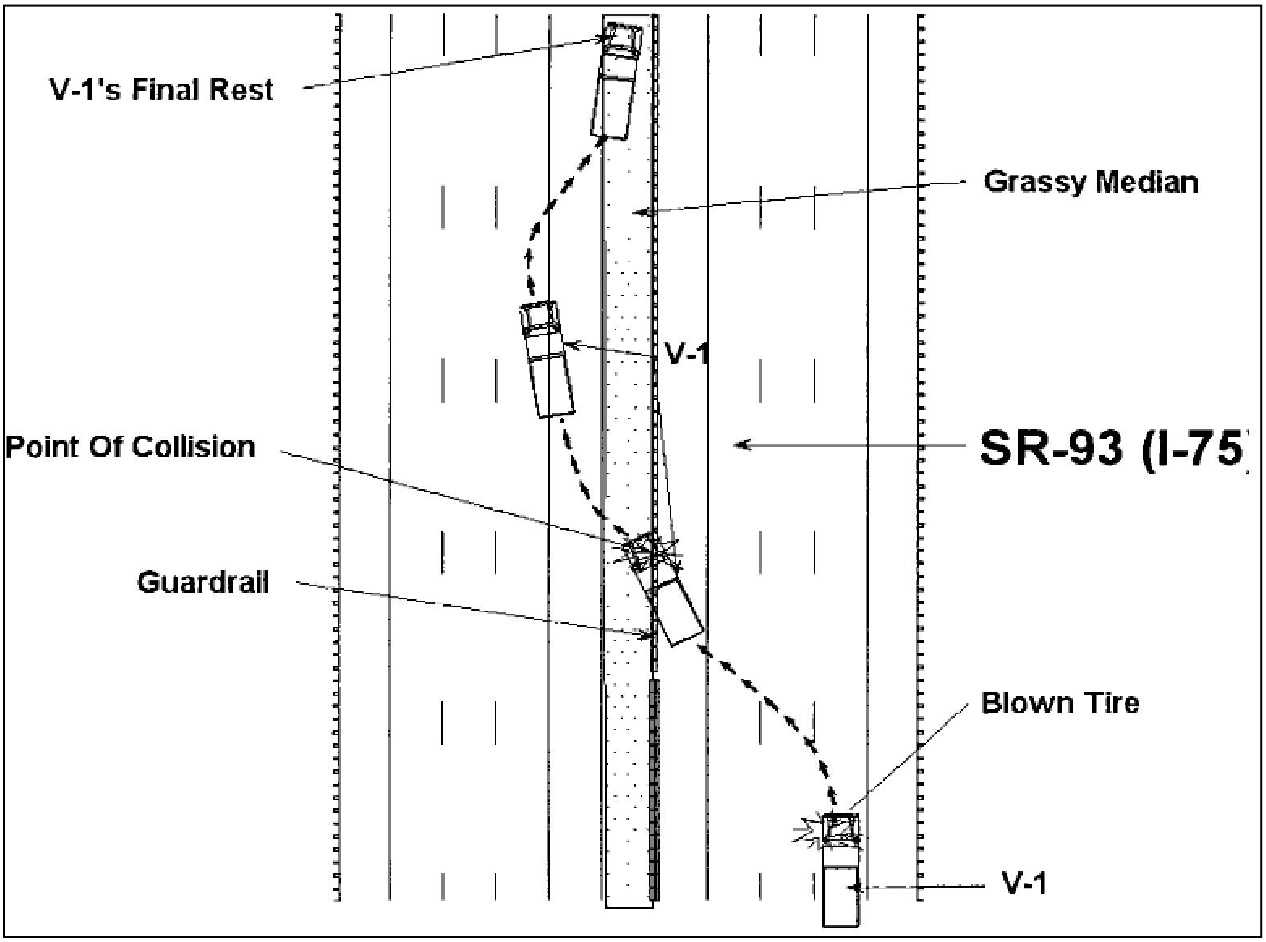


Figure 3-2: Example of a Guardrail Crossover Penetration Crash (Crash # 768686940)

V-1 was traveling northbound on State Road #91 Florida Turnpike. Upon reaching the 154 mile marker, D-1 said he fell asleep while traveling in the outside lane. When D-1 awoke he said the outside guardrail was in front of the vehicle. V-1 collided with the outside guardrail three times. V-1 traveled over the outside guardrail and came to final rest facing north on the grass shoulder.

CONTRIBUTING CAUSES: CARELESS DRIVING : Traffic crash caused due to D-1 sleeping while driving.

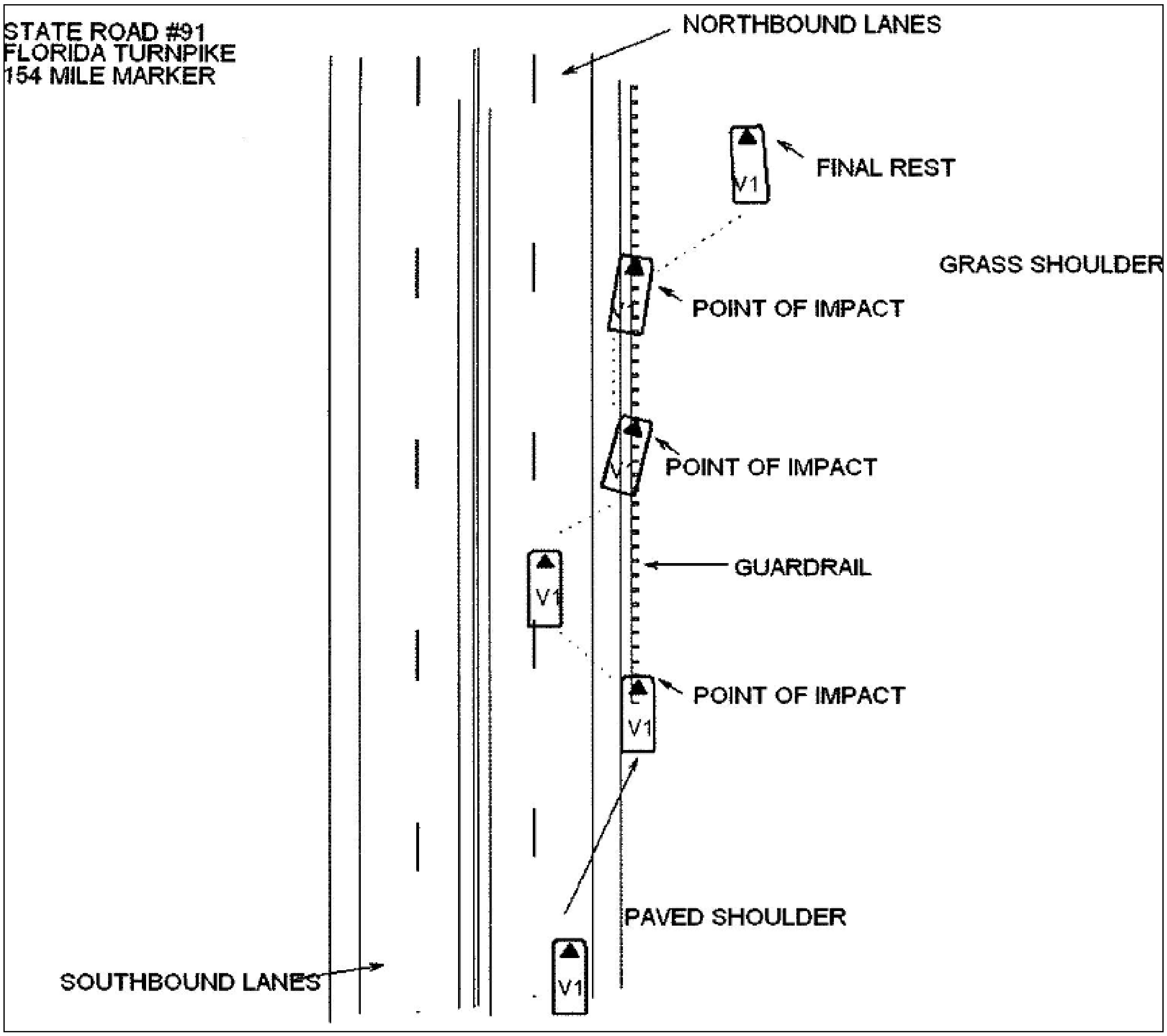


Figure 3-3: Example of a Guardrail Crossover Over-ride Crash (Crash # 770321580)

MY INVESTIGATION REVEALED: V1 WAS NORTHBOUND ON I-295 IN THE INSIDE LANE. V1 BEGAN TO SLOW FOR TRAFFIC. V1 BEGAN TO FISHTAIL. V1 THAN BEGAN TO SLIDE ON THE RIGHT SIDE. V1 THEN FLIPPED, AND D1 WAS EJECTED OFF V1. V1 THEN IMPACTED P1. D1 ALSO IMPACTED P1.

JSFRD RESPONDED TO THE SCENE. D1 REFUSED TO BE TRANSPORTED. D1 ACQUIRED ABRASIONS ON HIS BACK, ARMS, AND HANDS.

D1 STATED IT BEGAN TO RAIN AND TRAFFIC WAS SLOWING DOWN. D1 STATED HE WAS BRAKING AND HE BEGAN TO BRAKE HARDER TO AVOID HITTING ANOTHER VEHICLE. D1 STATED THE REAR WHEEL THEN LOCKED UP AND THE MOTORCYCLE BEGAN TO FISHTAIL. D1 STATED THE MOTORCYCLE WAS SLIDING AND HE WAS THEN FLIPPED OVER IT. D1 THEN STATED THE MOTORCYCLE WEDGED UNDER THE GUARDRAIL AND HIS HEAD HIT THE GUARD RAIL AS HE CAME TO A STOP.

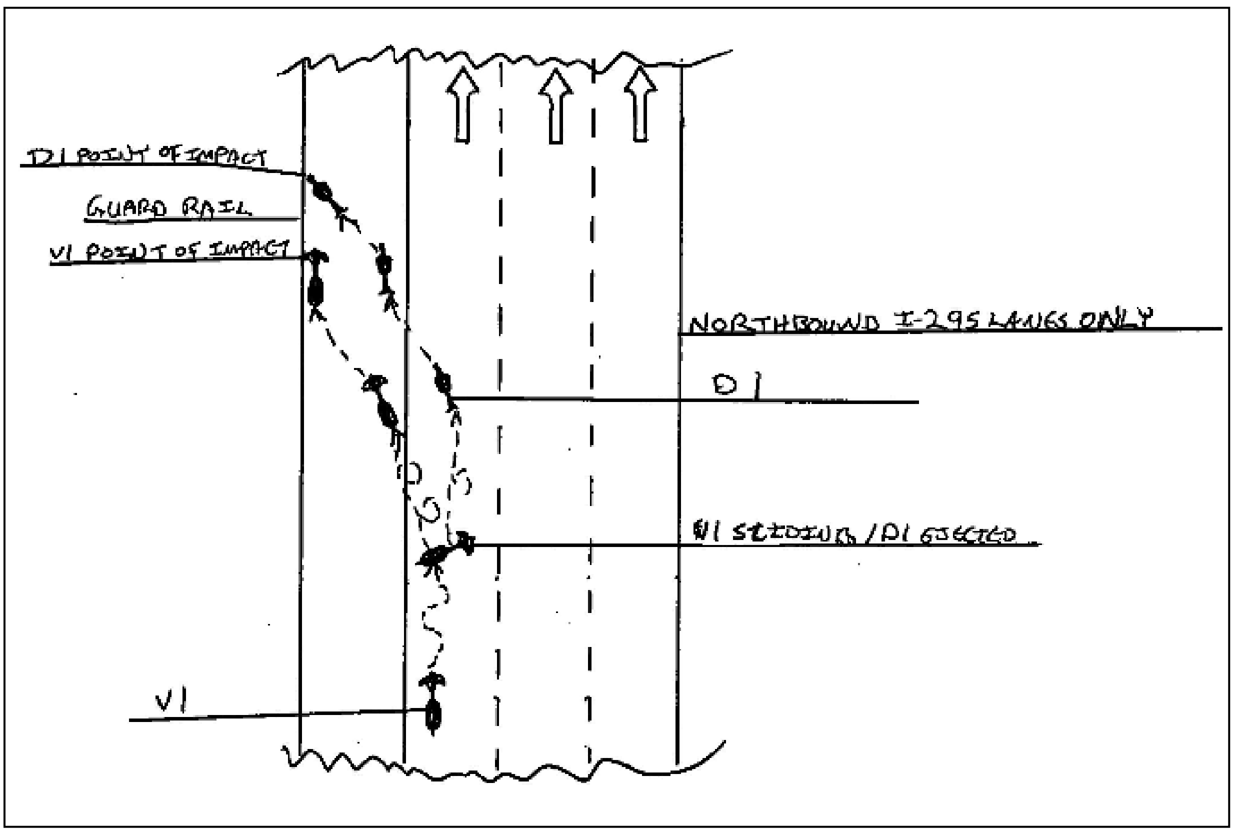


Figure 3-4: Example of a Guardrail Crossover Under-ride Crash (Crash # 917052330)

V-1, A MINIVAN, WAS NORTHBOUND ON SR 93 (I-75) IN THE CENTER LANE. V-2 WAS NORTHBOUND ON SR 93 IN THE INSIDE LANE. V-1 ATTEMPTED TO CHANGE LANES INTO THE INSIDE LANE. V-1 CROSSED DIRECTLY INTO THE PATH OF APPROACHING V-2, VIOLATING THE RIGHT OF WAY. V-2 TOOK EVASIVE ACTION AND BEGAN TO ROTATE COUNTER CLOCKWISE. THE FRONT/FRONT RIGHT OF V-2 COLLIDED WITH THE MEDIAN GUARDRAIL. V-2 CONTINUED TO ROTATE BEFORE THE REAR RIGHT COLLIDED WITH THE GUARDRAIL. V-1 CAME TO FINAL REST AGAINST THE GUARDRAIL FACING EAST BY SOUTHEAST. V-1 CAME TO A CONTROLLED STOP ON THE EAST SHOULDER.

*THERE WAS NO CONTACT WITH V-1 OR V-2. V-1 HAD PRIOR DAMAGE TO THE LEFT REAR CORNER

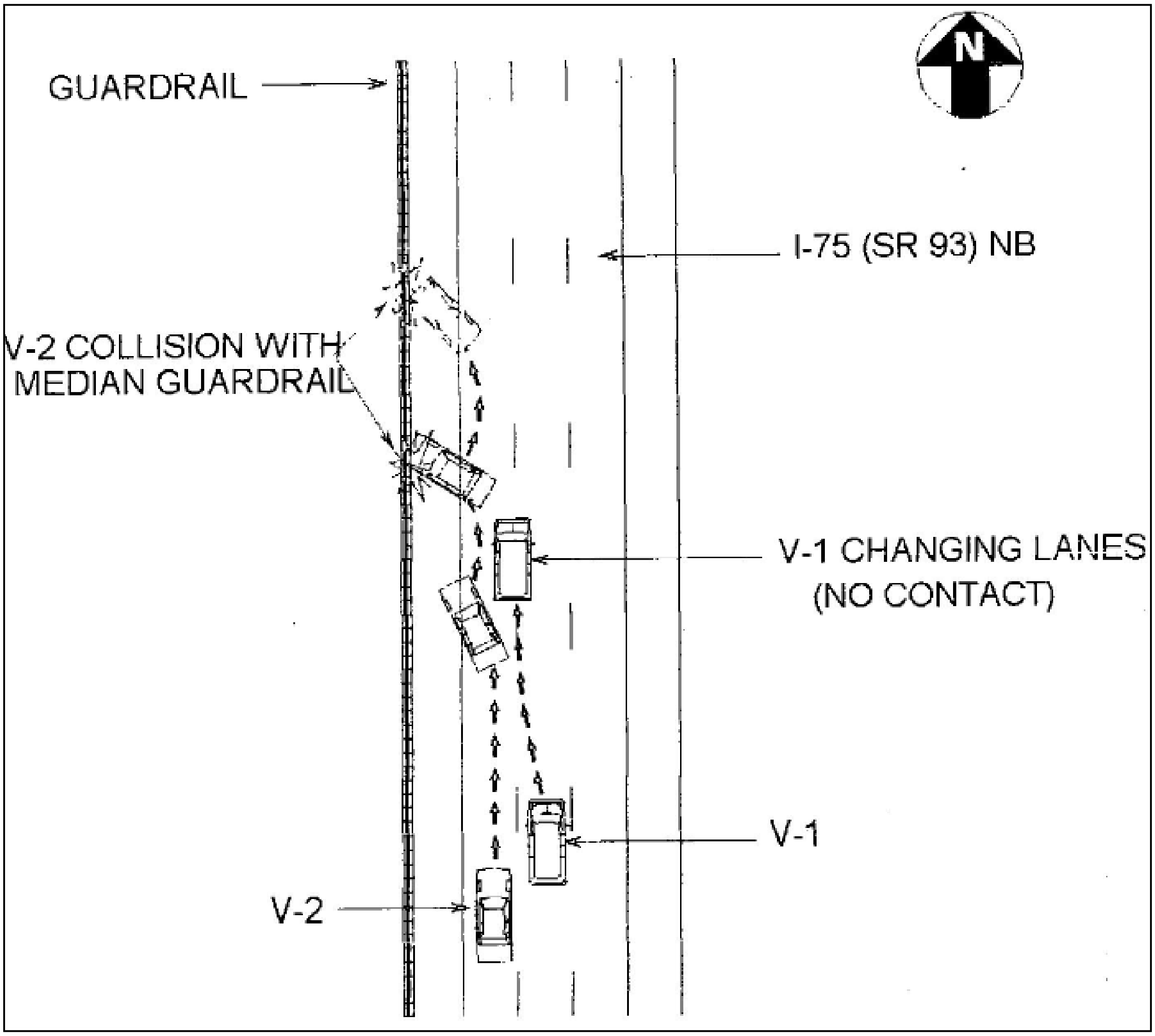


Figure 3-5: Example of a Non-Crossover Crash (Crash # 768670450)

3.4 Summary

This chapter discussed the data collection and data processing steps performed prior to conducting the analysis. Segments with all types of guardrails were first extracted from the 2010 RCI database. Locations installed with G4 (1S) strong-post W-beam guardrails were then identified using the Web-based VRICS application. A total of 685.22 miles of limited access facilities and 341.47 miles of non-limited access facilities with strong-post W-beam guardrails were identified and included in the analysis. Further, of the 685.22 miles of limited access facilities, 156.0 miles were found to have rub-rails in the median.

Five-year crash data from 2006-2010 were used to evaluate the safety performance of guardrails. Police reports of 40,738 crashes were reviewed. Only those crashes that involved vehicles hitting the guardrail were identified and reviewed in detail to identify crossover and non-crossover crashes. Based on the descriptions and illustrative sketches in the police reports, crossover crashes were further categorized as under-ride, over-ride, or penetration. Additionally, for each crash, other pertinent information, such as vehicle type, crash severity, and crash causation was also obtained.

CHAPTER 4
SAFETY EVALUATION OF GUARDRAILS ON LIMITED ACCESS FACILITIES

This chapter presents an analysis to evaluate the safety performance of G4 (1S) strong-post W-beam guardrails on limited access facilities in Florida. The evaluation is based on the percentages of vehicles prevented from crossing over the guardrail. The statistics are provided based on guardrail placement (i.e., roadside or median), and for guardrails with rub-rails; and by vehicle types and crash severity levels. For median guardrail locations, in addition to guardrail crossover statistics, median crossover statistics are also provided.

A total of 685.22 miles of limited access facilities were installed with G4 (1S) strong-post W-beam guardrails. Police reports of 33,513 crashes that occurred along the study locations from 2006-2010 were downloaded and reviewed. Of these crashes, 7,290 (21.7%) were identified as guardrail-related crashes, and are included in the analysis. As discussed in Chapter 1, crashes involving vehicles hitting the guardrail at any point during the crash were categorized as guardrail-related crashes.

