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

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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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				

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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 presents a study to evaluate the safety performance of cable median barriers on limited access facilities in Florida. A companion report (i.e., Volume I) focuses on the performance of the G4 (1S) type of strong-post W-beam guardrails in Florida. In this study, the performance of cable median barriers was evaluated based mainly on two types of analysis: (1) the percentages of barrier and median crossovers by site location, vehicle type, crash severity, and cable median barrier type; and (2) comparisons of median-related crash statistics before and after cable median barrier installations by crash severity and vehicle type.

Twenty-three locations with cable median barriers totaling about 101 miles were identified. Police reports of 8,818 crashes from years 2003-2010 at these locations were reviewed to verify and obtain detailed crash information. A total of 549 crashes were determined to be barrier crashes (i.e., involving vehicles hitting a barrier) and were reviewed in further detail to identify crossover crashes and the manner in which the vehicles crossed the barriers, i.e., either by over-riding, under-riding, or penetrating the barriers. Of the 549 barrier crashes, 16.4% (90) were found to have crossed over the barriers, and 83.6% were either contained or redirected by the barriers. Of the 90 crashes that involved vehicles crossing the barrier, 14 crashes resulted in vehicles crossing the median into the opposite travel lane. Overall, 98.1% of cars and 95.5% of light trucks that hit the barrier were prevented from crossing the median.

The before-and-after analysis was based on only median-related crashes (i.e., involving vehicles leaving the travel lane toward the median) to more precisely evaluate the impacts of cable median barrier installation and ensure that the results are not affected by other unrelated crashes. The analysis included 744 median-related crashes at three locations totaling 36 miles. The results show that cable median barrier installation reduced fatal crash rate by 42.2%, severe injury crash rate by 20.1%, and minor injury crash rate by 11.6%, but increased the crash rates involving possible injury and property damage by 53.1% and 88.1%, respectively, for an overall crash rate increase of 37.8%.

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EXECUTIVE SUMMARY

This study performed a safety performance evaluation of cable median barriers on limited access facilities in Florida using the following two types of analysis:

1. Percentages of barrier and median crossovers by site location, vehicle type, crash severity, and cable barrier type.
2. Comparisons of median-related crash statistics before and after cable median barrier installations by crash severity and vehicle type.

A total of 23 locations totaling about 101 miles with cable median barriers were identified. The construction periods for cable median barrier installation at the 23 locations were obtained from the district offices. In the years 2003-2010, a total of 8,818 crashes occurred at these locations. Police reports of these 8,818 crashes were downloaded and reviewed in detail. For before-and-after analysis, the review focused on identifying median-related crashes. A crash where an errant vehicle leaves the designated travel lane to the left (i.e., toward the median) at any point during the crash is classified as a median-related crash.

For crossover analysis, the review focused on identifying crossover crashes and the performance of the vehicle after hitting the cable median barrier. A crash in which an errant vehicle crosses the cable median barrier at any point during the crash is categorized as a barrier crossover crash. If the errant vehicle reaches the opposite travel lane after crossing the barrier, it becomes a median crossover crash. A barrier can be crossed over by under-riding, over-riding, or penetrating the cable median barrier. A crash is categorized as non-crossover when an errant vehicle does not cross over the cable median barrier at any point during the crash. A non-crossover crash can be classified as either redirected or contained by the cable barrier system.

Crossover Analysis

The 23 study locations experienced a total of 549 cable barrier related crashes, i.e., crashes in which the errant vehicles hit the cable median barrier at any point during the crash. Of the 549 crashes that hit the cable median barrier, 90 were barrier crossover crashes and 459 were non-crossover. The overall effective rate of installing cable median barrier in preventing barrier crossover crashes is high at 83.6%. Of the 549 crashes that involved errant vehicles hitting the cable median barrier, 14 (i.e., 2.6%) resulted in vehicle traversing into the opposite travel lane. A relatively high 98.1% of cars that hit the cable median barrier were prevented from traversing into the opposite travel lane. Likewise, 95.5% of light trucks were prevented from crossing over the median.

The 23 study locations were installed with one of the four types of cable barrier systems: Brifen, CASS, Safence, or Gibraltar systems. The performance of CASS and Gibraltar systems were compared. The Gibraltar system experienced greater proportion of penetrations compared to the CASS system. Further, the barrier crossover percentages for cars and light trucks were very similar for the two systems.

Of all the crashes that hit the cable median barrier, 5.8% were either fatal or incapacitating injury crashes; 29.1% resulted in moderate or minor injury; 58.7% were property damage only (PDO) crashes and the rest (6.4%) were of unknown severity. The CASS and Gibraltar systems performed very similarly in terms of severe injury crashes; however, the CASS system resulted in a slightly higher percentage of moderate and minor injury crashes compared to the Gibraltar system.

In summary, cable median barriers are successful in preventing median crossover crashes; a relatively high 97.4% of the cable median barrier crashes were prevented from crossing over the median. Of all the vehicles that hit the barrier, 83.6% were either redirected or contained by the cable barrier system.

Before-and-After Analysis

A before-and-after safety evaluation of cable median barriers was conducted based on median-related crashes on the following three locations (a total of approximately 36 miles): Florida Turnpike, SR 528, and I-4. The analysis focused on evaluating the change in crash rate of median-related crashes, median crossovers, and site-specific evaluation by crash severity and vehicle type. Crash Modification Factors (CMFs) and Crash Reduction Factors (CRFs) were also developed.

After the installation of cable median barriers, the overall median-related crash rate was increased by 37.8%; overall median crossover rate was decreased by 78.8%. SR 821 experienced the highest reduction of 88.8% in median crossover rate even though it experienced an increase of 26.6% in median-related crash rate. Similarly, a 69.5% reduction in median crossover rate was observed on I-4 while the median-related crash rate increased by 47.6%. Unlike these two locations, SR 528 experienced an 85.0% reduction in median crossover rate and a 3.5% reduction in median-related crash rate.

The installation of cable median barriers resulted in an increase in the PDO crash rate (88.1%) and possible injury crash rate (53.1%). This is expected as more vehicles hit the cable median barrier due to reduction in the effective clear-recovery width in the median. Reductions of 42.2%, 20.1%, and 11.6% were observed in fatal, incapacitating, and non-incapacitating crash rates, respectively. The overall fatal and severe injury (K+A) crash rate was reduced by 26.6%.

The highest reduction in K+A crash rate was experienced by motorcycles at 73.3%, followed by light trucks at 35.6%, and cars at 10.8%. Small sample sizes of medium and heavy trucks made it difficult to reach reliable conclusions. At each of the three locations, crash rate of light trucks increased in the after period. Crash rates of cars increased at two of the three locations, and stayed the same on SR 528.

Finally, CRFs and CMFs were calculated to estimate the expected reduction in median-related crash rate after installing cable median barriers. The results show that cable median barrier installation reduced fatal crash rate by 42.2%, severe injury crash rate by 20.1%, and minor injury crash rate by 11.6%, but increased the crash rates involving possible injury and property damage by 53.1% and 88.1%, respectively, for an overall crash rate increase of 37.8%.

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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
ADT	Average Daily Traffic
BCT	Breakaway Cable Terminal
CAR	Crash Analysis Reporting
CASS	Cable Safety System
CMB	Concrete Median Barrier
CMC	Cross-Median Crash
CME	Cross-Median Event
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
DOT	Department of Transportation
EPDO	Equivalent Property Damage Only
F+I	Fatal and Injury
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
GSBID	GIS-Based Statewide Barrier Inventory Database
IDOT	Illinois Department of Transportation
ISPE	In-Service Performance Evaluation
K+A	Fatal and Incapacitating Injury
MASH	Manual for Assessing Safety Hardware
MELT	Modified Eccentric Loader Terminal
MP	Mile Post
MVM	Million Vehicle Miles
NCHRP	National Cooperative Highway Research Program
PDO	Property Damage Only
RCI	Roadway Characteristics Inventory
TxDOT	Texas Department of Transportation
WRSF	Wire Rope Safety Fence
WSDOT	Washington State Department of Transportation