4.1 Performance of Roadside Guardrails

A total of 1,468 crashes involved vehicles hitting the roadside guardrail. Of these 1,468 roadside guardrail-related crashes, 81 (5.5%) resulted in guardrail crossovers and the remaining 1,387 (94.5%) did not cross the guardrail. Of the 81 guardrail crossover crashes, 38 (46.9%) were over-rides, 17 (21.0%) were penetrations, and none were under-rides. The guardrail crossover type of 26 crashes (32.1%) could not be determined due to insufficient information in the police reports. This section focuses on the performance of roadside guardrails (i.e., guardrail crossover and non-crossover crash statistics) by vehicle type and crash severity.

4.1.1 By Vehicle Type

When a crash involved multiple vehicles, the vehicle that actually hit the guardrail was used in the analysis. The vehicle types include cars, light trucks, medium trucks, heavy trucks, motorcycles, unknown vehicle types, and others. Light trucks include vans and pickup trucks with two or four rear tires; medium trucks include vehicles with four rear tires; and heavy trucks include vehicles with two or more rear axles and truck tractors. The “others” category include buses and other vehicles. A total of 15 vehicles were coded as unknown since these vehicles fled the crash site prior to the arrival of law enforcement.

Table 4-1 gives the crash performance statistics of guardrails at roadside locations in terms of guardrail crossover and non-crossover crashes by vehicle type. Overall, 94.5% of guardrail-related crashes did not cross over the guardrail, and 96.2% of cars that hit the guardrail were non-crossover. Likewise, 92.6% of light trucks (which include vans and pickup trucks with two or four rear tires) did not cross over. Medium and heavy trucks were found to have a lower non-crossover rate of 78.3% and 70.3%, respectively. This is expected as the guardrail has not been designed for these vehicle types.

Table 4-1: Guardrail Crossover Crash Statistics by Vehicle Type at Roadside Locations

Vehicle Type	Guardrail Crossover Crashes[4]				Total Guardrail Non-Crossover Crashes (e)	Total Crashes (f)= (d+e)	Percent of Guardrail Non-Crossover Crashes (e)/(f)
	Override (a)	Penetration (b)	Unknown Crossover (c)	Total Guardrail Crossover Crashes (d) = (a+b+c)			
Car	19	7	15	41	1029	1070	96.2%
Light Truck[1]	13	4	6	23	286	309	92.6%
Medium Truck[2]	2	0	3	5	18	23	78.3%
Heavy Truck[3]	3	6	2	11	26	37	70.3%
Motorcycle	0	0	0	0	7	7	100.0%
Other	0	0	0	0	7	7	100.0%
Unknown	1	0	0	1	14	15	93.3%
Total	**38**	**17**	**26**	**81**	**1387**	**1468**	**94.5%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks include vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.
[4] None of the guardrail crossover crashes were under-rides.

4.1.2 By Crash Severity

Table 4-2 gives the crash performance statistics of guardrails at roadside locations in terms of guardrail crossover and non-crossover crashes by crash severity. Crash severity could be identified from the CAR system using “Crash Severity” and “Injury Severity” variables. The variable “Crash Severity” identifies if a crash is a fatal, injury, or PDO. The variable “Injury Severity” is supposed to code the severity of the injury (fatal, incapacitating, non-incapacitating, possible, or PDO). However, it was found that the variable “Injury Severity” in the CAR database was often blank. Therefore, injury severity information that includes the following codes was identified from the police reports:

- K – Fatal Injury
- A – Incapacitating Injury
- B – Non-Incapacitating Injury
- C – Possible Injury
- O – Property Damage Only
- Unknown – The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.

Of the 81 guardrail crossover crashes, 14 (17.3%) were fatal; of the 1,387 guardrail non-crossover crashes, 10 (0.7%) were fatal. On the other hand, 19 of 81 (23.5%) guardrail crossovers were PDOs; while 684 of 1,387 (49.3%) non-crossovers were PDOs. From these statistics, it could be inferred that guardrail crossover crashes, as expected, were more severe compared to guardrail non-crossover crashes. In addition, over-rides resulted in more fatalities compared to penetrations.

Table 4-2: Guardrail Crossover Crash Statistics by Crash Severity at Roadside Locations

Crash Severity[1]	Guardrail Crossover Crashes[3]					Guardrail Non-Crossover Crashes		Total Crashes (f)= (d+e)	Percent of Total Crashes (f)/1468
	Over-ride (a)	Pene-tration (b)	Unknown Crossover (c)	Total Guardrail Crossover Crashes (d) = (a+b+c)	Percent of Total Guardrail Crossover Crashes (d)/81	Total Guardrail Non-Crossover Crashes (e)	Percent of Total Guardrail Non-Crossover Crashes (f)/1387		
K	7	3	4	14	17.3%	10	0.7%	24	1.6%
A	7	6	5	18	22.2%	74	5.3%	92	6.3%
B	10	2	5	17	21.0%	267	19.3%	284	19.3%
C	7	0	6	13	16.0%	348	25.1%	361	24.6%
PDO	7	6	6	19	23.5%	684	49.3%	703	47.9%
Unknown[2]	0	0	0	0	0.0%	4	0.3%	4	0.3%
Total	**38**	**17**	**26**	**81**	**100.0%**	**1387**	**100.0%**	**1468**	**100.0%**

[1] K = fatal injury; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; PDO = property damage only.

[2] The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.

[3] None of the guardrail crossover crashes were under-rides.

4.2 Performance of Median Guardrails

This section focuses on the performance of guardrails installed in the median in terms of vehicle type, crash severity, and presence of rub-rail. A total of 5,808 crashes involved vehicles hitting the guardrail installed in the median. Of these 5,808 median guardrail-related crashes, 263 (4.5%) resulted in guardrail crossovers and the remaining 5,545 (95.5%) did not cross the guardrail. In addition to guardrail crossover crash statistics, median crossover crash statistics are also provided. As discussed in Chapter 1, median crossover crashes were identified as crashes in which the errant vehicle clears the median and onto the opposite travel lanes after crossing the guardrail installed in the median. Of the 5,808 guardrail-related crashes, 83 (1.4%) were median crossovers.

4.2.1 By Vehicle Type

Table 4-3 gives the crash performance statistics of guardrails installed in the median in terms of guardrail crossover and non-crossover crashes by vehicle type. Of the 263 guardrail crossover crashes, 190 (72.2%) were over-rides, 30 (11.4%) were penetrations, and one (0.4%) involving a motorcycle was an under-ride. The guardrail crossover type of 42 crashes (16.0%) could not be determined due to insufficient information in the police reports. Overall, 95.5% of all guardrail-related crashes did not cross the guardrail, and 97.8% of cars that hit the guardrail were non-crossover. Likewise, 91.3% of light trucks did not cross over. As expected, medium and heavy trucks were found to have a lower non-crossover rate of 78.9% and 78.1%, respectively. Compared to roadside, guardrails installed in the medians had a slightly higher guardrail non-crossover percentage.

Table 4-3: Guardrail Crossover Crash Statistics by Vehicle Type at Median Locations

Vehicle Type	Guardrail Crossover Crashes					Total Guardrail Non-Crossover Crashes (f)	Total Crashes (g)= (e+f)	Percent of Guardrail Non-Crossover Crashes (f)/(g)
	Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Guardrail Crossover Crashes (e) = (a+b+ c+d)			
Car	0	76	7	9	92	4065	4157	97.8%
Light Truck[1]	0	92	10	16	118	1240	1358	91.3%
Medium Truck[2]	0	8	3	4	15	56	71	78.9%
Heavy Truck[3]	0	11	10	9	30	107	137	78.1%
Motorcycle	1	1	0	0	2	16	18	88.9%
Other	0	2	0	3	5	24	29	82.8%
Unknown	0	0	0	1	1	37	38	97.4%
Total	**1**	**190**	**30**	**42**	**263**	**5545**	**5808**	**95.5%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks are vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.

Table 4-4 gives the crash performance statistics of guardrails installed in the median in terms of median crossover and non-crossover crashes by vehicle type. Of the 5,808 median guardrail-related crashes, 83 (1.4%) crossed the median guardrail, cleared the median, and went into the opposite travel lanes. In other words, 98.6% of crashes involving vehicles hitting the guardrail in the median were prevented from crossing over the median (i.e., median non-crossover crashes). A high 99.4% of cars that hit the median guardrail were prevented from crossing over the median. Likewise, 97.4% of light trucks were median non-crossovers. Medium trucks had a median non-crossover rate of 94.4%, while 88.3% of heavy trucks were median non-crossovers. Further, 58 (69.9%) of these 83 median crossover crashes were due to over-rides; and 48 (82.8%) of these 58 over-rides were either cars or light trucks.

Table 4-4: Median Crossover Crash Statistics by Vehicle Type

Vehicle Type	Median Crossover Crashes[4]				Total Median Non-Crossover Crashes (e)	Total Crashes (f) = (d+e)	Percent of Median Non-Crossover Crashes (e)/(f)
	Over-ride (a)	Penetration (b)	Unknown Crossover (c)	Total Median Crossover Crashes (d) = (a+b+c)			
Car	21	1	1	23	4134	4157	99.4%
Light Truck[1]	27	4	4	35	1323	1358	97.4%
Medium Truck[2]	1	1	2	4	67	71	94.4%
Heavy Truck[3]	6	6	4	16	121	137	88.3%
Motorcycle	1	0	0	1	17	18	94.4%
Other	2	0	1	3	26	29	89.7%
Unknown	0	0	1	1	37	38	97.4%
Total	**58**	**12**	**13**	**83**	**5725**	**5808**	**98.6%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks are vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.
[4] None of the crossover crashes were under-rides.

4.2.2 By Crash Severity

Table 4-5 gives the crash performance statistics of guardrails installed in the median in terms of guardrail crossover and non-crossover crashes by crash severity. Of the 263 guardrail crossover crashes, 20 (7.6%) were fatal; of the 5,545 guardrail non-crossover crashes, 57 (1.0%) were fatal. On the other hand, 58 (22.1%) of 263 guardrail crossovers were PDOs; while 2,548 of 5,545 (46.0%) non-crossovers were PDOs. Therefore, as expected, guardrail crossovers were more severe compared to guardrail non-crossover crashes. Table 4-6 gives median crossover crash statistics by crash severity. Median crossover crashes resulted in a greater proportion of severe injury crashes compared to median non-crossover crashes. Further, among the median crossovers, over-rides were more severe than penetrations. Note that none of the median crossovers were due to under-rides.

Table 4-5: Guardrail Crossover Crash Statistics by Crash Severity at Median Locations

Crash Severity[1]	Guardrail Crossover Crashes						Guardrail Non-Crossover Crashes		Total Crashes (g)= (e+f)	Percent of Total Crashes (g)/5808
	Under-ride (a)	Over-ride (b)	Pene-tration (c)	Unknown Crossover (d)	Total Guardrail Crossover Crashes (e) = (a+b +c+d)	Percent of Total Guardrail Crossover Crashes (e)/263	Total Guardrail Non-Crossover Crashes (f)	Percent of Total Guardrail Non-Crossover Crashes (f)/5545		
K	0	16	2	2	20	7.6%	57	1.0%	77	1.3%
A	0	47	5	3	55	20.9%	448	8.1%	503	8.7%
B	1	64	6	16	87	33.1%	1115	20.1%	1202	20.7%
C	0	29	10	4	43	16.3%	1364	24.6%	1407	24.2%
PDO	0	34	7	17	58	22.1%	2548	46.0%	2606	44.9%
Unknown[2]	0	0	0	0	0	0.0%	13	0.2%	13	0.2%
Total	**1**	**190**	**30**	**42**	**263**	**100.0%**	**5545**	**100.0%**	**5808**	**100.0%**

1 K = fatal injury; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; PDO = property damage only.
2 The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.

Table 4-6: Median Crossover Crash Statistics by Crash Severity

Crash Severity[1]	Median Crossover Crashes[3]					Median Non-Crossover Crashes		Total Crashes (f)= (d)+(e)	Percent of Total Crashes (f)/5808
	Over-ride (a)	Pene-tration (b)	Unknown Crossover (c)	Total Median Crossover Crashes (d) = (a+b+c)	Percent of Total Median Crossover Crashes (d)/83	Total Median Non-Crossover Crashes (e)	Percent of Median Non-Crossover Crashes (e)/5725		
K	6	1	0	7	8.4%	70	1.2%	77	1.3%
A	14	3	2	19	22.9%	484	8.5%	503	8.7%
B	20	3	7	30	36.1%	1172	20.5%	1202	20.7%
C	7	5	1	13	15.7%	1394	24.3%	1407	24.2%
PDO	11	0	3	14	16.9%	2592	45.3%	2606	44.9%
Unknown[2]	0	0	0	0	0.0%	13	0.2%	13	0.2%
Total	**58**	**12**	**13**	**83**	**100.0%**	**5725**	**100.0%**	**5808**	**100.0%**

1 K = fatal injury; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; PDO = property damage only.
2 The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.
3 None of the median crossover crashes were under-rides.

4.2.3 By Presence of Rub-rail

This section focuses on the safety performance of strong-post W-beam guardrails that were fitted with rub-rails. Locations were installed with rub-rails only in the median; none of the roadside guardrails were fitted with rub-rails. The analysis is based on a total of 156.0 miles of limited access facilities that were installed with strong-post W-beam guardrails with rub-rails. For the years 2006-2010, only the crashes that involved vehicles hitting the guardrail in the median at the study locations were identified and analyzed. A total of 884 crashes involved vehicles leaving the roadway and striking the median guardrail with rub-rail.

Tables 4-7 and 4-8 give the guardrail and median crossover crash statistics by vehicle type at locations with rub-rail, respectively. Of the 884 crashes, 41 (4.6%) resulted in vehicles crossing over the guardrail. Of the 41 guardrail crossover crashes, 30 (73.2%) were over-rides, 4 (9.8%) were penetrations, and none were under-rides. The guardrail crossover type of 7 (17.1%) crashes could not be determined due to insufficient information in the police reports. Overall, 95.4% of all guardrail-related crashes did not cross over the guardrail, and 99.1% of cars that hit the guardrail were non-crossover. Likewise, 88.4% of light trucks did not cross over.

Of the 884 median guardrail-related crashes, only 15 (1.7%) crossed the median guardrail, cleared the median, and went into the opposite travel lanes. In other words, 98.3% of crashes involving vehicles hitting the guardrail in the median were prevented from crossing over the median (i.e., median non-crossover crashes). A high 99.7% of cars that hit the median guardrail were prevented from crossing over the median. Likewise, 95.5% of light trucks were median non-crossovers. Further, 11 (73.3%) of these 15 median crossover crashes were due to over-rides; and 9 (81.8%) of these 11 over-rides were either cars or light trucks.

Table 4-7: Guardrail Crossover Crash Statistics by Vehicle Type at Locations with Rub-rail

Vehicle Type	Guardrail Crossover Crashes[4]				Guardrail Non-Crossover Crashes (e)	Total Crashes (f) = (d+e)	Percent of Guardrail Non-Crossover Crashes (e)/(f)
	Over-ride (a)	Penetration (b)	Unknown Crossover (c)	Total Guardrail Crossover Crashes (d) = (a+b+c)			
Car	6	0	0	6	630	636	99.1%
Light Truck[1]	18	2	3	23	176	199	88.4%
Medium Truck[2]	4	1	2	7	8	15	53.3%
Heavy Truck[3]	2	1	1	4	21	25	84.0%
Motorcycle	0	0	0	0	2	2	100.0%
Others	0	0	1	1	1	2	50.0%
Unknown	0	0	0	0	5	5	100.0%
Total	**30**	**4**	**7**	**41**	**843**	**884**	**95.4%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks are vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.
[4] None of the guardrail crossover crashes were under-rides.

Table 4-8: Median Crossover Crash Statistics by Vehicle Type at Locations with Rub-rail

Vehicle Type	Median Crossover Crashes[4]				Median Non-Crossover Crashes (e)	Total Crashes (f) = (d+e)	Percent of Median Non-Crossover Crashes (e)/(f)
	Over-ride (a)	Penetration (b)	Unknown Crossover (c)	Total Median Crossover Crashes (d) = (a+b+c)			
Car	2	0	0	2	634	636	99.7%
Light Truck[1]	7	1	1	9	190	199	95.5%
Medium Truck[2]	1	0	1	2	13	15	86.7%
Heavy Truck[3]	1	0	1	2	23	25	92.0%
Motorcycle	0	0	0	0	2	2	100.0%
Others	0	0	0	0	2	2	100.0%
Unknown	0	0	0	0	5	5	100.0%
Total	**11**	**1**	**3**	**15**	**869**	**884**	**98.3%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks are vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.
[4] None of the median crossover crashes were under-rides.

Tables 4-9 and 4-10 give the guardrail and median crossover crash statistics by crash severity at locations with rub-rail, respectively. Of the 41 guardrail crossover crashes, 3 (7.3%) were fatal; of the 843 guardrail non-crossover crashes, 11 (1.3%) were fatal. On the other hand, 11 (26.8%) of 41 guardrail crossovers were PDOs; while 376 of 843 (44.6%) non-crossovers were PDOs. Therefore, as expected, guardrail crossovers were more severe compared to guardrail non-crossover crashes. Among the median crossovers, over-rides resulted in more severe crashes compared to penetrations. Note that none of the median crossovers were due to under-rides.

Table 4-9: Guardrail Crossover Crash Statistics by Crash Severity at Locations with Rub-rail

Crash Severity[1]	Guardrail Crossover Crashes[3]					Guardrail Non-Crossover Crashes		Total Crashes (f) = (d+e)	Percent of Total Crashes (f)/884
	Over-ride (a)	Pene-tration (b)	Unknown Crossover (c)	Total Guardrail Crossover Crashes (d) = (a+b+c)	Percent of Total Guardrail Crossover Crashes (d)/41	Total Guardrail Non-Crossover Crashes (e)	Percent of Total Guardrail Non-Crossover Crashes (e)/843		
K	3	0	0	3	7.3%	11	1.3%	14	1.6%
A	5	1	2	8	19.5%	90	10.7%	98	11.1%
B	9	1	2	12	29.3%	157	18.6%	169	19.1%
C	5	1	1	7	17.1%	208	24.7%	215	24.3%
O	8	1	2	11	26.8%	376	44.6%	387	43.8%
Unknown[2]	0	0	0	0	0.0%	1	0.1%	1	0.1%
Total	**30**	**4**	**7**	**41**	**100.0%**	**843**	**100.0%**	**884**	**100.0%**

[1] K = fatal injury; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; O = property damage only.
[2] The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.
[3] None of the guardrail crossovers were under-rides.

Table 4-10: Median Crossover Crash Statistics by Crash Severity at Locations with Rub-rail

Crash Severity[1]	Median Crossover Crashes[3]					Median Non-Crossover Crashes		Total Crashes (f) = (d+e)	Percent of Total Crashes (f)/884
	Over-ride (a)	Pene-tration (b)	Unknown Crossover (c)	Total Median Crossover Crashes (d) = (a+b+c)	Percent of Total Median Crossover Crashes (d)/15	Total Median Non-Crossover Crashes (e)	Percent of Median Non-Crossover Crashes (e)/869		
K	1	0	0	1	6.7%	13	1.5%	14	1.6%
A	3	0	1	4	26.7%	94	10.8%	98	11.1%
B	2	1	1	4	26.7%	165	19.0%	169	19.1%
C	2	0	0	2	13.3%	213	24.5%	215	24.3%
O	3	0	1	4	26.7%	383	44.1%	387	43.8%
Unknown[2]	0	0	0	0	0.0%	1	0.1%	1	0.1%
Total	**11**	**1**	**3**	**15**	**100.0%**	**869**	**100.0%**	**884**	**100.0%**

[1] K = fatal injury; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; O = property damage only.

[2] The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.

[3] None of the guardrail crossovers were under-rides.

Table 4-11 and 4-12 compare the percentages of guardrail non-crossover crash statistics of all median guardrails and median guardrail with rub-rails by crash severity and vehicle type, respectively. From the tables, it could be inferred that the performance of median guardrails with rub-rail was very similar to the performance of median guardrails.