CHAPTER 1
INTRODUCTION

The primary purpose of cable median barrier is to prevent errant vehicles which leave the travel lane from striking a roadside obstacle (hazard), traversing non-recoverable terrain, or colliding with traffic from the opposite direction. Alberson et al. (2007) has identified the following six cable barrier systems as currently being installed in the United States:

1. U.S Low Tension
2. Brifen USA Wire Rope Safety Fence (WRSF)
3. Blue Systems Safence 350 Wire Rope Barrier
4. Nucor High Tension Cable Barrier
5. Trinity Industries Cable Safety System (CASS)
6. Gibraltar Cable Barrier System

Brifen and Safence have four cables/strands while the other high-tension cable systems (i.e., Nucor, CASS, and Gibraltar) have three cables. Figure 1-1 shows all the five types of high-tension pre-stretched cable barrier systems being used by the Florida Department of Transportation (FDOT).

The main objective of this project is to evaluate the safety performance of cable median barrier systems installed on limited access facilities (i.e., freeways and expressways) in Florida. This safety performance evaluation was conducted using the following two types of analysis:

1. Percentages of barrier and median crossovers by site location, vehicle type, crash severity, and cable barrier type.
2. Comparisons of median-related crash statistics before and after cable median barrier installations by crash severity and vehicle type.

In the crossover analysis, the performance of cable median barrier is measured by the percentages of errant vehicles prevented from: (1) crossing the barrier, i.e., barrier crossover; and (2) crossing the median, i.e., median crossover. A crash in which an errant vehicle crosses the cable median barrier at any point during the crash is categorized as a barrier crossover crash. If after crossing the barrier the errant vehicle clears the median and onto the opposite travel lanes, it becomes a median crossover crash.

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

- An under-ride crossover crash is classified as a crash which involves an errant vehicle crossing the cable median barrier by sliding under the cables.
- An over-ride crossover crash is classified as a crash which involves an errant vehicle crossing the cable median barrier by riding on top of the cables.
- A penetration (or through-ride) crossover crash is classified as a crash which involves an errant vehicle crossing the cable median barrier by going through the cables.

A crash is categorized as non-crossover when an errant vehicle does not cross over the cable median barrier at any point during the crash. A non-crossover crash can be classified as either redirected or contained by the cable barrier system. Again, by definition:

- A redirected non-crossover crash is classified as one when an errant vehicle hits the cable median barrier and is gradually redirected away from the median due to the dynamic deflection characteristics of the cables.
- A contained non-crossover crash is classified as one when an errant vehicle hits the cable median barrier and is restrained by the cables.


a) Brifen[1]


b) Safence[1]


c) CASS[1]


d) Gibraltar[2]


e) Nucor Marion[2]

Figure 1-1: Types of High-Tension Cable Barrier Systems Used in Florida
Sources: [1] Cook and Johnson (2006); [2]Alberson et al. (2007)

Detailed analysis of median-related crashes at locations with cable median barriers is required to accurately evaluate the safety performance of cable median barrier installations. This information is unavailable in the crash summary statistics. Detailed crash-specific information, such as; crashes directly related to cable median barrier, crossover crash classification, type of vehicle that hit the cable median barrier, 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.

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 cable median barriers.
- 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 analysis of crossover crashes, including both barrier and median crossovers.
- Chapter 5 concentrates on the before-and-after analysis of median-related crashes.
- Chapter 6 provides a summary of this project effort and the relevant conclusions.

CHAPTER 2
LITERATURE REVIEW

This chapter covers a comprehensive review of literature on conducting In-Service Performance Evaluations (ISPE) of roadside safety features. Specific ISPE procedures applicable to this project are also discussed. A review of recent literature pertaining to the safety performance of cable median barriers in several states is included.