Table 4-11: Guardrail Non-Crossover Crash Percentages at all Median Locations and at Locations with Rub-rail by Crash Severity

Crash Severity	Percent of Guardrail Non-Crossover Crashes	
	All Median Guardrail Locations	Locations with Rub-rail
Fatal (K)	74.0%	78.6%
Incapacitating (A)	89.1%	91.8%
Non-Incapacitating (B)	92.8%	92.9%
Possible (C)	96.9%	96.7%
PDO (O)	97.8%	97.2%
Unknown	100.0%	100.0%
Total	**95.5%**	**95.4%**

Table 4-12: Guardrail Non-Crossover Crash Percentages at all Median Locations and at Locations with Rub-rail by Vehicle Type

Vehicle Type	Percent of Guardrail Non-Crossover Crashes	
	All Median Guardrail Locations	**Locations with Rub-rail**
Car	97.8%	99.1%
Light Truck[1]	91.3%	88.4%
Medium Truck[2]	78.9%	53.3%
Heavy Truck[3]	78.1%	84.0%
Motorcycle	88.9%	100.0%
Others	82.8%	50.0%
Unknown	97.4%	100.0%
Total	**95.5%**	**95.4%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks are vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.

4.3 Overall Performance of Guardrails

This section focuses on the overall safety performance of guardrails on limited access facilities. Table 4-13 gives the summary statistics of guardrail-related crashes by guardrail placement (i.e., roadside or median). Note that the guardrail placement of 14 guardrail-related crashes was unknown due to insufficient information in the police reports. During the five-year analysis period, the 685.22 miles of limited access facilities experienced 7,290 guardrail-related crashes. Compared to roadside locations, more locations were installed with guardrails in the median. This is reflected in the data shown in Table 4-13. Of the 7,290 guardrail-related crashes, 5,808 (79.7%) occurred in the median, while 1,468 (20.1%) occurred in the roadside. Guardrails installed in the median had a slightly higher percentage of guardrail non-crossovers at 95.5%. Roadside guardrails prevented 94.5% of crashes from crossing over the guardrail. Overall, 95.3% of guardrail-related crashes were prevented from crossing over the guardrail.

Table 4-13: Summary Statistics of Guardrail-related Crashes by Guardrail Placement

Guardrail Location	Guardrail Crossover Crashes (a)	Guardrail Non-Crossover Crashes (b)	Total Guardrail-related Crashes (c) = (a+b)	Percent of Guardrail Non-Crossover Crashes (b)/(c)
Median	264	5,544	5,808	95.5%
Roadside	81	1,387	1,468	94.5%
Not Sure	0	14	14	100.0%
Total	**345**	**6,945**	**7,290**	**95.3%**

Tables 4-14 and 4-15 give the overall guardrail crossover crash statistics by vehicle type and crash severity, respectively. Overall, 97.5% of cars that hit the guardrail were prevented from crossing over. Likewise, 91.6% of light trucks did not cross over the guardrail. As expected, fewer percentages of medium and heavy trucks were prevented from crossing over the guardrail. Table 4-15 shows that a 45.5% of guardrail non-crossover crashes were PDOs while only 22.4% guardrail crossovers were PDOs. In addition, only 1.4% of guardrail non-crossovers were fatal crashes while 9.9% of guardrail crossovers were fatal. From Table 4-15, it could be inferred that guardrail crossover crashes were more severe compared to guardrail non-crossover crashes.

Table 4-14: Guardrail Crossover Crash Statistics by Vehicle Type at all Locations

Vehicle Type	Guardrail Crossover Crashes					Total Guardrail Non-Crossover Crashes (f)	Total Crashes (g)=(e+f)	Percent of Guardrail Non-Crossover Crashes (f)/(g)
	Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Guardrail Crossover Crashes (e) = (a+b+c+d)			
Car	0	95	14	24	133	5104	5237	97.5%
Light Truck[1]	0	105	14	22	141	1528	1669	91.6%
Medium Truck[2]	0	10	3	7	20	74	94	78.7%
Heavy Truck[3]	0	14	16	11	41	135	176	76.7%
Motorcycle	1	1	0	0	2	23	25	92.0%
Other	0	2	0	3	5	31	36	86.1%
Unknown	0	1	0	1	2	51	53	96.2%
Total	**1**	**228**	**47**	**68**	**344**	**6946**	**7290**	**95.3%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks are vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.

Table 4-15: Guardrail Crossover Crash Statistics by Crash Severity at all Locations

Crash Severity[1]	Guardrail Crossover Crashes						Guardrail Non-Crossover Crashes		Total Crashes (g)= (e+f)	Percent of Total Crashes (f)/7290
	Under-ride (a)	Over-ride (b)	Pene--tration (c)	Unknown Crossover (d)	Total Guardrail Crossover Crashes (e) = (a+b+c+d)	Percent of Total Guardrail Crossover Crashes (e)/344	Total Guardrail Non-Crossover Crashes (f)	Percent of Total Guardrail Non-Crossover Crashes (f)/6946		
K	0	23	5	6	34	9.9%	68	1.0%	102	1.4%
A	0	54	11	8	73	21.2%	522	7.5%	595	8.2%
B	1	74	8	21	104	30.2%	1382	19.9%	1486	20.4%
C	0	36	10	10	56	16.3%	1713	24.7%	1769	24.3%
PDO	0	41	13	23	77	22.4%	3243	46.7%	3320	45.5%
Unknown[2]	0	0	0	0	0	0.0%	18	0.3%	18	0.2%
Total	**1**	**228**	**47**	**68**	**344**	**100.0%**	**6946**	**100.0%**	**7290**	**100.0%**

[1] K = fatal injury; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; O = property damage only.
[2] The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.

4.4 Summary

This chapter focused on the safety performance of G4 (1S) strong-post W-beam guardrails on limited access facilities in Florida. The evaluation was based on guardrail crossover and non-crossover statistics by vehicle type and crash severity. Separate statistics were provided based on guardrail placement, i.e., roadside or median. For locations installed with guardrails in the median, median crossover crash statistics were also provided. Also, a majority of guardrails installed in the medians were fitted with rub-rails to mainly avoid snagging of the vehicle on the posts. The performance of rub-rails was also provided.

A total of 685.22 miles of limited access facilities were installed with G4 (1S) strong-post W-beam guardrails. Police reports of 33,513 crashes that occurred along these study locations from 2006-2010 were reviewed. Of these crashes, 7,290 (21.8%) were identified as guardrail-related crashes. In other words, 7,290 crashes involved vehicles hitting the guardrail at any point during the crash. Overall, 95.3% of guardrail-related crashes were prevented from crossing over the guardrail. Of all the cars that hit the guardrail, 97.5% were prevented from crossing over. Likewise, 91.6% of light trucks were non-crossover crashes. As expected, medium and heavy trucks were found to have a lower non-crossover rate as the guardrail has not been designed for these vehicle types. Further, as expected, guardrail crossover crashes resulted in more severe crashes compared to guardrail non-crossover crashes. Also, among the guardrail crossover crashes, over-rides were more severe.

Of all the crashes that involved vehicles hitting the guardrail in the roadside, 94.5% did not cross over the guardrail. Compared to roadside, guardrails installed in the medians had a slightly higher guardrail non-crossover percentage of 95.5%. Median crossover crashes resulted in a greater proportion of severe injury crashes compared to median non-crossover crashes. Further, among the median crossovers, over-rides were more severe than penetrations.

A total of 156.0 miles of limited access facilities were installed with strong-post W-beam guardrails with rub-rails. Rub-rails were found to be installed only in the medians. A total of 884 crashes involved vehicles leaving the roadway and striking the median guardrail with rub-rail. Of the 884 crashes, 41 (4.6%) resulted in vehicles crossing over the guardrail. Overall, 95.4% of median-guardrail-related crashes were non-crossover crashes. Also, only 15 (1.7%) of the 884 crashes crossed the median guardrail, cleared the median, and went into the opposite travel lanes. In other words, 98.3% of crashes involving vehicles hitting the guardrail in the median were prevented from crossing over the median (i.e., median non-crossover crashes). Further, 11 (73.3%) of these 15 median crossover crashes were due to over-rides; and 9 (81.8%) of these 11 over-rides were either cars or light trucks. The performance of median guardrails with rub-rails was found to be very similar to the performance of median guardrails.

CHAPTER 5
SAFETY EVALUATION OF GUARDRAILS ON NON-LIMITED ACCESS FACILITIES

This chapter presents an analysis to evaluate the safety performance of G4 (1S) strong-post W-beam guardrails on non-limited access facilities in Florida. The evaluation is based on the percentages of vehicles prevented from crossing over the guardrail. The statistics are provided based on guardrail placement (i.e., roadside or median); and by vehicle types and crash severity levels.

A total of 341.47 miles of non-limited access facilities were installed with G4 (1S) strong-post W-beam guardrails. Police reports of 7,225 crashes that occurred along the study locations from 2006-2010 were downloaded and reviewed. Of these crashes, 1,384 (19.2%) were identified as guardrail-related crashes, and are included in the analysis. As discussed in Chapter 1, crashes involving vehicles hitting the guardrail at any point during the crash were categorized as guardrail-related crashes. The following sections focus on the performance of guardrails based on guardrail placement (i.e., roadside or median), vehicle type, and crash severity.

5.1 By Guardrail Placement

Table 5-1 gives the summary statistics of guardrail-related crashes by guardrail placement (i.e., roadside or median). Note that the locations of 9 guardrail-related crashes were unknown due to insufficient information in the police reports. During the five-year analysis period, the 347.47 miles of non-limited access facilities experienced 1,384 guardrail-related crashes. Of these 1,384 guardrail-related crashes, 811 (58.6%) occurred in the median, and 564 (40.8%) occurred in the roadside. Guardrails installed in the median had a higher percentage of guardrail non-crossovers at 93.8%. Roadside guardrails prevented 90.6% of crashes from crossing over the guardrail. Overall, 92.6% of guardrail-related crashes were prevented from crossing over the guardrail.

Table 5-1: Summary Statistics of Guardrail-related Crashes by Guardrail Placement

Guardrail Placement	Guardrail Crossover Crashes (a)	Guardrail Non-Crossover Crashes (b)	Total Guardrail-related Crashes (c) = (a)+(b)	Percent of Guardrail Non-Crossover Crashes (b)/(c)
Median	50	761	811	93.8%
Roadside	53	511	564	90.6%
Not Sure	0	9	9	100.0%
Total	**103**	**1281**	**1384**	**92.6%**

5.2 By Vehicle Type

This section focuses on the safety performance of guardrails on non-limited access facilities by vehicle type. When a crash involved multiple vehicles, the vehicle that actually hit the guardrail was used in the analysis. The vehicle types include cars, light trucks, medium trucks, heavy trucks, motorcycles, unknown vehicle types, and others. Light trucks include vans and pickup trucks with two or four rear tires; medium trucks include vehicles with four rear tires; and heavy trucks include vehicles with two or more rear axles and truck tractors. The “others” category include buses and other vehicles. A total of 11 vehicles were coded as unknown since these vehicles fled the crash site prior to the arrival of law enforcement.

Table 5-2 gives the crash performance statistics of guardrails on non-limited access facilities in terms of guardrail crossover and non-crossover crashes by vehicle type. Overall, 92.6% of all guardrail-related crashes were non-crossover crashes, and 95.3% of cars that hit the guardrail were non-crossover. Likewise, 87.9% of light trucks (which include vans and pickup trucks with two or four rear tires) did not cross over. Medium and heavy trucks were found to have a lower non-crossover rate of 83.3% and 78.5%, respectively. This is expected as the guardrail has not been designed for these vehicle types.

Table 5-2: Guardrail Crossover Crash Statistics by Vehicle Type at all Locations

Vehicle Type	Guardrail Crossover Crashes[4]				Guardrail Non-Crossover Crashes Total (e)	Total Crashes (f)= (d)+(e)	Percent of Guardrail Non-Crossover Crashes (e)/(f)
	Over-ride (a)	Penetration (b)	Unknown Crossover (c)	Total (d) = (a)+(b)+(c)			
Car	26	10	9	45	904	949	95.3%
Light Truck[1]	27	6	7	40	291	331	87.9%
Medium Truck[2]	2	0	0	2	10	12	83.3%
Heavy Truck[3]	3	6	5	14	51	65	78.5%
Motorcycle	0	0	0	0	12	12	100.0%
Other	1	1	0	2	2	4	50.0%
Unknown	0	0	0	0	11	11	100.0%
Total	**59**	**23**	**21**	**103**	**1281**	**1384**	**92.6%**

[1] Light Trucks include vans and pickup trucks with two or four rear tires.
[2] Medium Trucks are vehicles with four rear tires.
[3] Heavy Trucks include truck tractors.
[4] None of the guardrail crossover crashes were under-rides.

5.3 By Crash Severity

Table 5-3 gives the crash performance statistics of guardrails in terms of guardrail crossover and non-crossover crashes by crash severity. Crash severity information was obtained from the police reports using the following codes:

- K – Fatal Injury
- A – Incapacitating Injury
- B – Non-Incapacitating Injury
- C – Possible Injury
- O – Property Damage Only
- Unknown – The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.

Of the 103 guardrail crossover crashes, 10 (9.7%) were fatal; of the 1,281 guardrail non-crossover crashes, 19 (1.5%) were fatal. On the other hand, 15 (14.6%) of 103 guardrail crossovers were PDOs; while 596 (46.5%) of 1,281 non-crossovers were PDOs. From these statistics, it could be inferred that guardrail crossover crashes, as expected, were more severe compared to guardrail non-crossover crashes.

Table 5-3: Guardrail Crossover Crash Statistics by Crash Severity at all Locations

Crash Severity[1]	Guardrail Crossover Crashes[3]					Guardrail Non-Crossover Crashes		Total Crashes (f)= (d)+(e)	Percent of Total Crashes (f)/1384
	Over-ride (a)	Pene-tration (b)	Unknown Crossover (c)	Total Guardrail Crossover Crashes (d) = (a)+(b)+(c)	Percent of Total Guardrail Crossover Crashes (d)/103	Total Guardrail Non-Crossover Crashes (e)	Percent of Total Guardrail Non-Crossover Crashes (e)/1281		
K	3	3	4	10	9.7%	19	1.5%	29	2.1%
A	11	3	3	17	16.5%	93	7.3%	110	7.9%
B	21	11	6	38	36.9%	246	19.2%	284	20.5%
C	13	4	4	21	20.4%	299	23.3%	320	23.1%
PDO	11	1	3	15	14.6%	596	46.5%	611	44.1%
Unknown[2]	0	1	1	2	1.9%	28	2.2%	30	2.2%
Total	**59**	**23**	**21**	**103**	**100.0%**	**1281**	**100.0%**	**1384**	**100.0%**

[1] K = fatal injury; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; PDO = property damage only.
[2] The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement or when a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report.
[3] None of the guardrail crossover crashes were under-rides.

5.4 Summary

This chapter focused on the safety performance of G4 (1S) strong-post W-beam guardrails on non-limited access facilities in Florida. The evaluation was based on guardrail crossover and non-crossover statistics by guardrail placement, vehicle type, and crash severity.

A total of 341.47 miles of non-limited access facilities were installed with G4 (1S) strong-post W-beam guardrails. Police reports of 7,225 crashes that occurred along these study locations from 2006-2010 were reviewed. Of these crashes, 1,384 (19.2%) were identified as guardrail-related crashes. Overall, 92.6% of guardrail-related crashes were prevented from crossing over the guardrail. Guardrails installed in the median had a higher percentage of guardrail non-crossovers at 93.8%. Roadside guardrails prevented 90.6% of crashes from crossing over the guardrail. Compared to all vehicle types, greater percentage of cars were prevented from crossing over the guardrail at 95.3%. Cars were followed by light trucks at 87.9%, medium trucks at 83.3%, and heavy trucks at 78.5%. Further, as expected, guardrail crossover crashes were more severe compared to guardrail non-crossover crashes.

CHAPTER 6
GUARDRAIL INVENTORY

In this chapter, the proposed list of guardrail inventory features to be included in the inventory tool is first listed. It also includes a detailed discussion on a Web-based application developed to record and maintain guardrail inventory data for all state roads in Florida.

6.1 Proposed List of Guardrail Inventory Features

Based on the studies discussed in Section 2.4.1, the following list of features is proposed to be included in the guardrail inventory. Description of each variable is also given.

- *General Information*

  - Date of Inspection: Date when guardrail inspection was done (MM/DD/YY).
  - District: FDOT District ID (from 1 through 8).
  - County: Florida County name.
  - Roadway ID: ID number of roadway.
  - Begin Milepost: Begin milepost of the guardrail.
  - End Milepost: End milepost of the guardrail.
  - Roadway Type: Type of roadway (interstate, expressway, arterial, local, collector, or other).
  - Route Name: Name of the roadway or state road number (e.g., SR 9).
  - Area Type: Type of land use where guardrail is located (urban, rural, or suburban).
  - Position: Roadway side where guardrail is located (median or roadside shoulder).
  - Shoulder Type: Type of roadside shoulder (paved or unpaved).
  - Shoulder Condition: Condition of roadside shoulder (good or poor).

- *Guardrail Characteristics and Conditions*

  - Guardrail ID: ID number of guardrail.
  - Type of Guardrail: Type of guardrail (W-beam or thrie-beam).
  - Guardrail Segment Length: Roadway stretch length occupied by guardrail in feet.
  - Direction of Travel: Direction of travel where guardrail is located (NB, SB, WB, or EB).
  - Year of Installation: Year when guardrail was installed.
  - Guardrail Height to Top of Rail: Height from the ground to the top of guardrail in inches.
  - Post Type: Type of guardrail post (wooden or steel).
  - Post: Composition of the post (single-faced or double-faced).
  - Lateral Offset from Pavement Edge: Distance from guardrail to the nearest pavement edge in feet.
  - Post Spacing: Spacing between successive posts in feet.
  - End Treatment Installation: Whether end treatment exists (none, both ends, or one end only).
  - End Treatment Type: Type of end treatment (crash cushion or crash attenuator).

- Space Type behind: Type of space behind guardrail (river, vegetation, trees, or other).
- Rub-rail Existent: Whether rub-rail is existent (Yes or No).
- Block-out Missing: Whether the guardrail block-out is missing (Yes or No). If Yes: Count of Missing Block-outs.
- Splice Bolt and Nut Missing: Whether splice bolts and nuts are missing (Yes or No). If Yes: Count of Missing Splice Bolts and Nuts.

- *Guardrail Damage Conditions*

  - Rail Damaged: Whether rail is damaged (Yes or No). If Yes:
    - Length of Damaged Rail: Length of damaged portion of the rail in feet.
    - Rail Displacement from Original Position: Rail offset from original position after damage in inches.
  - Rub-rail Damaged: Whether rub-rail is damaged (Yes or No). If Yes:
    - Length of Damaged Rub-rail: Length of damaged portion of the rub-rail in feet.
    - Rub-Rail Displacement from Original Position: Rub-rail offset from original position after damage in inches.
  - Post Damaged: Whether the guardrail post is damaged (Yes or No). If Yes: Count of Damaged Posts.
  - Block-out Damaged: Whether the guardrail block-out is damaged (Yes or No). If Yes: Count of Damaged Block-outs.
  - End Treatment Damaged: Whether end treatment is damaged (Yes or No). If Yes: Count of Damaged End Treatments.
  - Splice Bolt and Nut Damaged: Whether splice bolts and nuts are damaged (Yes or No). If Yes:
    - Count of Failed Splice Bolts and Nuts.
    - Count of Broken/Bent Splice Bolts and Nuts.

- *Guardrail Component Repair Records*

  - Date of Repair: Date when each specific guardrail component was repaired (MM/DD/YY).
  - Component(s) Repaired: Specific guardrail component repaired (i.e., rail, rub-rail, post, block-out, end treatment, and splice bolts and nuts).
  - Labor Cost: Cost of labor of each repaired component.
  - Material Cost: Cost of each component's material.
  - Other Cost: Other costs to repair each component.
  - Performing Contractor or Agency: Name of the agency or contractor performing guardrail repair.

6.2 Guardrail Inventory System

This section describes a Web-based system that was developed for the recording and maintenance of guardrail systems on Florida's state roads. The inventory includes all the proposed features identified in the previous section. Named Florida Guardrail Inventory (FGI), the system was developed using ASP.NET 3.5 and C#.NET within the Microsoft Visual Studio

2008 environment. The database system is in SQL Server 2008. Figure 6-1 shows the main screen of the system. It allows the user to either query or update the inventory by making selection on a number of inventory fields provided. The inventory is accessible to all users. However, only authorized users are allowed to update the inventory.

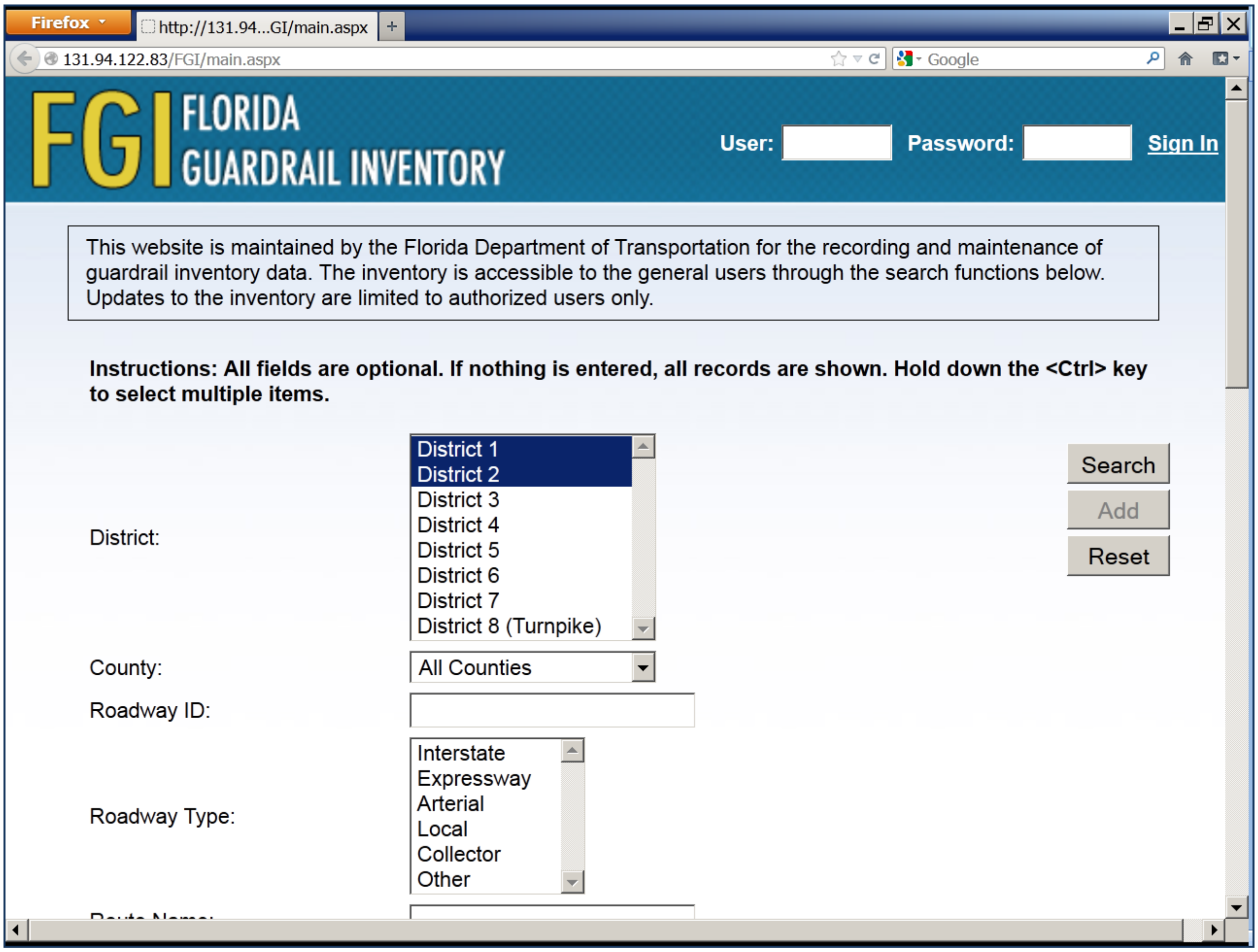
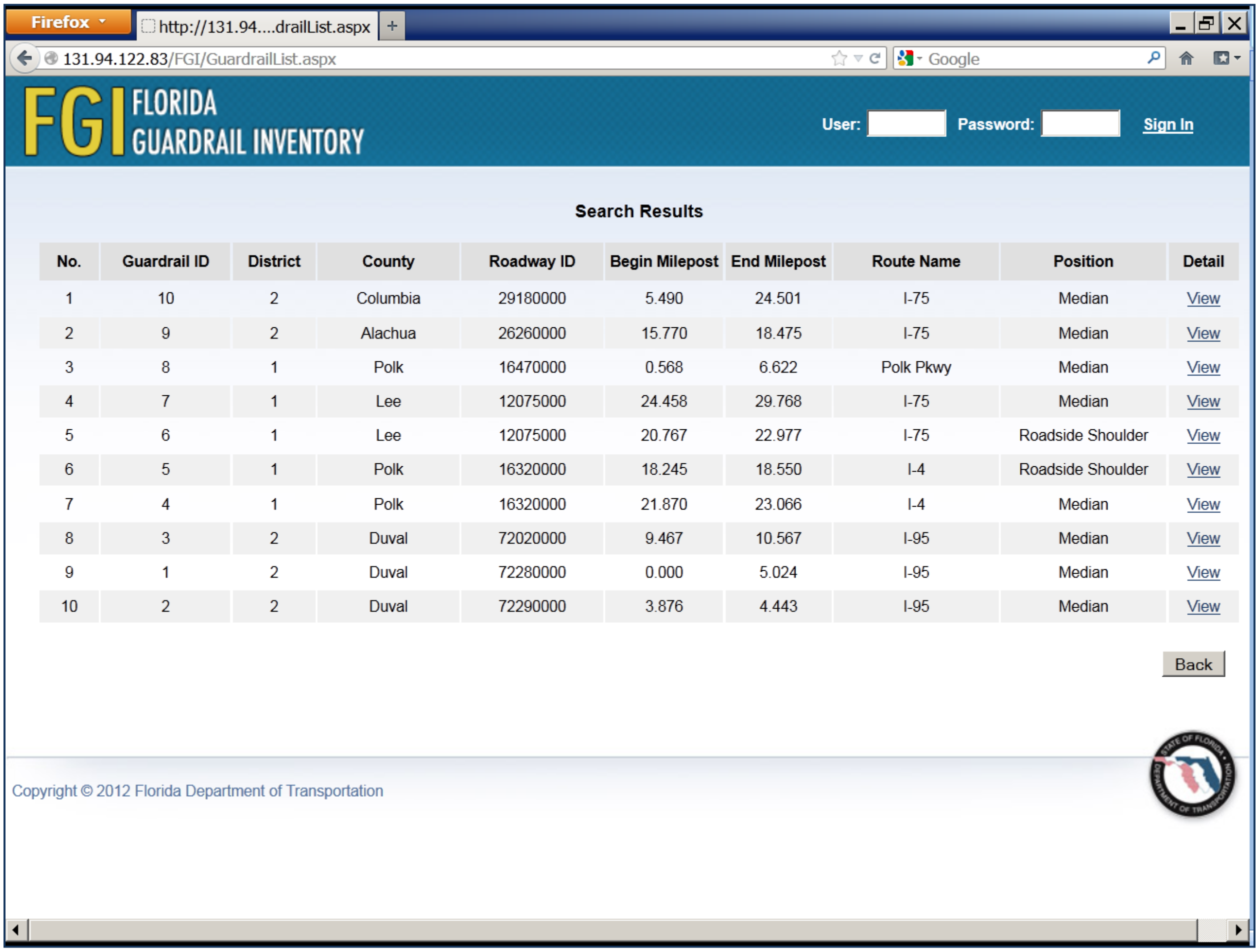


Figure 6-1: Main Screen of Guardrail Inventory System

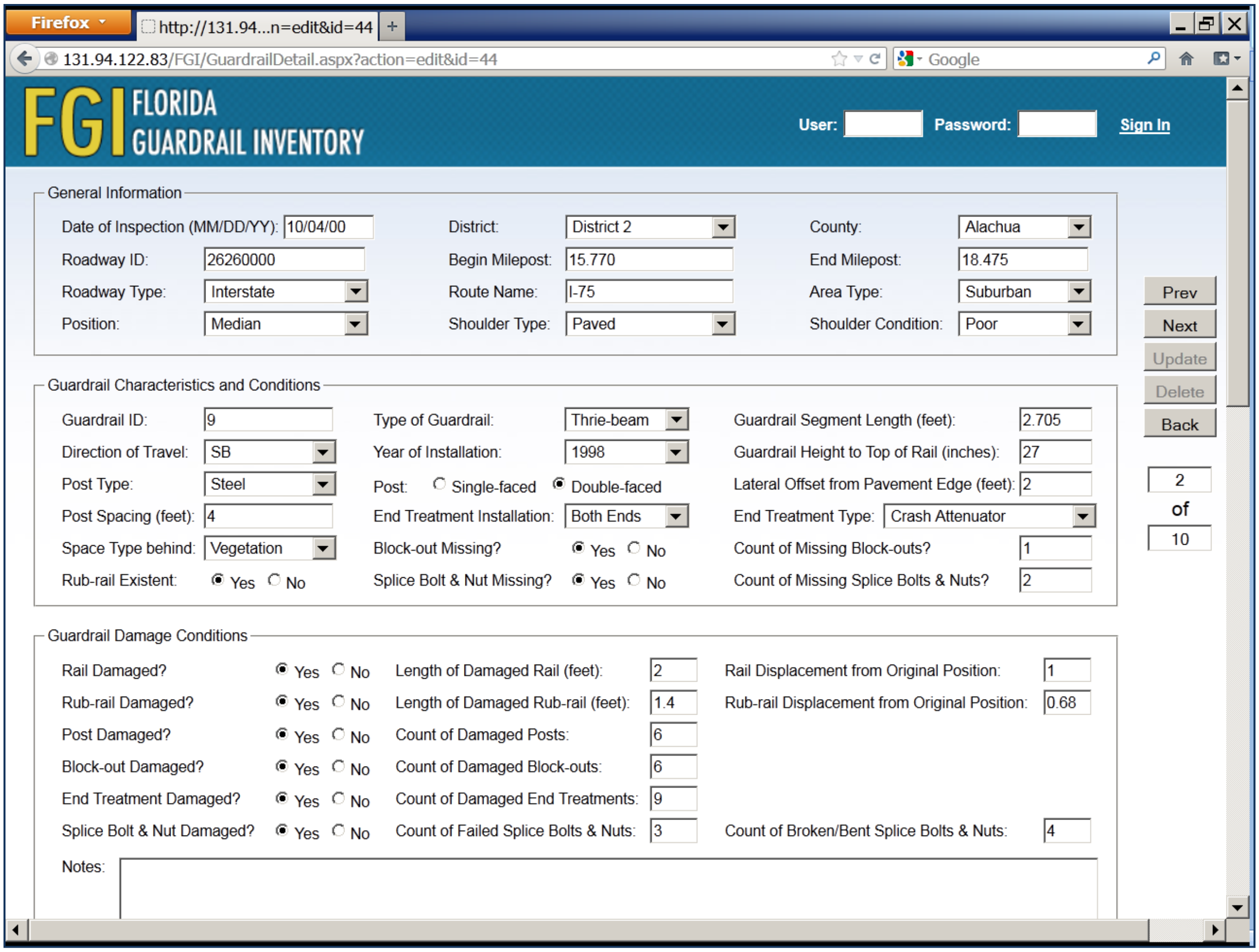
6.2.1 Querying the Inventory

As indicated on the main screen as instructions to the user, all fields are optional. If no selections are made, all records will be shown. For fields with multiple selection items, the user can hold down the **<Ctrl>** key to select more than one item. After the query selections are made, the user can either click on the **Reset** button to start over or click the **Search** button to retrieve guardrail segment records. Only the records that satisfy all the query selections will be retrieved. Figure 6-2 shows a sample list of retrieved records. Based on some basic segment location information provided for each retrieved records, the user can then identify a target record and click on the corresponding **View** link on the **Detail** column to display the complete data for the record on a form. Figures 6-3 and 6-4 show the upper and lower portions, respectively, of an example form displaying the detailed inventory data of a record. The screen includes a floating button panel that allows the user to navigate among the retrieved records. The floating panel also shows the current record number and the total number of retrieved records.



No.	Guardrail ID	District	County	Roadway ID	Begin Milepost	End Milepost	Route Name	Position	Detail
1	10	2	Columbia	29180000	5.490	24.501	I-75	Median	View
2	9	2	Alachua	26260000	15.770	18.475	I-75	Median	View
3	8	1	Polk	16470000	0.568	6.622	Polk Pkwy	Median	View
4	7	1	Lee	12075000	24.458	29.768	I-75	Median	View
5	6	1	Lee	12075000	20.767	22.977	I-75	Roadside Shoulder	View
6	5	1	Polk	16320000	18.245	18.550	I-4	Roadside Shoulder	View
7	4	1	Polk	16320000	21.870	23.066	I-4	Median	View
8	3	2	Duval	72020000	9.467	10.567	I-95	Median	View
9	1	2	Duval	72280000	0.000	5.024	I-95	Median	View
10	2	2	Duval	72290000	3.876	4.443	I-95	Median	View

Figure 6-2: List of Retrieved Records



Firefox | http://131.94...n=edit&id=44

131.94.122.83/FGI/GuardrailDetail.aspx?action=edit&id=44

FGI FLORIDA GUARDRAIL INVENTORY

User: Password: Sign In

General Information

Date of Inspection (MM/DD/YY): 10/04/00 | District: District 2 | County: Alachua

Roadway ID: 26260000 | Begin Milepost: 15.770 | End Milepost: 18.475

Roadway Type: Interstate | Route Name: I-75 | Area Type: Suburban

Position: Median | Shoulder Type: Paved | Shoulder Condition: Poor

Prev | Next | Update | Delete | Back

2 of 10

Guardrail Characteristics and Conditions

Guardrail ID: 9 | Type of Guardrail: Thrie-beam | Guardrail Segment Length (feet): 2.705

Direction of Travel: SB | Year of Installation: 1998 | Guardrail Height to Top of Rail (inches): 27

Post Type: Steel | Post: Single-faced / Double-faced (selected) | Lateral Offset from Pavement Edge (feet): 2

Post Spacing (feet): 4 | End Treatment Installation: Both Ends | End Treatment Type: Crash Attenuator

Space Type behind: Vegetation | Block-out Missing? Yes (selected) No | Count of Missing Block-outs? 1

Rub-rail Existent: Yes (selected) No | Splice Bolt & Nut Missing? Yes (selected) No | Count of Missing Splice Bolts & Nuts? 2

Guardrail Damage Conditions

Rail Damaged? Yes (selected) No | Length of Damaged Rail (feet): 2 | Rail Displacement from Original Position: 1

Rub-rail Damaged? Yes (selected) No | Length of Damaged Rub-rail (feet): 1.4 | Rub-rail Displacement from Original Position: 0.68

Post Damaged? Yes (selected) No | Count of Damaged Posts: 6

Block-out Damaged? Yes (selected) No | Count of Damaged Block-outs: 6

End Treatment Damaged? Yes (selected) No | Count of Damaged End Treatments: 9

Splice Bolt & Nut Damaged? Yes (selected) No | Count of Failed Splice Bolts & Nuts: 3 | Count of Broken/Bent Splice Bolts & Nuts: 4

Notes:

Figure 6-3: Upper Portion of a Form Displaying Detailed Retrieved Data

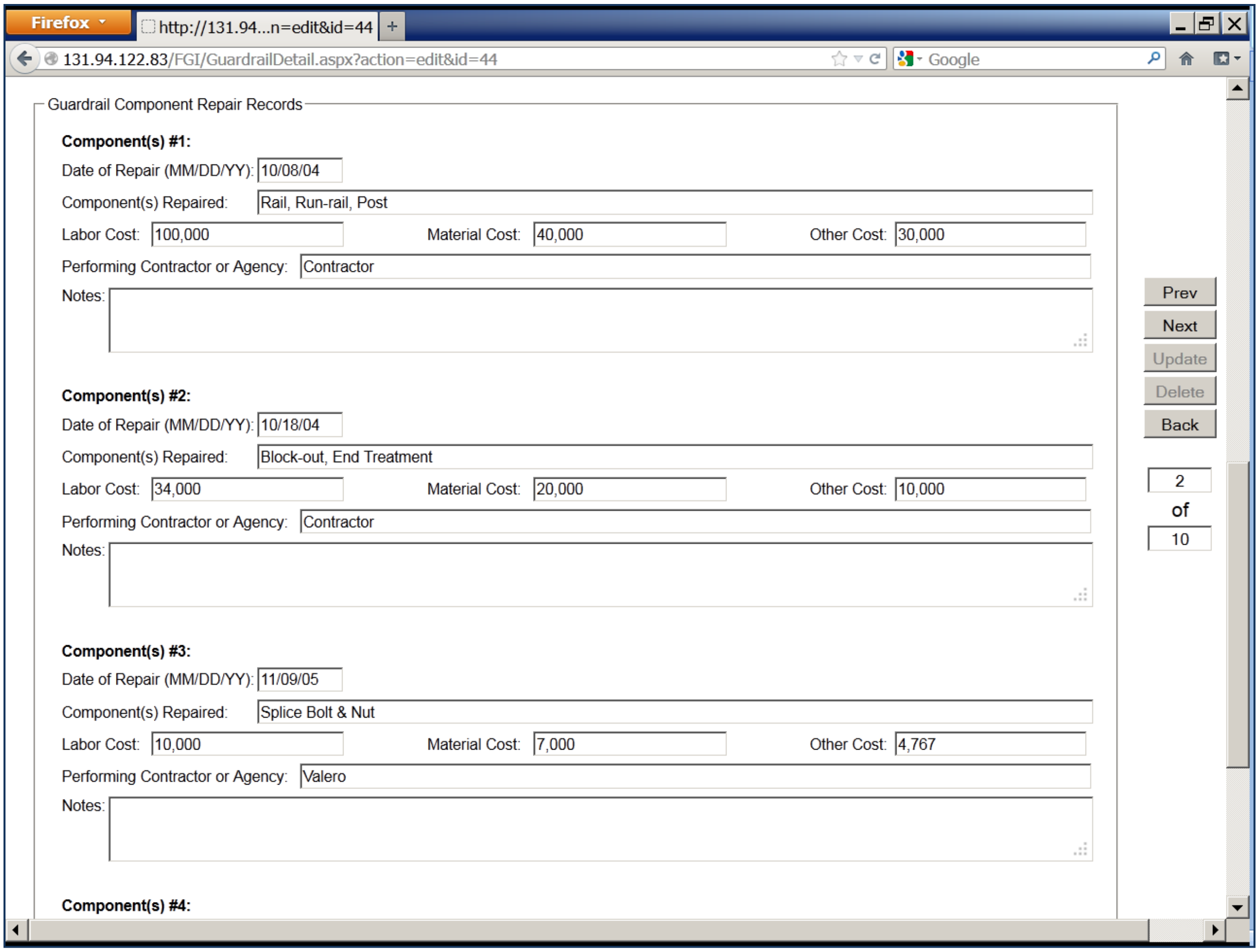


Figure 6-4: Lower Portion of a Form Displaying Detailed Retrieved Data

6.2.2 Adding a New Record to Inventory

To add a new record to the inventory, the user must first sign into the system. The top-right corner of the main screen allows an authorized user with a pre-assigned user account to do so by entering his or her username and password. After the user has signed in, the **Add** button on the floating panel on the main screen will be activated (see Figure 6-1). Figure 6-5 shows an empty form that is ready for data entry. After the data entry is completed, the user will simply click on the **Save** button to save it as a new record.