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 Evaluation	Full Scale Crash Test
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 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:

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 data needed and data 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 needs to be obtained. Using this information, quantitative analysis, such as 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:

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

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

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

where,

(1- α) = the confidence level,
2w = the desired interval width (i.e., precision), and
ρ = 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:

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

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

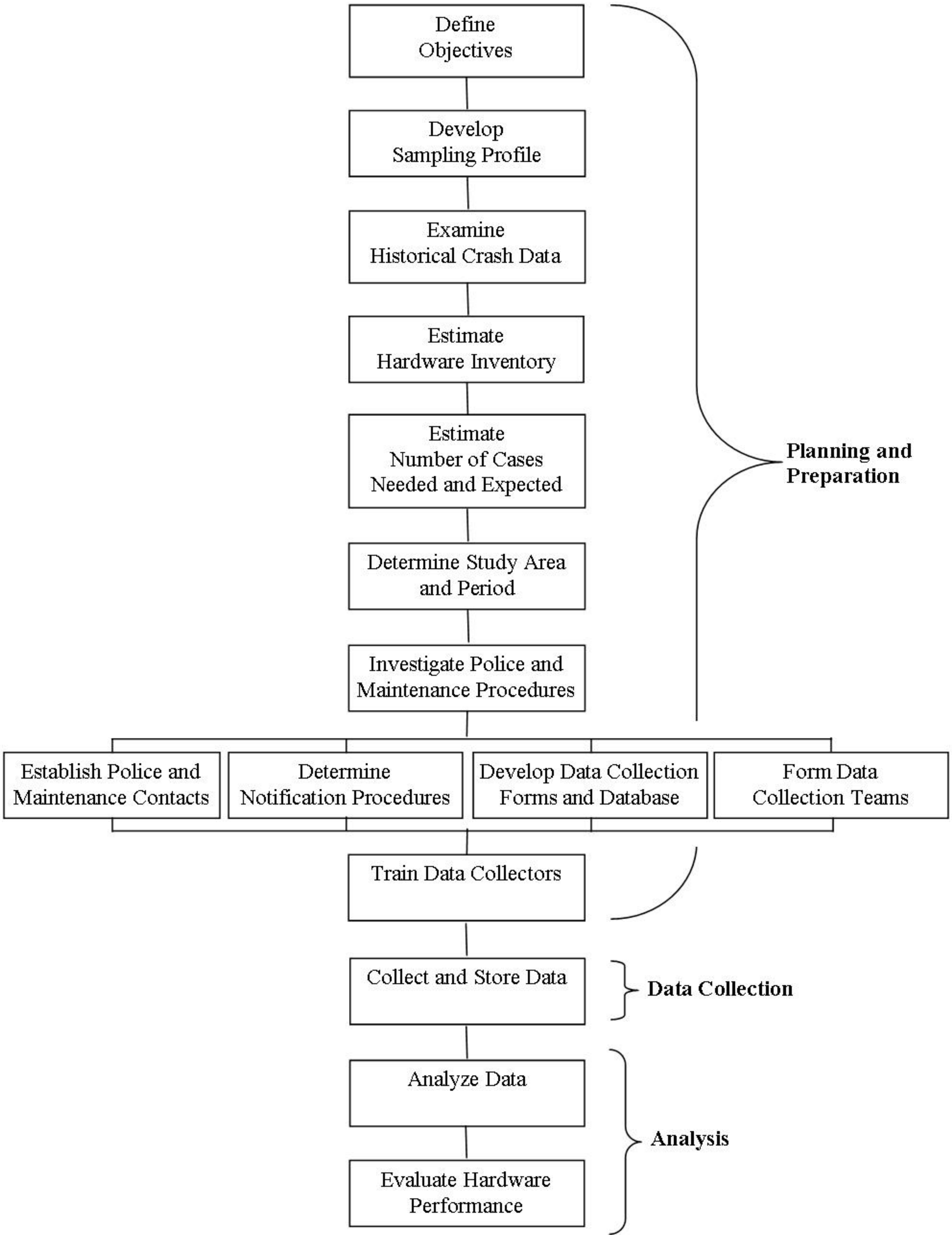

Figure 2-1: Flow Chart of the ISPE Process (Ray et al. 2003)

From the above expression,

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

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

6. *Determine Study Area and Period:* 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, crashes, 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.

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

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 cable median barrier system on limited access facilities on the State Highway System in Florida.