6.2.3 Updating and Deleting an Existing Record in Inventory

The process to update or delete an existing record is similar to adding a new record. The user is required to first sign into the system, as described in the previous section. After signing in, the user can simply use the search function to identify and retrieve existing records. The list of retrieved records is similar to the one in Figure 6-2 except that instead of the **View** link the screen will show an **Edit** link. The user can then click on the **Edit** link of a target record to display its detailed data. On this screen the user can make changes to any of the fields. The user can then click the **Update** button to save the changes. The user can also click on the **Delete** button to delete a record.

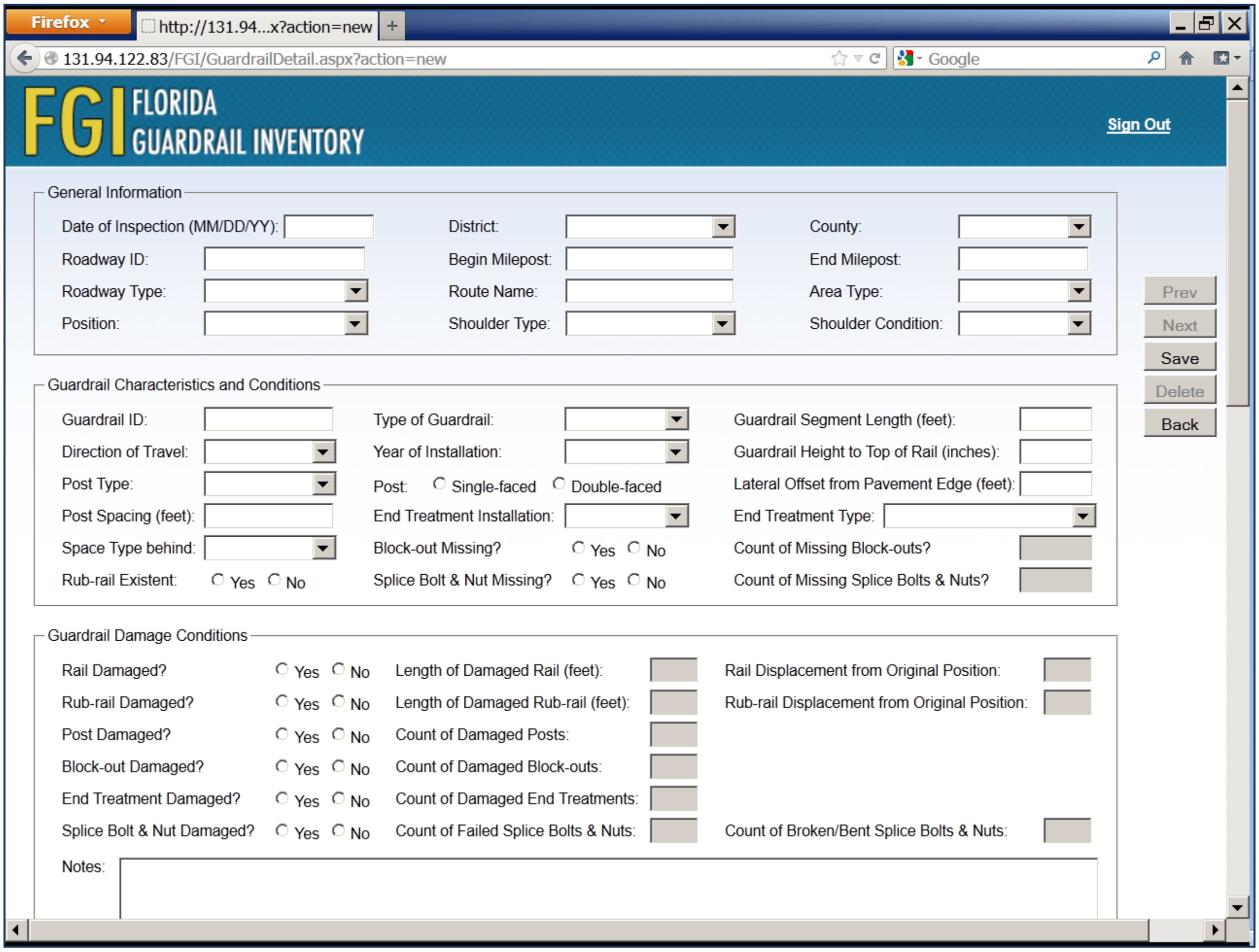


Figure 6-5: Upper Portion of an Empty Form for Data Entry

6.2.4 User Account Administration

The system provides a function to allow a designated system administrator to set up a new account and edit or delete an existing account. To setup a user account, the system administrator will enter the username and password on the top right corner of the main screen, similar to any user login. However, the system will recognize the special administrative account entered and will open the screen shown in Figure 6-6, which lists all the existing accounts.

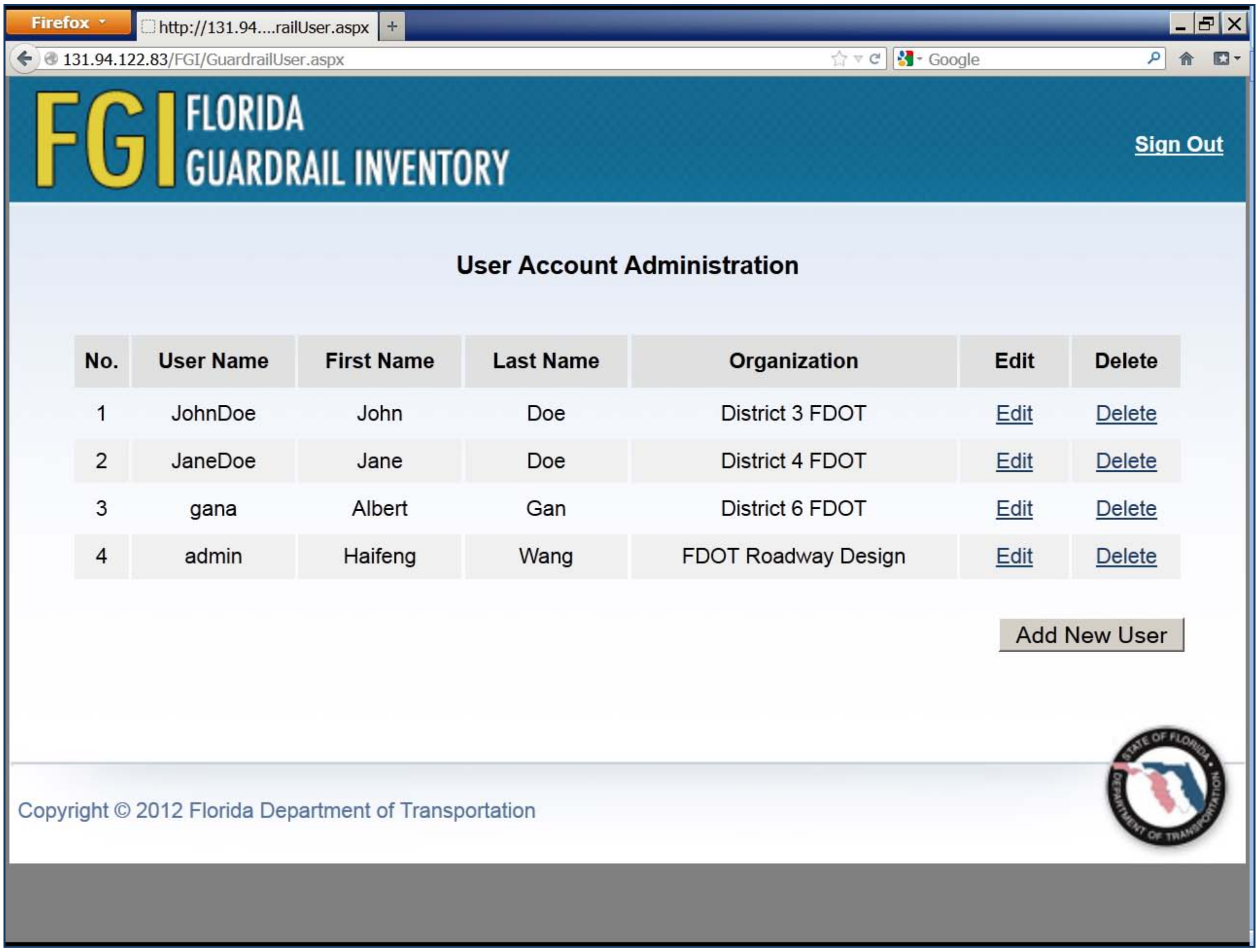


Figure 6-6: Main Screen of User Account Administration Page

To add a new user, the administrator clicks the **Add New User** button at the bottom right of the account listing. This will open a data entry area (see Figure 6-7) that allows a new account to be created. The administrator can then enter the first name, last name, organization, and email of the user, along with a username and a password assigned by the administrator. Both the username and password are not case-sensitive, and up to 20 alphanumeric characters may be specified for each. The administrator can then click **Add** to confirm the new user account or **Cancel** to close the data entry area without saving. The administrator can also click the **Edit** or **Delete** link next to each user account record to make changes to or delete an existing account (see Figure 6-8).

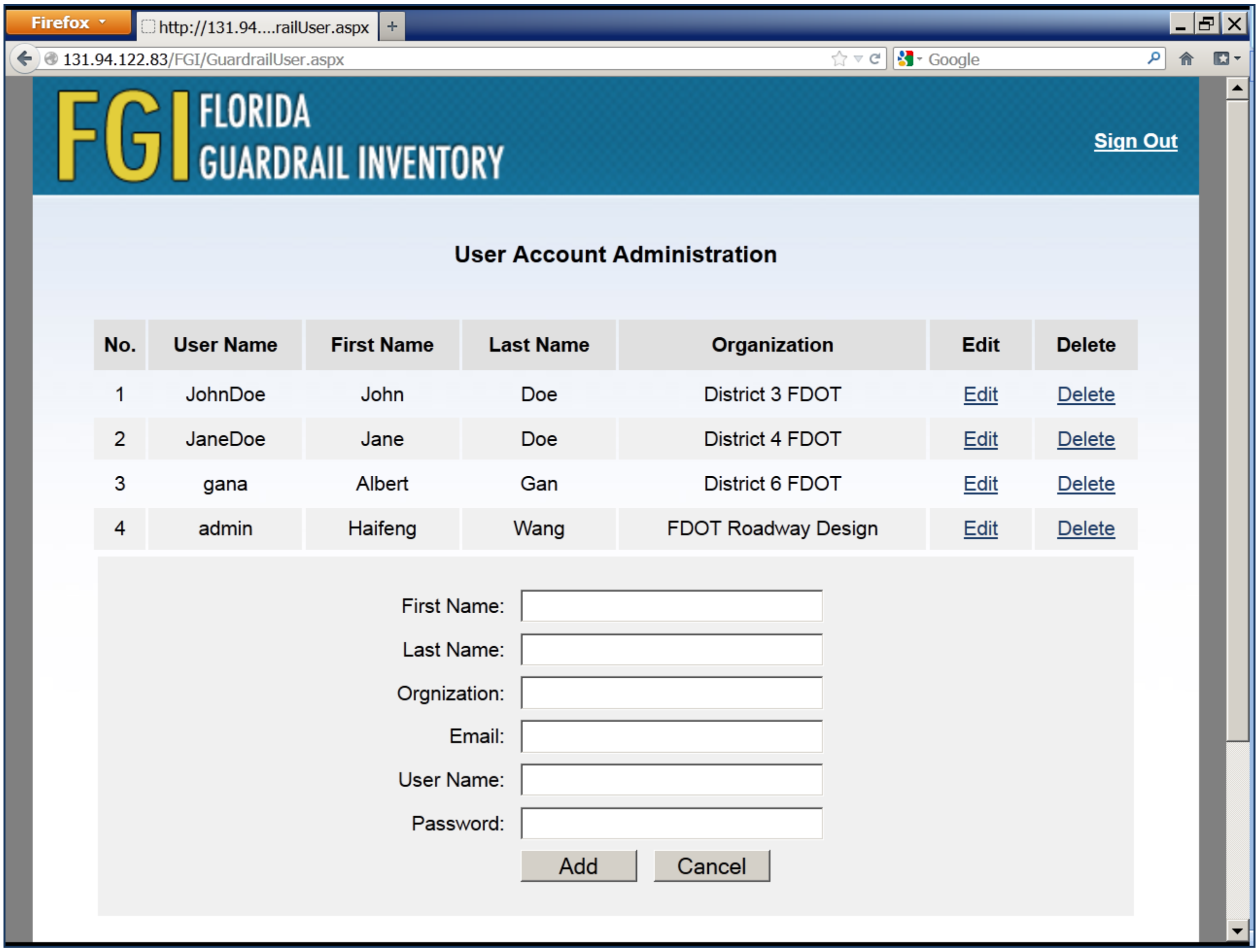


Figure 6-7: Adding a New User Account

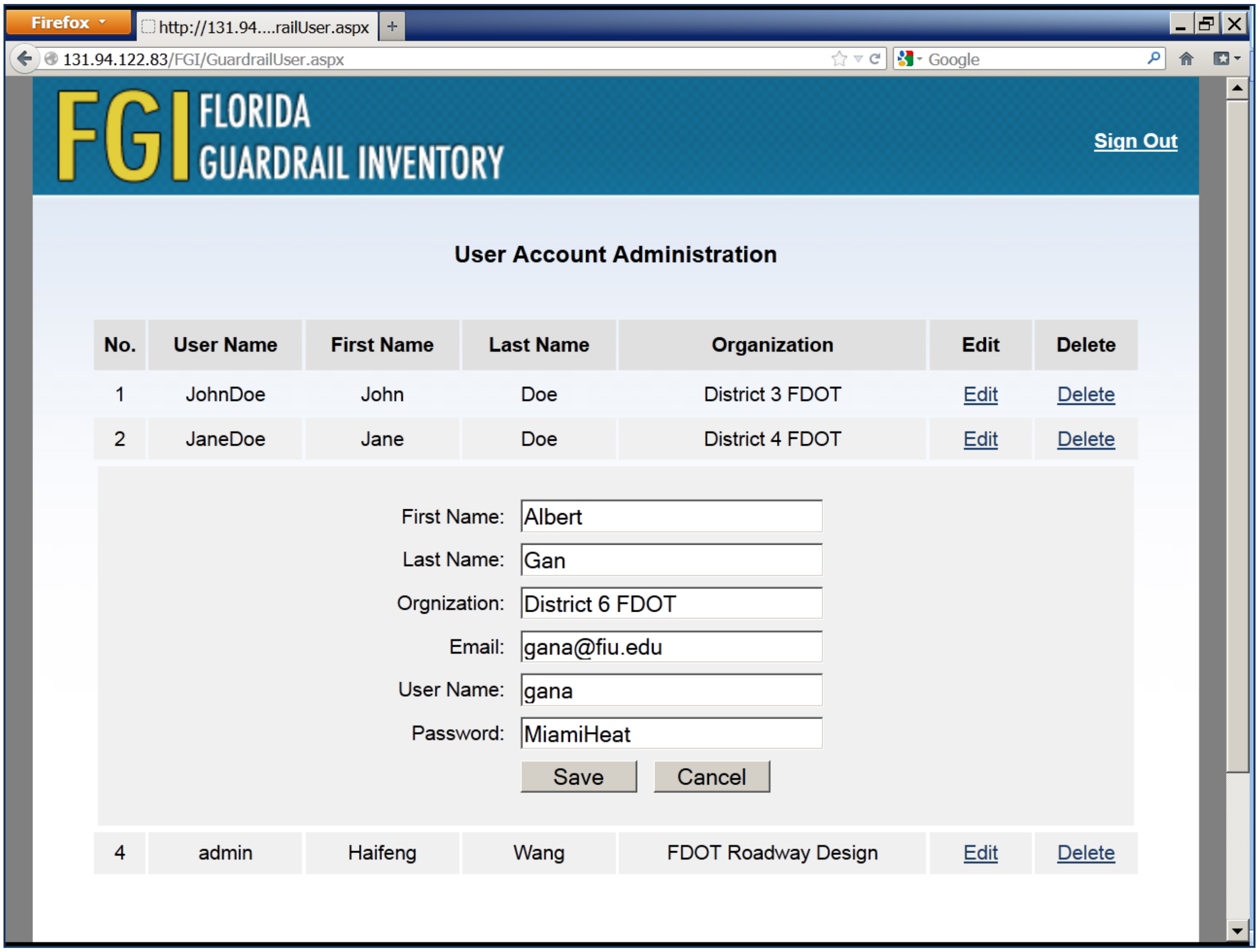


Figure 6-8: Editing a User Account

CHAPTER 7
SUMMARY AND CONCLUSIONS

The main objective of this project is to evaluate the safety performance of G4 (1S) strong-post W-beam guardrail systems installed on both limited and non-limited access facilities in Florida. In this study, the effectiveness of guardrails is measured by the percentages of errant vehicles prevented from crossing the guardrail, i.e., guardrail crossover crashes. Guardrails installed in the medians are also evaluated based on median crossover crashes. A crash in which an errant vehicle crosses the guardrail at any point during the crash is categorized as a guardrail crossover crash. If the errant vehicle reaches the opposite travel lane after crossing the guardrail in the median, it is a median crossover crash. A guardrail can be crossed over by under-riding, over-riding, or penetrating the guardrail. A crash is categorized as non-crossover when an errant vehicle does not cross the guardrail at any point during the crash.

For this study, two Web-based applications were developed: the Visual Roadway Inventory Collection System (VRICS) to collect and verify roadway characteristics data, and the Florida Guardrail Inventory (FGI) application to record and maintain guardrail inventory data on all state roads in Florida. As part of data processing, the VRICS application was used to identify state roads with G4 (1S) strong-post W-beam guardrails. The application was later customized to identify locations on limited access facilities where the guardrails were fitted with rub-rails.

In total, 685.2 miles of limited access facilities and 341.5 miles of non-limited access facilities were identified to have G4 (1S) strong-post W-beam guardrails. A majority of strong-post W-beam guardrails along medians on limited access facilities were fitted with rub-rails. However, these rub-rails were often along shorter segments and not continuous. Only the freeway sections longer than three miles and with continuous sections of rub-rails were analyzed. A total of 156.0 miles of limited access facilities were identified and used to evaluate the safety performance of rub-rails.

For the years 2006-2010, the limited and non-limited access facilities that were installed with strong-post W-beam guardrails experienced a total of 33,513 and 7,225 crashes, respectively. The police reports of all the 40,738 crashes were downloaded from the Hummingbird web system hosted on FDOT's Intranet and reviewed in detail. The review focused on identifying crash consequences of vehicles hitting the guardrail.

During the five-year analysis period, the 685.2 miles of limited access facilities experienced 7,290 guardrail-related crashes. In other words, 7,290 crashes involved vehicles hitting the guardrail at any point during the crash. Overall, 95.3% of guardrail-related crashes were prevented from crossing the guardrail. Of all the cars that hit the guardrail, 97.5% were prevented from crossing over. Likewise, 91.6% of light trucks were non-crossover crashes. As expected, medium and heavy trucks were found to have a lower non-crossover rate as the guardrail has not been designed for these vehicle types. Further, as expected, guardrail crossover crashes resulted in more severe crashes compared to guardrail non-crossover crashes. Also, among the guardrail crossover crashes, over-rides were more severe.

Of all the crashes that involved vehicles hitting the roadside guardrail, 94.5% did not cross over the guardrail. Compared to roadside, guardrails installed in the medians had a slightly higher guardrail non-crossover percentage of 95.5%. Median crossover crashes resulted in a greater proportion of severe injury crashes compared to median non-crossover crashes. Further, among the median crossovers, over-rides were more severe than penetrations.

A special evaluation was performed based on 156.0 miles of median guardrail locations installed with rub-rail. A total of 884 crashes involved vehicles leaving the roadway and striking the median guardrail with rub-rail. Of the 884 crashes, 41 (4.6%) resulted in vehicles crossing over the guardrail. Overall, 95.4% of median-guardrail-related crashes were non-crossover crashes. Also, only 15 (1.7%) of the 884 crashes crossed the median guardrail, cleared the median, and went into the opposite travel lanes. In other words, 98.3% of crashes involving vehicles hitting the guardrail in the median were prevented from crossing over the median (i.e., median non-crossover crashes). Further, 11 (73.3%) of these 15 median crossover crashes were due to over-rides; and 9 (81.8%) of these 11 over-rides were either cars or light trucks. The results showed that these locations did not perform differently when compared to all median guardrail locations (with and without rub-rail).

From 2006-2010, the 347.5 miles of non-limited access facilities experienced a total of 1,384 guardrail-related crashes. Overall, 92.6% of guardrail-related crashes were prevented from crossing over the guardrail. Guardrails installed in the median had a higher percentage of guardrail non-crossovers at 93.8%. Roadside guardrails prevented 90.6% of crashes from crossing over the guardrail.

As part of this project, the existing guardrail inventory methods currently being used in other states were reviewed and a set of guardrail inventory features was proposed for Florida's application. A Web-based database application, named the Florida Guardrail Inventory (FGI), that incorporates these features was developed. The system allows FDOT to collect and maintain inventory and repair records for guardrails on Florida's state roads.

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APPENDIX A

STUDY LOCATIONS

Table A-1: Study Locations on Limited Access Facilities in Florida

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
58010000	1.151	1.169	0.018	Caroline St
58010000	1.169	1.263	0.094	Caroline St
58010000	1.263	1.289	0.026	Caroline St
58010000	1.355	1.374	0.019	Caroline St
58010000	1.671	1.694	0.023	Caroline St
75002000	9.008	9.297	0.289	Martin Andersen Beachline Expwy
75002000	9.297	9.816	0.519	Martin Andersen Beachline Expwy
75474000	0.152	0.759	0.607	Florida 408
86080000	16.443	16.931	0.488	Florida 84
91470000	0.000	3.515	3.515	Turnpike/Florida 91
91470000	3.515	4.455	0.940	Turnpike/Florida 91
8070000	5.128	5.300	0.172	Florida 50
10002000	0.709	1.001	0.292	Crosstown Expwy
10002000	6.790	7.267	0.477	Crosstown Expwy
10002000	7.267	7.452	0.185	Crosstown Expwy
10002000	8.224	8.377	0.153	Crosstown Expwy
10002000	8.377	11.387	3.010	Crosstown Expwy
10140000	5.220	5.360	0.140	W Courtney Campbell Causeway
10470000	1.540	12.206	10.666	Veterans Expressway
10471000	0.394	2.689	2.295	Veterans Expressway
11470000	0.000	23.876	23.876	Turnpike/Florida 91
12075000	20.767	22.977	2.210	I-75
12075000	22.977	23.878	0.901	I-75
12075000	23.878	24.458	0.580	I-75
12075000	24.458	29.768	5.310	I-75
12075000	29.768	30.404	0.636	I-75
15035000	2.335	2.460	0.125	Florida 686
15035000	2.460	2.654	0.194	Florida 686
15035000	2.654	2.944	0.290	Florida 686
15190000	12.166	13.596	1.430	I-275
15190900	0.000	0.115	0.115	I-275
15240000	5.630	5.760	0.130	I-275 off ramp
16320000	18.245	18.550	0.305	I-4
16320000	19.010	19.110	0.100	I-4
16320000	19.445	19.590	0.145	I-4
16320000	21.870	23.066	1.196	I-4
16470000	0.568	6.622	6.054	Polk Pkwy
16470000	6.622	6.708	0.086	Polk Pkwy
16470000	6.708	7.150	0.442	Polk Pkwy
16470000	7.150	7.963	0.813	Polk Pkwy
16470000	9.087	10.827	1.740	Polk Pkwy
16470000	12.637	13.543	0.906	Polk Pkwy
16470000	18.337	18.462	0.125	Polk Pkwy/Florida 570
17075000	18.903	20.002	1.099	I-75
18070000	0.000	0.247	0.247	Florida 44
18070000	0.247	0.380	0.133	Florida 44
18130000	0.000	0.203	0.203	I-75
18130000	0.203	1.758	1.555	I-75
18130000	1.758	2.416	0.658	I-75
18130000	2.416	14.070	11.654	I-75

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
18130000	14.070	14.296	0.226	I-75
18130000	14.296	14.402	0.106	I-75
18130000	14.402	15.431	1.029	I-75
18130000	15.431	21.050	5.619	I-75
18130000	22.099	25.337	3.238	I-75
18130000	26.091	28.996	2.905	I-75
18470000	0.000	1.584	1.584	Turnpike
18470000	2.699	6.360	3.661	Turnpike
18470000	6.360	6.909	0.549	Turnpike
18470000	6.909	10.045	3.136	Turnpike
18470000	10.045	10.670	0.625	Turnpike
26060000	0.000	0.558	0.558	North Main Street
26260000	15.770	18.475	2.705	I-75
26260000	18.942	20.866	1.924	I-75
29180000	0.000	4.614	4.614	I-75
29180000	5.490	24.501	19.011	I-75
29180000	26.046	27.631	1.585	I-75
29180000	28.579	29.187	0.608	I-75
32100000	0.000	0.662	0.662	I-75
32100000	2.385	7.768	5.383	I-75
32100000	8.345	12.813	4.468	I-75
32100000	13.235	20.165	6.930	I-75
32100000	20.714	25.755	5.041	I-75
32100000	26.444	28.746	2.302	I-75
36030000	0.673	1.032	0.359	N Pine Ave
36030000	1.307	1.792	0.485	N Pine Ave/NW 3rd Street
36210000	0.000	8.793	8.793	I-75
36210000	9.144	28.055	18.911	I-75
36210000	28.606	33.877	5.271	I-75
36210000	34.408	38.282	3.874	I-75
37120000	23.240	25.508	2.268	I-10
37130000	0.000	3.656	3.656	I-75
46010000	0.390	0.850	0.460	US 98
46040000	9.966	10.083	0.117	US 231
46040000	10.083	10.122	0.039	US 231
46040000	16.838	16.963	0.125	US 231
46040000	26.053	26.165	0.112	US 231
46040000	28.723	28.830	0.107	US 231
46040000	31.886	32.005	0.119	US 231
48004000	6.243	6.517	0.274	W Florida Drive
48010000	14.604	14.971	0.367	N Davis Hwy
48040000	8.572	8.699	0.127	Pensacoola Blvd
48060000	3.064	3.249	0.185	Century Blvd
48060000	10.025	10.152	0.127	N Century Blvd
48060000	13.324	13.463	0.139	N Century Blvd
48080000	3.573	3.685	0.112	New Warrington Spur
48080000	3.912	4.038	0.126	New Warrington Spur
48260000	5.017	5.242	0.225	I-10
48260000	5.429	5.641	0.212	I-10
48260000	6.992	7.181	0.189	I-10
48260000	9.879	10.737	0.858	I-10
48260000	10.737	12.092	1.355	I-10

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
48260000	12.092	12.235	0.143	I-10
48260000	13.160	13.809	0.649	I-10
48260000	16.256	19.164	2.908	I-10
48270000	6.011	6.191	0.180	I-110
48270000	6.191	6.341	0.150	I-110
50001000	13.022	13.182	0.160	I-10
50001000	13.949	14.129	0.180	I-10
50001000	31.747	31.965	0.218	I-10
50001000	32.702	32.972	0.270	I-10
50001000	33.425	33.508	0.083	I-10
50020000	15.339	15.544	0.205	US 27
50020000	15.640	15.944	0.304	US 27
50030000	11.907	12.039	0.132	Blue Star Hwy
50030000	12.964	13.147	0.183	Blue Star Hwy
52002000	1.470	1.644	0.174	I-10
52002000	1.946	2.147	0.201	I-10
52002000	3.628	3.823	0.195	I-10
52002000	7.601	7.861	0.260	I-10
52002000	8.306	8.370	0.064	I-10
52002000	19.380	19.542	0.162	I-10
52002000	21.086	21.276	0.190	I-10
53002000	2.008	4.506	2.498	I-10
53002000	5.092	7.812	2.720	I-10
53002000	8.345	11.012	2.667	I-10
53002000	14.344	14.544	0.200	I-10
53002000	15.239	15.420	0.181	I-10
53002000	25.156	25.329	0.173	I-10
53030000	13.339	13.471	0.132	US 231
53030035	1.451	1.620	0.169	US 231
54001000	0.891	1.113	0.222	I-10
54001000	2.089	2.322	0.233	I-10
54001000	5.579	5.750	0.171	I-10
54001000	9.205	9.386	0.181	I-10
54001000	11.406	11.566	0.160	I-10
54001000	16.995	17.171	0.176	I-10
54030000	6.199	6.369	0.170	S 19 Hwy
55050000	14.984	15.185	0.201	Thomasville Rd
55050000	15.280	15.577	0.297	Thomasville Rd
55050000	15.891	16.063	0.172	Thomasville Rd
55050000	16.783	16.885	0.102	Thomasville Rd
55050000	17.310	17.491	0.181	Thomasville Rd
55050000	17.714	17.948	0.234	Thomasville Rd
55050000	18.214	18.278	0.064	Thomasville Rd
55060000	0.000	0.151	0.151	W Tennessee Street
55060000	0.151	0.193	0.042	W Tennessee Street/Blue Star Hwy
55320000	10.407	10.478	0.071	I-10
55320000	11.870	11.941	0.071	I-10
55320000	13.662	16.375	2.713	I-10
57002000	2.531	2.710	0.179	I-10
57002000	3.613	3.870	0.257	I-10
57002000	5.977	6.273	0.296	I-10
57002000	8.727	9.373	0.646	I-10

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
57002000	9.512	9.983	0.471	I-10
57002000	10.309	10.701	0.392	I-10
57002000	11.541	11.897	0.356	I-10
57002000	12.154	12.475	0.321	I-10
57002000	13.759	13.934	0.175	I-10
57002000	16.467	16.796	0.329	I-10
57002000	18.746	19.055	0.309	I-10
57002000	22.165	22.390	0.225	I-10
57002000	23.292	23.402	0.110	I-10
57002000	23.547	23.667	0.120	I-10
57002000	24.505	24.554	0.049	I-10
57050000	3.355	3.438	0.083	Florida 85
57050000	3.438	3.493	0.055	Florida 85
57050000	13.305	13.328	0.023	Florida 85
57050000	13.328	13.435	0.107	Florida 85
57050000	13.435	13.465	0.030	Florida 85
57050000	13.465	13.491	0.026	Florida 85
57050000	13.564	13.589	0.025	Florida 85
58002000	2.611	2.964	0.353	I-10
58002000	5.078	5.222	0.144	I-10
58002000	9.309	9.494	0.185	I-10
58002000	10.533	11.260	0.727	I-10
58002000	14.635	14.797	0.162	I-10
58010000	0.151	0.204	0.053	Caroline St
58010000	0.204	0.220	0.016	Caroline St
58010000	1.783	2.030	0.247	Caroline St
58010000	2.030	2.044	0.014	Caroline St
60002000	0.000	0.124	0.124	I-10
60002000	0.319	0.664	0.345	I-10
60002000	2.387	2.567	0.180	I-10
60002000	3.213	3.392	0.179	I-10
60002000	3.923	4.089	0.166	I-10
60002000	6.720	6.990	0.270	I-10
60002000	7.817	8.051	0.234	I-10
60002000	17.472	17.682	0.210	I-10
60002000	23.409	23.619	0.210	I-10
60002000	23.806	24.062	0.256	I-10
60002000	25.147	25.305	0.158	I-10
60002000	25.653	25.797	0.144	I-10
60020000	17.486	17.660	0.174	I-10
61001000	0.687	0.902	0.215	I-10
61001000	1.117	1.293	0.176	I-10
61001000	1.603	1.795	0.192	I-10
61001000	12.906	12.983	0.077	I-10
61001000	14.804	14.930	0.126	I-10
61001000	16.750	16.946	0.196	I-10
70220000	0.000	12.000	12.000	I-95
70220000	12.000	12.415	0.415	I-95
70220000	12.415	12.476	0.061	I-95
70220000	12.476	12.570	0.094	I-95
70220000	12.570	13.073	0.503	I-95
70220000	13.073	13.576	0.503	I-95

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
70220000	13.576	15.458	1.882	I-95
70220000	15.458	15.596	0.138	I-95
70220000	15.596	16.582	0.986	I-95
70220000	34.462	34.771	0.309	I-95
70225000	3.178	3.396	0.218	I-95
72001000	0.733	20.259	19.526	I-295/Florida 9A
72002000	0.000	5.407	5.407	I-295/Florida 9A
72002000	13.125	14.776	1.651	I-295/Florida 9A
72002000	14.776	14.967	0.191	I-295/Florida 9A
72002000	14.967	15.686	0.719	I-295/Florida 9A
72002000	15.686	16.181	0.495	I-295/Florida 9A
72002000	16.181	17.305	1.124	I-295/Florida 9A
72002000	24.420	25.532	1.112	I-295/Florida 9A
72020000	9.467	10.567	1.100	I-95
72030000	8.730	9.234	0.504	Roosevelt Blvd
72030000	9.517	10.088	0.571	Roosevelt Blvd
72090000	6.447	6.873	0.426	Hart Bridge Expwy
72090000	8.389	8.567	0.178	Commodore Point Expwy
72090000	10.730	10.907	0.177	Commodore Point Expwy
72090445	0.210	0.593	0.383	Gator Bowl Blvd
72270000	17.102	17.777	0.675	I-10
72280000	0.000	5.024	5.024	I-95
72280000	5.461	5.502	0.041	I-95
72280000	5.502	6.260	0.758	I-95
72280000	6.260	7.261	1.001	I-95
72280000	7.261	7.772	0.511	I-95
72280000	7.772	10.494	2.722	I-95
72280000	10.878	12.476	1.598	I-95
72290000	2.190	3.597	1.407	I-95
72290000	3.597	3.743	0.146	I-95
72290000	3.743	3.876	0.133	I-95
72290000	3.876	4.443	0.567	I-95
72290000	4.443	4.667	0.224	I-95
72290000	4.667	6.324	1.657	I-95
72290000	6.324	6.449	0.125	I-95
72290000	6.449	10.342	3.893	I-95
72290000	10.342	10.513	0.171	I-95
73001000	0.000	1.458	1.458	I-95
73001000	1.625	2.330	0.705	I-95
73001000	2.475	2.507	0.032	I-95
73001000	2.507	9.421	6.914	I-95
73001000	9.421	9.722	0.301	I-95
73001000	9.722	18.689	8.967	I-95
73001000	18.689	18.729	0.040	I-95
74160000	0.000	0.719	0.719	I-95
74160000	0.719	0.833	0.114	I-95
74160000	0.833	8.101	7.268	I-95
74160000	8.101	8.185	0.084	I-95
74160000	8.185	8.328	0.143	I-95
74160000	9.097	11.725	2.628	I-95
74160000	11.725	12.226	0.501	I-95
75002000	9.816	14.757	4.941	Martin Andersen Beachline Expwy

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
75002000	14.757	14.781	0.024	Martin Andersen Beachline Expwy
75002000	15.391	15.635	0.244	Martin Andersen Beachline Expwy
75002000	15.635	16.974	1.339	Martin Andersen Beachline Expwy
75002000	16.974	17.705	0.731	Martin Andersen Beachline Expwy
75002000	17.705	19.348	1.643	Martin Andersen Beachline Expwy
75008000	11.884	12.998	1.114	Florida 408
75008160	2.352	2.726	0.374	Florida 408
75008170	1.417	2.455	1.038	Florida 408
75008170	2.664	2.903	0.239	Florida 408
75008170	3.078	3.543	0.465	Florida 408
75008170	3.903	4.953	1.050	Florida 408
75280000	0.000	0.799	0.799	I-4
75280000	0.799	2.027	1.228	I-4
75280000	2.027	2.548	0.521	I-4
75280000	2.548	8.316	5.768	I-4
75280000	8.316	8.585	0.269	I-4
75280000	10.346	11.764	1.418	I-4
75280000	11.764	11.813	0.049	I-4
75280000	11.813	12.018	0.205	I-4
75280000	12.018	12.174	0.156	I-4
75280000	12.174	12.307	0.133	I-4
75280000	12.307	12.696	0.389	I-4
75280000	12.696	12.727	0.031	I-4
75300000	8.127	9.435	1.308	Eastern Beltway
75300000	9.781	10.007	0.226	Eastern Beltway
75301000	0.868	1.408	0.540	Central Florida GreeneWay
75301000	1.523	1.688	0.165	Central Florida GreeneWay
75301000	2.018	2.328	0.310	Central Florida GreeneWay
75301000	2.908	3.073	0.165	Central Florida GreeneWay
75301000	3.503	3.683	0.180	Central Florida GreeneWay
75301000	4.868	5.033	0.165	Central Florida GreeneWay
75301000	5.178	5.333	0.155	Central Florida GreeneWay
75301000	5.828	6.018	0.190	Central Florida GreeneWay
75301000	6.308	6.483	0.175	Central Florida GreeneWay
75301000	6.838	6.998	0.160	Central Florida GreeneWay
75301000	7.223	7.383	0.160	Central Florida GreeneWay
75301000	8.398	8.553	0.155	Central Florida GreeneWay
75301000	8.978	9.488	0.510	Central Florida GreeneWay
75301000	9.758	9.913	0.155	Central Florida GreeneWay
75301000	10.628	10.960	0.332	Central Florida GreeneWay
75301000	15.378	15.553	0.175	Central Florida GreeneWay
75301000	16.423	16.608	0.185	Central Florida GreeneWay
75301000	16.843	17.003	0.160	Central Florida GreeneWay
75301000	17.763	17.923	0.160	Central Florida GreeneWay
75301000	19.213	19.680	0.467	Central Florida GreeneWay
75320000	33.784	34.480	0.696	Western Expwy
75470000	0.000	5.771	5.771	Turnpike
75470000	15.884	23.840	7.956	Turnpike
75470000	23.840	24.913	1.073	Turnpike
75471000	0.388	5.387	4.999	Martin Andersen Beachline Expwy
75471000	6.444	7.127	0.683	Martin Andersen Beachline Expwy
75471000	7.208	7.262	0.054	Martin Andersen Beachline Expwy

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
75471000	7.262	8.114	0.852	Martin Andersen Beachline Expwy
75471000	8.114	8.172	0.058	Martin Andersen Beachline Expwy
75473000	0.000	0.436	0.436	New Independence Pkwy
75473000	0.436	5.285	4.849	New Independence Pkwy
75473000	5.285	5.325	0.040	New Independence Pkwy
75474000	0.000	0.152	0.152	Florida 408
77010101	0.171	0.521	0.350	W Seminole Blvd
77160000	0.000	3.620	3.620	I-4
77160000	3.620	4.550	0.930	I-4
77160000	4.550	6.092	1.542	I-4
77160000	6.092	12.038	5.946	I-4
77160000	12.038	12.650	0.612	I-4
77160000	12.650	13.646	0.996	I-4
77160000	13.646	14.135	0.489	I-4
78080000	0.000	2.786	2.786	I-95
78080000	3.587	30.388	26.801	I-95
78080000	30.388	30.848	0.460	I-95
78080000	30.848	34.855	4.007	I-95
79002000	26.147	28.575	2.428	I-95
79002000	28.575	29.677	1.102	I-95
79002000	29.677	31.608	1.931	I-95
79002000	31.608	36.475	4.867	I-95
79002000	36.475	36.817	0.342	I-95
79002000	36.942	37.376	0.434	I-95
79002000	37.376	40.091	2.715	I-95
79002000	40.091	40.638	0.547	I-95
79002000	40.685	40.748	0.063	I-95
79002000	40.748	40.827	0.079	I-95
79002000	40.887	40.949	0.062	I-95
79002000	40.949	41.508	0.559	I-95
79002000	41.508	41.866	0.358	I-95
79002000	41.866	43.839	1.973	I-95
79002000	43.843	45.804	1.961	I-95
79040101	0.000	0.113	0.113	S Charles Richard Beall Blvd
79110000	1.032	3.080	2.048	I-4
79110000	3.080	3.657	0.577	I-4
79110000	3.657	4.606	0.949	I-4
79110000	4.606	4.720	0.114	I-4
79110000	4.720	4.993	0.273	I-4
79110000	5.351	5.605	0.254	I-4
79110000	5.978	9.648	3.670	I-4
79110000	9.648	15.463	5.815	I-4
79110000	16.305	17.954	1.649	I-4
79110000	18.766	20.425	1.659	I-4
79110000	21.243	24.491	3.248	I-4
79110000	25.215	27.272	2.057	I-4
86075000	6.268	12.345	6.077	I-75
86075000	12.345	17.478	5.133	I-75
86075000	17.478	18.059	0.581	I-75
86075000	18.059	19.408	1.349	I-75
86075000	19.408	19.590	0.182	I-75
86075000	43.015	44.982	1.967	I-75/Alligator Alley