2. *Mark the Study Area:* All the locations on limited access facilities in the State Highway System in Florida with cable median barriers were identified. For the detailed analysis, all the median-related crashes were identified and analyzed. Locations where cable median barriers were constructed in the years 2005-2008 were identified. The construction time played a crucial role in selecting locations for analysis as the police reports are available only for the years 2003-2010.

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, Google Earth (http://earth.google.com) was used to obtain the inventory information.

4. *Obtain Historic Crash Data:* Multiple years of crash data within the study area are required. Crashes that occurred at locations where cable median barriers 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 cable median barriers.

5. *Obtain Maintenance Records:* As discussed in the earlier sections, in addition to the reported crashes, analysis of unreported crashes plays a deciding 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:* Traffic data along with roadway characteristics information were captured from the FDOT Roadway Characteristics Inventory (RCI) database. This information was required to calculate the collision rates and perform in-depth statistical analyses to evaluate the cable median barrier system's safety performance.

7. *Perform Analyses:* Detailed descriptive analyses on the type of collisions, types of vehicles involved, and crash severity were performed. Analysis of median crossover crashes was conducted. Detailed location specific before-and-after analysis of median-related crashes was also conducted.

8. *Present Results and Findings:* The results and findings of the in-service safety performance evaluation of cable median barriers in Florida were presented.

2.3 Safety Performance Assessment of Cable Median Barriers

Since the early 1970s, state Departments of Transportation (DOT) have been performing in-service performance evaluations of several roadside safety hardware. In this section, selected previous studies relevant to the present research project are reviewed.

2.3.1 Multiple States

Several studies on the safety performance of cable median barriers have been conducted. Ray et al. (2009) have very well documented the development of median barrier guidelines, safety performance of median barriers, state policies, and summaries of pioneering states. The authors have also compiled the performance of cable median barriers by state. Table 2-3 gives the annual cross-median crash frequency before and after the installation of cable median barriers by state. The original studies from which these numbers were obtained are included in Ray et al. (2009). From the table, it is observed that the percent reduction of fatal cross-median crashes has varied from 43% to 100%. Most of the states that have reported a 100% reduction have either fewer miles of sections with cable median barriers, or the cable median barriers were installed only recently. Also, it is noted that the percent reduction in cross-median crash frequencies are likely underestimated as the numbers do not account for yearly growth in traffic and the frequency of unreported crashes.

Table 2-4 gives the effectiveness of cable median barriers in preventing cross-median crashes by state. The effectiveness is calculated as the percentage of vehicles contained by the cable median barrier. An effectiveness rate of over 90% was observed in all the states. In other words, over 90% of the vehicles that hit the cable median barrier have not crossed over to the opposite side.

Table 2-3: Reduction in Cross-Median Crashes After the Installation of Cable Median Barriers (Ray et al. 2009)

State	Annual Crash Frequency in the Before Period	Annual Crash Frequency in the After Period	Percent Reduction
Fatal Cross-Median Crashes			
Alabama	47.5	27.0	43%
Arizona	1.7	0.7	59%
Missouri	24.0	2.0	92%
North Carolina	2.1	0.0	100%
Ohio	40.0	0.0	100%
Oklahoma	0.5	0.0	100%
Oregon	0.6	0.0	100%
Texas	30.0	1.0	97%
Utah	15.0	0.0	100%
Washington	4.4	0.4	91%
Cross-Median Crashes			
Florida	--	--	70%
North Carolina	25.4	1.0	96%
Ohio	371.0	27.5	93%
Utah	114.0	55.0	52%
Washington	42.4	11.2	74%

Table 2-4: Effectiveness of Cable Median Barriers in Various States (Ray et al. 2009)

State	Number of Collisions	Number of Penetrations	Effectiveness+ (%)
Arkansas	1829	152	91.7%
Iowa	20	0	100.0%
North Carolina	71	5	93.0%
New York	99	4	96.0%
Ohio	372	4	98.9%
Oklahoma	400	1	99.8%
Oregon	53	2	96.2%
Rhode Island	20	0	100.0%
South Carolina	3000	15	99.5%
Utah	18	2	88.9%
Washington	774	41	94.7%

+ The effectiveness is calculated as the percentage of vehicles contained by the cable median barrier. The cable median barrier is considered to be effective if it prevented the vehicle from crossing to the opposing lanes of traffic (i.e., preventing a median crossover crash).