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
86095000	0.000	9.953	9.953	I-595
86095000	9.953	10.251	0.298	I-595
86100000	7.388	7.621	0.233	US 441
86471000	0.000	7.706	7.706	Turnpike Homestead Extension
86472000	0.000	1.951	1.951	Florida 869/Sawgrass Expwy
86472000	1.951	2.469	0.518	Florida 869/Sawgrass Expwy
86472000	2.469	19.868	17.399	Florida 869/Sawgrass Expwy
87004000	2.737	3.835	1.098	Florida 112
87005000	0.000	0.457	0.457	Florida 874
87005000	1.572	1.694	0.122	Florida 874
87021000	0.365	0.462	0.097	Snapper Creek Expwy
87075000	0.632	0.707	0.075	I-75
87075000	0.707	1.419	0.712	I-75
87075000	1.419	1.921	0.502	I-75
87075000	2.425	2.557	0.132	I-75
87075000	3.431	3.578	0.147	I-75
87075000	4.429	4.552	0.123	I-75
87075000	4.745	5.442	0.697	I-75
87120000	5.924	6.060	0.136	US 41
87140000	11.883	12.044	0.161	US 441
87170000	0.174	0.373	0.199	Florida 91
87200000	1.968	2.112	0.144	Florida 836
87200000	5.144	5.470	0.326	Florida 836
87200000	7.994	8.094	0.100	Florida 836
87240000	13.310	13.412	0.102	Florida 9
87470000	0.000	0.176	0.176	Turnpike/Florida 91
87470000	0.176	0.340	0.164	Turnpike/Florida 92
87471000	0.538	0.688	0.150	Turnpike Homestead Extension
87471000	0.688	3.155	2.467	Turnpike Homestead Extension
87471000	9.228	10.584	1.356	Turnpike Homestead Extension
87471000	10.584	20.499	9.915	Turnpike Homestead Extension
87471000	20.957	21.234	0.277	Turnpike Homestead Extension
87471000	21.681	26.437	4.756	Turnpike Homestead Extension
87471000	33.435	33.945	0.510	Turnpike Homestead Extension
87471000	33.945	34.400	0.455	Turnpike Homestead Extension
87471000	34.400	35.620	1.220	Turnpike Homestead Extension
87471000	35.620	39.680	4.060	Turnpike Homestead Extension
87471000	39.680	40.150	0.470	Turnpike Homestead Extension
88010000	10.118	10.203	0.085	US 1
88081000	14.059	16.408	2.349	I-95
88470000	0.000	7.992	7.992	Turnpike/Florida 91
88470000	15.464	17.452	1.988	Turnpike/Florida 92
89095000	6.278	8.627	2.349	I-95
89095000	11.044	13.130	2.086	I-95
90020000	2.964	3.078	0.114	US 1
90060000	22.538	22.682	0.144	US 1
91470000	4.455	7.472	3.017	Turnpike/Florida 91
92070000	20.165	20.304	0.139	Florida 60
92070000	21.206	21.330	0.124	Florida 60
92090000	4.410	4.632	0.222	W Irlo Bronson Memorial Hwy
92130000	0.000	6.093	6.093	I-4
92130000	6.093	6.535	0.442	I-4

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
92130000	6.535	7.885	1.350	I-4
92470000	0.000	17.972	17.972	Florida 91
92471000	0.000	7.414	7.414	Florida 91
92471000	8.281	17.195	8.914	Florida 91
92471000	18.348	21.178	2.830	Florida 91
92471000	22.276	40.760	18.484	Florida 91
92473000	0.000	1.947	1.947	New Independence Pkwy
92473000	1.947	2.403	0.456	New Independence Pkwy
92473000	2.403	3.985	1.582	New Independence Pkwy
92473000	3.985	4.438	0.453	New Independence Pkwy
92473000	4.438	4.528	0.090	New Independence Pkwy
93220000	6.397	7.816	1.419	I-95
93310000	18.49	18.970	0.480	Bee Line Hwy
94001000	0.000	0.414	0.414	I-95
94001000	3.309	5.487	2.178	I-95
94001000	5.934	6.295	0.361	I-95
94001000	6.295	6.800	0.505	I-95
94001000	6.800	7.550	0.750	I-95
94001000	7.550	7.671	0.121	I-95
94001000	10.676	11.309	0.633	I-95
94001000	11.947	12.340	0.393	I-95
94001000	13.719	14.063	0.344	I-95
94001000	14.354	14.622	0.268	I-95
94001000	15.367	15.520	0.153	I-95
94001000	17.574	17.753	0.179	I-95
94001000	18.161	18.412	0.251	I-95
94001000	20.015	20.509	0.494	I-95
94001000	23.000	25.324	2.324	I-95
94005000	5.766	6.168	0.402	N 25th street
94120000	6.872	7.342	0.470	SE Port Saint Lucie Blvd
94470000	6.440	7.859	1.419	Florida 91
94470000	15.403	17.930	2.527	Florida 91
94470000	17.930	19.102	1.172	Florida 91
94470000	19.102	19.483	0.381	Florida 91
94470000	19.483	20.822	1.339	Florida 91
87060000	0.532	0.822	0.290	Florida A1A/MacArthur Causeway

Table A-2: Study Locations with Rub-rails on Limited Access Facilities in Florida

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
78080000	12.587	25.587	13.000	SR 9
11470000	1	13	12.000	SR 91
29180000	5.49	14.49	9.000	SR 93
92471000	8.281	17.195	8.914	SR 91
92471000	1	7.414	6.414	SR 91
11470000	15	21	6.000	SR 91
26260000	22.592	28.592	6.000	SR 93
70220000	6	12	6.000	SR 9
92470000	11	17	6.000	SR 91
26260000	6.174	12.174	6.000	SR 93
29180000	15.49	21.49	6.000	SR 93
18130000	8.416	14.07	5.654	SR 93
18130000	15.431	21.05	5.619	SR 93
77160000	6.092	11.092	5.000	SR 400
18130000	2.416	7.416	5.000	SR 93
92471000	22.276	27.276	5.000	SR 91
32100000	8.345	12.813	4.468	SR 93
74160000	3.833	8.101	4.268	SR 9
70220000	1	5	4.000	SR 9
92470000	6	10	4.000	SR 91
16470000	0.568	4.568	4.000	SR 570
78080000	3.587	7.587	4.000	SR 9
78080000	26.587	30.388	3.801	SR 9
29180000	1	4.614	3.614	SR 93
79110000	21.243	24.491	3.248	SR 400
32100000	13.235	16.235	3.000	SR 93
86472000	8.469	11.469	3.000	SR 869
72001000	1.733	4.733	3.000	SR 9A

Table A-3: Study Locations on Non-limited Access Facilities in Florida

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
09060000	31.000	32.000	1	SR 70
53070000	0.588	0.632	0.044	SR 2
57030000	17.444	17.458	0.014	SR 30
78070000	14.196	14.200	0.004	SR 13
90050000	1.200	1.300	0.1	SR 5
90050000	1.229	1.658	0.429	SR 5
90050000	1.600	1.700	0.1	SR 5
89070000	8.200	8.300	0.1	SR 710
89070000	8.400	8.500	0.1	SR 710
89070000	8.700	9.000	0.3	SR 710
89070000	10.000	10.093	0.093	SR 710
89070000	11.000	12.000	1	SR 710
89070000	12.100	12.400	0.3	SR 710
89070000	12.600	12.800	0.2	SR 710
89070000	13.405	13.666	0.261	SR 710
89070000	14.000	15.000	1	SR 710
89470000	0.100	0.500	0.4	SR 91
89470000	0.600	0.800	0.2	SR 91
89470000	1.000	3.900	2.9	SR 91
89470000	5.000	6.000	1	SR 91
89470000	6.100	7.000	0.9	SR 91
90030000	2.946	4.193	1.247	SR 5
93060000	1.188	1.233	0.045	SR A1A
93080000	3.919	3.965	0.046	SR A1A
93090000	8.162	8.181	0.019	SR 811
93090000	8.552	8.578	0.026	SR 811
93100000	2.300	2.400	0.1	SR 25
93100000	2.500	3.000	0.5	SR 25
93110000	0.593	2.000	1.407	SR 80
93130000	2.000	2.3	0.3	SR 15
93130000	2.400	2.6	0.2	SR 15
93130000	4.080	5.7	1.62	SR 15
93130000	5.800	7.8	2	SR 15
93130000	7.900	8	0.1	SR 15
93140000	6.193	6.214	0.021	SR 15
93140000	7.481	8.174	0.693	SR 15
93140000	8.756	8.797	0.041	SR 15
93140000	9.441	9.459	0.018	SR 15
93140000	10.363	10.78	0.417	SR 15
93140000	11.010	11.037	0.027	SR 15
93140000	11.050	11.063	0.013	SR 15
93140000	12.830	12.862	0.032	SR 15
93140000	12.880	13.645	0.765	SR 15
93140000	14.141	14.196	0.055	SR 15
93140000	15.586	15.738	0.152	SR 15

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
93140000	17.727	17.791	0.064	SR 15
93140000	17.804	17.895	0.091	SR 15
93140000	17.977	18.052	0.075	SR 15
93140000	18.062	18.132	0.07	SR 15
93140000	18.313	18.372	0.059	SR 15
93140000	18.38	18.412	0.032	SR 15
93160000	4.3	4.4	0.1	SR 25
93160000	15.5	15.6	0.1	SR 25
93160000	18.2	18.4	0.2	SR 25
93160000	20.3	20.4	0.1	SR 25
93160000	24.7	24.8	0.1	SR 25
93160000	25.3	25.576	0.276	SR 25
93180000	9.838	9.853	0.015	SR 802
93180000	10.152	10.182	0.03	SR 802
93200000	2.4	2.5	0.1	SR 804
93200000	2.9	3	0.1	SR 804
93210000	5.6	5.8	0.2	SR 7
93210000	6	7	1	SR 7
93210000	8	8.6	0.6	SR 7
93210000	8.7	9	0.3	SR 7
93210000	11	12	1	SR 7
93210000	12.4	12.7	0.3	SR 7
93210000	12.9	13.756	0.856	SR 7
93210000	14	14.1	0.1	SR 7
93210000	14.3	15	0.7	SR 7
93210000	15.1	15.2	0.1	SR 7
93210000	15.3	15.5	0.2	SR 7
93210000	15.6	16	0.4	SR 7
93210000	16.1	16.2	0.1	SR 7
93210000	16.4	16.6	0.2	SR 7
93210000	16.8	18	1.2	SR 7
93210000	19	19.7	0.7	SR 7
93210000	20.1	20.6	0.5	SR 7
93210000	20.8	21.2	0.4	SR 7
93210000	21.3	21.7	0.4	SR 7
93210000	21.8	22.2	0.4	SR 7
93210000	22.3	22.7	0.4	SR 7
93210000	22.8	23	0.2	SR 7
93210000	23.1	23.2	0.1	SR 7
93210000	23.3	23.4	0.1	SR 7
93210000	23.5	23.6	0.1	SR 7
93210000	23.7	23.9	0.2	SR 7
93280000	3.524	3.681	0.157	SR 704
93280000	3.73	3.808	0.078	SR 704
94004000	1.1	1.5	0.4	SR 614
94004000	1.6	1.9	0.3	SR 614

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
94005000	0.1	0.2	0.1	SR 615
94005000	0.3	0.4	0.1	SR 615
94005000	0.5	0.7	0.2	SR 615
94005000	0.8	1	0.2	SR 615
94005000	5.8	6	0.2	SR 615
94009000	0.4	0.5	0.1	SR 607
94009000	0.6	0.8	0.2	SR 607
94009000	0.9	1	0.1	SR 607
94009000	1.1	1.5	0.4	SR 607
94009000	1.6	1.7	0.1	SR 607
94009000	1.8	2.525	0.725	SR 607
94010000	0.1	0.3	0.2	SR 5
94010000	0.4	0.5	0.1	SR 5
94010000	0.6	0.8	0.2	SR 5
94010000	0.9	1	0.1	SR 5
94030000	4.4	5	0.6	SR 70
94030000	23	24	1	SR 70
90060000	33.952	34	0.048	SR 5
90060000	37	37.5	0.5	SR 5
90060000	37.8	38	0.2	SR 5
91050000	4.822	5	0.178	SR 15
91070000	5.2	5.4	0.2	SR 70
91070000	10.892	11	0.108	SR 70
91090000	0.2	1	0.8	SR 700
91470000	1	1.2	0.2	SR 91
91470000	1.4	1.8	0.4	SR 91
91470000	1.9	2	0.1	SR 91
91470000	4.455	7.472	3.017	SR 91
92010100	1	1.354	0.354	SR 600
92030000	29.128	29.161	0.033	SR 15
92030000	33.423	33.429	0.006	SR 15
92470000	0	3	3	SR 91
92470000	4	11	7	SR 91
92470000	12	17.972	5.972	SR 91
92471000	0	1	1	SR 91
92471000	2	4	2	SR 91
92471000	6	7.414	1.414	SR 91
92471000	8.281	10	1.719	SR 91
92471000	11	12	1	SR 91
92471000	12.1	12.4	0.3	SR 91
92471000	12.5	13.2	0.7	SR 91
92471000	13.3	14	0.7	SR 91
92471000	16	17	1	SR 91
92471000	18.348	20.4	2.052	SR 91
92471000	20.5	21.178	0.678	SR 91
92471000	22.276	24	1.724	SR 91

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
92471000	25	25.1	0.1	SR 91
92471000	25.2	26	0.8	SR 91
92471000	27.1	27.2	0.1	SR 91
92471000	27.3	27.7	0.4	SR 91
92471000	28.2	28.6	0.4	SR 91
92471000	28.7	30.907	2.207	SR 91
93010000	15.084	15.095	0.011	SR 5
93016000	1.92	1.989	0.069	SR 882
93016000	3.153	3.259	0.106	SR 882
93030000	2.04	2.065	0.025	SR 806
73010000	5.005	5.034	0.029	SR 5
73010000	9.281	9.297	0.016	SR 5
73010000	16.843	16.86	0.017	SR 5
73010000	20.877	20.893	0.016	SR 5
73040000	7.626	10.2	2.574	SR 20
73040000	10.3	10.5	0.2	SR 20
73040000	10.6	11	0.4	SR 20
73040000	17.138	17.147	0.009	SR 20
73050000	0.802	0.848	0.046	SR 11
73050000	7.194	7.218	0.024	SR 11
74040001	0	0.041	0.041	SR 200
74040001	0.415	0.511	0.096	SR 200
75002000	16	19.2	3.2	SR 482
75002000	20.5	20.6	0.1	SR 482
75020000	5.988	6	0.012	SR 500
75050000	8.858	9	0.142	SR 50
75060000	20.051	20.065	0.014	SR 50
75060000	28.873	28.994	0.121	SR 50
75140000	17.3	18.206	0.906	SR 520
76020000	7.3	7.6	0.3	SR 19
76110000	3.906	4	0.094	SR 100
77010000	13.9	14	0.1	SR 15
77010101	0	0.016	0.016	SR 15
77010101	0.113	0.211	0.098	SR 15
77030000	7.484	7.59	0.106	SR 46
77030000	7.644	7.787	0.143	SR 46
78040000	3	3.006	0.006	SR A1A
79010000	3.095	3.219	0.124	SR 5
79010000	6.123	6.136	0.013	SR 5
79010000	7.555	7.577	0.022	SR 5
79010000	8.24	8.258	0.018	SR 5
79010000	8.508	8.537	0.029	SR 5
79010000	16.977	17.443	0.466	SR 5
79010000	22.448	22.459	0.011	SR 5
79010000	22.469	22.519	0.05	SR 5
79010000	24.739	24.751	0.012	SR 5

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
79010000	26.621	26.649	0.028	SR 5
79070000	10.508	10.854	0.346	SR 44
79070000	28.804	28.948	0.144	SR 44
79070000	29.775	29.966	0.191	SR 44
79070000	29.978	30.088	0.11	SR 44
79070000	30.098	30.286	0.188	SR 44
79070000	30.296	30.397	0.101	SR 44
79120000	12.38	12.43	0.05	SR 415
79140000	3	3.22	0.22	SR 46
79140000	5	5.167	0.167	SR 46
79150000	0.949	0.955	0.006	SR 40
79180000	0.292	0.302	0.01	SR A1A
79180000	0.306	0.497	0.191	SR A1A
79180000	0.516	0.534	0.018	SR A1A
79181000	0.516	0.555	0.039	SR 472
79181000	3.32	3.358	0.038	SR 472
79181000	3.382	3.483	0.101	SR 472
79190000	4	4.2	0.2	SR 5A
79190000	4.3	5	0.7	SR 5A
79190006	0	0.67	0.67	SR 5A
79270000	1.87	1.98	0.11	SR 483
79270000	2.194	2.263	0.069	SR 483
86006000	5.038	5.086	0.048	SR 842
86006000	5.336	5.384	0.048	SR 842
86012000	1.474	1.609	0.135	SR 869
86012000	1.67	1.696	0.026	SR 869
86012000	2.081	2.152	0.071	SR 869
86015000	2.454	2.965	0.511	SR 818
86015000	2.987	3.263	0.276	SR 818
86015000	3.287	3.383	0.096	SR 818
86015000	3.419	3.454	0.035	SR 818
86015000	3.984	4.671	0.687	SR 818
86015000	4.861	4.983	0.122	SR 818
86015000	4.994	5.033	0.039	SR 818
86015000	5.086	5.25	0.164	SR 818
86015000	5.259	6.001	0.742	SR 818
86015000	6.015	6.048	0.033	SR 818
86028000	3.596	3.602	0.006	SR 834
86060000	7.464	7.602	0.138	SR 25
86060000	14.289	14.321	0.032	SR 25
86060000	15.407	15.44	0.033	SR 25
86060000	15.462	17.202	1.74	SR 25
86060000	17.224	19.056	1.832	SR 25
86060000	19.079	19.302	0.223	SR 25
86060000	27.666	27.678	0.012	SR 25
86080550	7.041	7.168	0.127	SR 84

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
86080550	8.357	8.408	0.051	SR 84
86100000	20.713	20.749	0.036	SR 7
86100000	21	21.055	0.055	SR 7
86110000	2.915	2.953	0.038	SR 838
86120000	7.67	7.731	0.061	SR 810
86190000	3.246	3.322	0.076	SR 823
86190000	3.343	3.499	0.156	SR 823
86190000	3.528	4.004	0.476	SR 823
86190000	4.035	4.501	0.466	SR 823
86190000	4.524	4.745	0.221	SR 823
86190000	4.758	4.867	0.109	SR 823
86190000	4.881	4.986	0.105	SR 823
86190000	5.763	6.021	0.258	SR 823
86190000	7.014	7.1	0.086	SR 823
86190000	7.421	7.443	0.022	SR 823
86190000	8.171	8.471	0.3	SR 823
86190000	8.571	8.971	0.4	SR 823
86190000	9.171	9.471	0.3	SR 823
86190000	9.771	9.871	0.1	SR 823
86190000	10.69	10.822	0.132	SR 823
86220000	0.3	0.416	0.116	SR 817
86220000	2.667	2.767	0.1	SR 817
86220000	2.934	3.034	0.1	SR 817
86220000	3.134	3.234	0.1	SR 817
86220000	3.167	3.267	0.1	SR 817
86220000	3.367	3.467	0.1	SR 817
86220000	3.767	3.867	0.1	SR 817
86220000	4.234	4.334	0.1	SR 817
86220000	4.267	4.367	0.1	SR 817
86220000	4.434	4.534	0.1	SR 817
86220000	20.795	20.807	0.012	SR 817
86230000	2.388	2.4	0.012	SR 822
86230000	2.536	2.629	0.093	SR 822
87001000	0	0.23	0.23	SR 94
87002000	1	1.2	0.2	SR 823
87002000	1.3	1.5	0.2	SR 823
87002000	1.6	1.7	0.1	SR 823
87002000	1.8	1.9	0.1	SR 823
87002000	2	2.2	0.2	SR 823
87002000	2.3	2.5	0.2	SR 823
87002000	2.6	2.8	0.2	SR 823
87002000	3.1	3.2	0.1	SR 823
87002000	3.3	3.5	0.2	SR 823
87002000	3.6	3.7	0.1	SR 823
87002000	3.8	3.814	0.014	SR 823
87002000	5.1	5.4	0.3	SR 823

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
87002000	7	7.1	0.1	SR 823
87002000	7.3	7.4	0.1	SR 823
87008000	2.045	3	0.955	SR 916
87010000	2.1	2.4	0.3	SR 5
87010000	8.3	8.7	0.4	SR 5
87012000	1.5	1.6	0.1	SR 847
87012000	1.7	1.9	0.2	SR 847
87012000	2	2.144	0.144	SR 847
87026000	7.3	7.4	0.1	SR 860
87039000	0.2	0.6	0.4	SR 992
87044000	6.924	7	0.076	SR 976
87080000	0.933	1	0.067	SR 934
87110000	19	20.2	1.2	SR 90
87110000	20.3	20.7	0.4	SR 90
87110000	20.8	21	0.2	SR 90
87110000	24	24.6	0.6	SR 90
87110000	24.7	25.489	0.789	SR 90
87120000	0	4	4	SR 90
87120000	4.1	4.3	0.2	SR 90
87120000	4.6	4.9	0.3	SR 90
87120000	6.1	6.8	0.7	SR 90
87120000	7.1	7.4	0.3	SR 90
87120000	7.6	7.9	0.3	SR 90
87120000	8.7	8.9	0.2	SR 90
87150000	15	15.4	0.4	SR 997
87150000	15.5	16	0.5	SR 997
87150000	16.1	16.2	0.1	SR 997
87150000	17.5	18	0.5	SR 997
87150000	19	20	1	SR 997
87150000	22	22.253	0.253	SR 997
87240000	13.412	13.69	0.278	SR 9
87471000	36.183	38.763	2.58	SR 821
88003000	0	0.716	0.716	SR 656
88060000	31.172	31.181	0.009	SR 60
88060000	31.787	31.9	0.113	SR 60
88470000	1.1	5.1	4	SR 91
88470000	5.2	6.3	1.1	SR 91
88470000	6.4	7	0.6	SR 91
88470000	16.1	16.3	0.2	SR 91
88470000	16.4	17	0.6	SR 91
89060000	11.358	11.4	0.042	SR 76
89060000	11.5	12	0.5	SR 76
89060000	14	15.7	1.7	SR 76
89070000	0.1	0.4	0.3	SR 710
89070000	0.5	1.9	1.4	SR 710
89070000	3	4.7	1.7	SR 710

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
89070000	4.8	5	0.2	SR 710
89070000	5.1	5.5	0.4	SR 710
89070000	5.6	6.1	0.5	SR 710
89070000	6.2	6.5	0.3	SR 710
89070000	6.8	7	0.2	SR 710
89070000	7.3	7.4	0.1	SR 710
89070000	7.5	7.7	0.2	SR 710
89070000	7.8	8.1	0.3	SR 710
46030000	0.186	0.33	0.144	SR 30
48004000	6.517	6.542	0.025	SR 295
48020000	22.4	22.5	0.1	SR 10A
48020000	22.6	22.7	0.1	SR 10A
48020000	23	23.1	0.1	SR 10A
50140000	2.387	2.417	0.03	SR 267
51010000	3.036	3.128	0.092	SR 30
51010000	3.919	3.922	0.003	SR 30
51020000	6.774	6.779	0.005	SR 71
51030000	5.419	5.442	0.023	SR 22
51502000	10.109	10.12	0.011	SR 30A
52010000	6.184	6.243	0.059	SR 10
52010000	6.583	6.617	0.034	SR 10
52010000	7.199	7.286	0.087	SR 10
52010000	7.313	7.417	0.104	SR 10
52010000	8.353	8.384	0.031	SR 10
52010000	8.409	8.459	0.05	SR 10
52010000	8.968	9	0.032	SR 10
52010000	13.149	13.18	0.031	SR 10
52010000	13.297	13.465	0.168	SR 10
52010000	13.583	13.769	0.186	SR 10
52010000	13.907	14.031	0.124	SR 10
52010000	22.376	22.398	0.022	SR 10
52010000	22.807	22.822	0.015	SR 10
52010000	27.353	27.386	0.033	SR 10
52030000	0	0.041	0.041	SR 79
52030000	5.336	5.396	0.06	SR 79
52030000	6.045	6.087	0.042	SR 79
52030000	9.444	9.457	0.013	SR 79
52030000	15.756	15.788	0.032	SR 79
52030000	15.89	15.919	0.029	SR 79
52040000	1.179	1.193	0.014	SR 2
52040000	6.098	6.286	0.188	SR 2
52040000	6.353	6.437	0.084	SR 2
52040000	7.286	7.305	0.019	SR 2
52040000	14.251	14.271	0.02	SR 2
53020000	22.61	22.638	0.028	SR 10
53020000	23.239	23.313	0.074	SR 10

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
53030035	1.46	1.499	0.039	SR 75
53050000	4.425	4.464	0.039	SR 73
53050000	5.279	5.308	0.029	SR 73
53050000	17.402	17.496	0.094	SR 73
53050000	17.52	17.554	0.034	SR 73
53060000	0.258	0.271	0.013	SR 2
53060000	0.346	0.475	0.129	SR 2
53070000	1.856	1.885	0.029	SR 2
53070000	2.756	2.788	0.032	SR 2
53070000	3.104	3.123	0.019	SR 2
53070000	3.39	3.457	0.067	SR 2
53070000	3.639	3.7	0.061	SR 2
53070000	4.691	4.746	0.055	SR 2
53070000	5.836	5.967	0.131	SR 2
53070000	6.468	6.604	0.136	SR 2
53070000	7.011	7.067	0.056	SR 2
53070000	7.317	7.387	0.07	SR 2
53120000	17.449	17.458	0.009	SR 73
53130000	11.231	11.27	0.039	SR 69
54030000	6.319	6.4	0.081	SR 57
54060000	0.964	1.205	0.241	SR 59
54060000	1.349	1.446	0.097	SR 59
54060000	2.005	2.032	0.027	SR 59
54060000	2.15	2.174	0.024	SR 59
54060000	3.148	3.173	0.025	SR 59
55020000	0.598	0.667	0.069	SR 10
55020000	15.532	15.571	0.039	SR 10
55020000	15.583	15.635	0.052	SR 10
55070000	6.812	6.889	0.077	SR 20
55080000	0.095	0.116	0.021	SR 20
55080000	0.156	0.196	0.04	SR 20
55080000	0.276	0.303	0.027	SR 20
55080000	0.503	0.574	0.071	SR 20
55080000	0.606	0.806	0.2	SR 20
55080000	1.789	1.87	0.081	SR 20
55080000	2.603	2.665	0.062	SR 20
55080000	8.616	8.711	0.095	SR 20
55080000	10.837	10.975	0.138	SR 20
55080000	11.059	11.073	0.014	SR 20
55300000	2.59	2.635	0.045	SR 267
56010000	0.4	0.747	0.347	SR 20
56010002	0.28	0.292	0.012	SR 20
56040000	21.471	21.505	0.034	SR 65
56040000	25.538	25.574	0.036	SR 65
57010000	11.881	11.884	0.003	SR 10
57010000	13.066	13.127	0.061	SR 10

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
57030000	0.913	0.947	0.034	SR 30
57030000	5.556	5.581	0.025	SR 30
57030000	6.028	6.055	0.027	SR 30
57030000	6.843	6.875	0.032	SR 30
57030000	16.774	16.831	0.057	SR 30
57040000	15.959	16	0.041	SR 20
57050000	13.344	13.367	0.023	SR 85
57050000	13.439	13.477	0.038	SR 85
57080000	0.033	0.091	0.058	SR 4
57080000	0.42	0.477	0.057	SR 4
57080000	3.812	4.027	0.215	SR 4
57080000	7.52	7.589	0.069	SR 4
58040000	2.705	2.716	0.011	SR 87
58040000	2.724	2.74	0.016	SR 87
58040000	2.833	2.841	0.008	SR 87
58050000	6.429	6.445	0.016	SR 87
58050000	6.462	6.493	0.031	SR 87
58050000	15.417	15.5	0.083	SR 87
58050000	16.859	16.916	0.057	SR 87
58050000	19.26	19.325	0.065	SR 87
58140000	0.557	0.601	0.044	SR 399
58170000	4.365	4.55	0.185	SR 281
58170000	10.266	10.319	0.053	SR 281
59010000	0.006	0.025	0.019	SR 30
59030000	0.819	0.852	0.033	SR 375
59030000	2.263	2.28	0.017	SR 375
59030000	3.762	3.796	0.034	SR 375
60040000	7.215	7.276	0.061	SR 83
60050000	7.07	7.14	0.07	SR 83
60050000	10.12	10.193	0.073	SR 83
60050000	11.062	11.249	0.187	SR 83
60050000	12.037	12.12	0.083	SR 83
60050000	13.012	13.063	0.051	SR 83
60080000	1.248	1.266	0.018	SR 85
60100000	5.743	5.756	0.013	SR 81
60100000	8.456	8.648	0.192	SR 81
61040000	0.06	0.084	0.024	SR 79
61040000	11.767	11.849	0.082	SR 79
61040000	12.94	12.948	0.008	SR 79
61040000	13.232	13.276	0.044	SR 79
61040000	15.698	15.798	0.1	SR 79
61040000	23.29	23.345	0.055	SR 79
61060000	6.131	6.155	0.024	SR 277
61060000	6.246	6.317	0.071	SR 277
61060000	11.988	12.104	0.116	SR 277
61060000	12.167	12.198	0.031	SR 277

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
61080000	0.654	0.784	0.13	SR 77
61080000	16.473	16.564	0.091	SR 77
61080000	17.642	17.661	0.019	SR 77
61121000	0.178	0.233	0.055	SR 20
70001000	3.878	4	0.122	SR 405
70004000	0.983	1	0.017	SR 404
70004000	2.4	2.6	0.2	SR 404
70004000	2.9	3	0.1	SR 404
70010000	2	3	1	SR 5
70020000	12.2	12.4	0.2	SR 5
70020000	12.7	13	0.3	SR 5
70020000	14	14.8	0.8	SR 5
70020000	14.9	15	0.1	SR 5
70080000	4.683	4.77	0.087	SR 401
70100000	0.066	2.883	2.817	SR 520
70100000	3	4	1	SR 520
70100000	14	14.106	0.106	SR 520
70110000	0.035	3.3	3.265	SR 50
70110000	3.4	4.1	0.7	SR 50
70140000	8.522	9	0.478	SR 3
72120201	0	0.028	0.028	SR 228
72150000	5	5.023	0.023	SR 115
09060000	36	36.334	0.334	SR 70
10010000	22.8	22.9	0.1	SR 41
10030101	1.445	1.462	0.017	SR 39
10060000	5	5.34	0.34	SR 45
10140000	2	2.3	0.3	SR 60
10140000	2.292	2.423	0.131	SR 60
10140000	2.5	5	2.5	SR 60
10140000	5.2	5.3	0.1	SR 60
10140000	5.225	5.743	0.518	SR 60
11010000	11.522	11.622	0.1	SR 19
11010000	11.722	11.822	0.1	SR 19
11010000	11.869	12	0.131	SR 19
11010000	12.022	12.222	0.2	SR 19
11020000	11	11.2	0.2	SR 33
11060000	14.227	14.318	0.091	SR 19
11130000	11.523	11.611	0.088	SR 46
11470000	0.3	0.4	0.1	SR 91
11470000	0.6	0.7	0.1	SR 91
11470000	1	1.2	0.2	SR 91
11470000	1.4	1.6	0.2	SR 91
11470000	1.7	14	12.3	SR 91
11470000	14.4	14.8	0.4	SR 91
11470000	15	15.6	0.6	SR 91
11470000	16	23.876	7.876	SR 91

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
14090000	1	1.048	0.048	SR 54
15040000	6.39	9.443	3.053	SR 60
15150000	32	32.1	0.1	SR 55
15200000	9.17	9.391	0.221	SR 679
15220000	0.664	1	0.336	SR 60
16100000	5.561	5.731	0.17	SR 546
16118000	2.5	3.395	0.895	SR 540
16130000	21.157	21.346	0.189	SR 60
16130000	21.3	21.4	0.1	SR 60
16130000	21.9	24	2.1	SR 60
16130000	22.312	23.112	0.8	SR 60
16130000	23.212	23.712	0.5	SR 60
16130000	23.912	23.965	0.053	SR 60
16130000	24	24.1	0.1	SR 60
16130000	24.2	24.4	0.2	SR 60
17070000	13	13.1	0.1	SR 72
17070000	13.2	13.3	0.1	SR 72
17070000	13.7	13.8	0.1	SR 72
17070000	20.2	20.5	0.3	SR 72
17070000	20.6	20.7	0.1	SR 72
18470000	0.1	0.9	0.8	SR 91
18470000	1.1	2.1	1	SR 91
18470000	2	3.1	1.1	SR 91
18470000	3	4.1	1.1	SR 91
18470000	4	5	1	SR 91
18470000	4.2	5	0.8	SR 91
18470000	5	6.1	1.1	SR 91
18470000	6.1	6.4	0.3	SR 91
18470000	6.9	7.6	0.7	SR 91
18470000	7.9	8.1	0.2	SR 91
18470000	8	9	1	SR 91
18470000	8.3	10	1.7	SR 91
26004000	0	0.924	0.924	SR 24A
01050000	4.484	5	0.516	SR 776
01050000	16.883	16.9	0.017	SR 776
02010000	30	30.007	0.007	SR 44
35020000	8	8.138	0.138	SR 6
35060000	19.813	20.222	0.409	SR 53
36008000	0.832	0.914	0.082	SR 492
37040000	0.992	1	0.008	SR 51
03010000	18	19	1	SR 45
03010000	19.883	20	0.117	SR 45
03010000	20.508	23.14	2.632	SR 45
03010000	21.145	23.145	2	SR 45
03010000	23.14	24.052	0.912	SR 45
03010000	24	25	1	SR 45

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
03010000	24.152	24.252	0.1	SR 45
03010000	24.352	24.552	0.2	SR 45
03010000	24.477	24.994	0.517	SR 45
03010000	25.052	25.252	0.2	SR 45
03010000	25.306	26.206	0.9	SR 45
03010000	25.652	34	8.348	SR 45
03010000	34.469	37	2.531	SR 45
03010000	38	40	2	SR 45
03010000	40.1	40.4	0.3	SR 45
03010000	40.5	41.1	0.6	SR 45
03010000	41.2	41.4	0.2	SR 45
03010000	41.5	42.1	0.6	SR 45
03010000	42	43	1	SR 45
03010000	42.4	43.3	0.9	SR 45
03010000	43.4	43.5	0.1	SR 45
03010000	43.7	44.151	0.451	SR 45
03030000	4	5	1	SR 951
03040000	0	3.4	3.4	SR 90
03040000	3.5	3.9	0.4	SR 90
03040000	4	4.1	0.1	SR 90
03040000	4	5	1	SR 90
03040000	4.5	6	1.5	SR 90
03040000	6.1	6.6	0.5	SR 90
03040000	6.7	8.8	2.1	SR 90
03040000	8.9	13	4.1	SR 90
03040000	12	16.1	4.1	SR 90
03040000	16.2	16.9	0.7	SR 90
03040000	17.1	21.1	4	SR 90
03040000	21	22	1	SR 90
03040000	21.3	21.4	0.1	SR 90
03040000	22	22.1	0.1	SR 90
03040000	22	23	1	SR 90
03040000	22.7	23.6	0.9	SR 90
03040000	23.7	24.6	0.9	SR 90
37070000	0	1	1	SR 49
39020000	0.029	0.15	0.121	SR 121
03040000	24.7	26.3	1.6	SR 90
03040000	26.4	27.1	0.7	SR 90
03040000	27	28	1	SR 90
03040000	27.3	27.5	0.2	SR 90
03040000	27.8	27.9	0.1	SR 90
03040000	28	28.1	0.1	SR 90
03040000	28	29	1	SR 90
03040000	28.2	32.308	4.108	SR 90
03050000	0	1	1	SR 82
03080000	2	3	1	SR 29

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
03080000	5	6	1	SR 29
03080000	9	10	1	SR 29
03080000	16	16.509	0.509	SR 29
03080000	17.44	18	0.56	SR 29
03080000	19	23	4	SR 29
03080000	23	24	1	SR 29
03080000	23.3	24.8	1.5	SR 29
03080000	24.9	25.8	0.9	SR 29
03080000	25.9	26.4	0.5	SR 29
03080000	26.5	27.2	0.7	SR 29
03080000	27.3	27.9	0.6	SR 29
03080000	28	28.7	0.7	SR 29
03080000	28.8	30.7	1.9	SR 29
03080000	30.8	31	0.2	SR 29
03080000	33	34	1	SR 29
03080000	35	36	1	SR 29
05010000	11.4	12	0.6	SR 25
05010000	14.4	16	1.6	SR 25
05020000	0.371	3	2.629	SR 78
05020000	3.615	5.6	1.985	SR 78
05020000	11.171	12.212	1.041	SR 78
05020000	14.4	14.5	0.1	SR 78
05020000	15.166	19	3.834	SR 78
05020000	20	28.843	8.843	SR 78
05020000	28.158	29.03	0.872	SR 78
06030000	1	1.3	0.3	SR 64
07010000	26	27	1	SR 29
07010000	28	30	2	SR 29
07010000	31	31.716	0.716	SR 29
07030000	4.741	6.92	2.179	SR 25
07030000	7.02	7.62	0.6	SR 25
07030000	7.72	8.12	0.4	SR 25
07030000	8.22	8.52	0.3	SR 25
07030000	8.62	8.72	0.1	SR 25
07030000	8.92	9.12	0.2	SR 25
07030000	9.22	10.12	0.9	SR 25
07030000	10.22	11.12	0.9	SR 25
07030000	11.22	13	1.78	SR 25
07060000	13	14.996	1.996	SR 29
08040000	9.633	9.713	0.080	SR 50
09010000	15.300	15.400	0.100	SR 25
09060000	17.000	17.200	0.200	SR 70
09060000	17.300	17.400	0.100	SR 70
09060000	17.500	18.000	0.500	SR 70
09060000	18.000	19.700	1.700	SR 70
09060000	19.800	21.500	1.700	SR 70

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name
09060000	21.600	21.800	0.200	SR 70
09060000	21.900	22.200	0.300	SR 70
09060000	22.400	25.200	2.800	SR 70
09060000	25.600	26.300	0.700	SR 70
09060000	26.400	26.700	0.300	SR 70
09060000	26.800	27.100	0.300	SR 70
09060000	27.000	28.000	1.000	SR 70
09060000	27.600	27.900	0.300	SR 70
09060000	28.100	28.300	0.200	SR 70
09060000	28.400	29.000	0.600	SR 70
09060000	29.400	30.000	0.600	SR 70
09060000	30.200	30.400	0.200	SR 70
09060000	30.500	30.900	0.400	SR 70
94060000	1.948	2.000	0.052	SR A1A
94120000	6.871	7.000	0.129	SR 716
94470000	20.447	34.959	14.512	SR 91