Donnell and Hughes (2005) conducted a nation-wide survey on state transportation agencies' median design and safety practices. From the survey responses, it is found that strong-post W-beam guardrail and concrete safety shape are the two most common roadside barriers installed in the medians. Besides the rigid barriers, more flexible three-strand cable and Brifen wire rope safety fence are being used more frequently in the United States to prevent cross-median crashes.

Installation of cable median barrier is found to be the most common safety improvement treatment implemented to address the problem of cross-median crashes.

Sheikh et al. (2008) presented the state of the practice of cable median barriers. Survey results from 27 states are discussed in relation to performance, design and construction, overall experience, and maintenance of cable barrier systems. The participating states identified the following as the factors influencing their decision to install cable median barriers:

- Lower installation cost and a better benefit-to-cost ratio.
- Ease of repair after an impact.
- Reduced snow buildup in areas of high snow drifting.
- Ability of the high-tension system to retain some functionality after impact.
- Ability to use on relatively higher median cross-slopes (6H:1V or flatter).
- Better aesthetic and "see-through" appearance.
- Lower accident severity.
- Ability to allow lateral drainage.

The following are the relevant excerpts from the survey:

- There was a decrease in the severity of crashes at locations where wire rope median barriers have been installed while the total crashes have increased.
- Even though some states continue to use nonproprietary low-tension systems, usage of proprietary low-tension systems continues to increase.
- Horizontal curvature has a direct impact on deflection associated with errant vehicle impacts, and therefore on the performance of the barriers.
- With continued and increasing installations of cable median barriers, more rigorous ISPEs need to be conducted to improve the system.

In 2005, the Illinois Department of Transportation (IDOT) coordinated a scanning tour to identify effective and efficient approaches of reducing the number and severity of freeway median crossover crashes. As part of the scanning tour, representatives from Illinois, Iowa, Minnesota, and Wisconsin visited sites with cable median barrier installations in Ohio, Oklahoma, and Texas. The following are the relevant conclusions drawn from the scanning tour (Medina and Benekohal 2005):

- High-tension cable systems have been successfully used for median crossover protection on highways with wide medians and flat median slopes.
- The general performance of the cable barrier systems at redirecting or stopping vehicles seems to be excellent.
- While maintenance of the barrier system requires workers to be exposed to highway traffic, traffic control and cleaning up after vehicle crashes also requires workers to be exposed to highway traffic.
- Warrants for installation of cable median barrier tend to identify locations with severe crash history.

2.3.2 Arizona

Chen (2004) evaluated the safety performance of cable barriers on Arizona highways from 1999-2003. Table 2-5 gives the median crash statistics by the type of crossover. From the table, it can be inferred that 1,677 of 1,829 vehicles that hit the barrier (i.e., 91.7%) were successfully contained by the barrier. Further, 4% of crossover crashes (i.e., under-ride + roll over + through/over-ride) resulted in a fatality, while only 0.8% of non-crossover crashes (i.e., contained by the cable median barrier) were fatal.

Table 2-5: Median Crash Data on Arizona Highways (Ray et al. 2009)

Crossover Type	Fatal Crashes		Total Crashes
	Number	Percentage	Number
Contained	13	0.8	1677
Redirected	0	0.0	0
Rolled Over	2	4.0	50
Through or over	4	4.2	96
Under-rode	0	0.0	6
Total penetrations	6	3.9	152
Total	19	10.4	1829

Original Data Source: Chen (2004)

Mak and Sicking (2002) conducted a continuous evaluation of in-service highway safety feature performance. As a part of this project, a program was developed 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 1 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 2 module is similar to several 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 1 subsystem. Level 3 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, and for incidents of device failure. 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 ISPE projects.

2.3.3 Kansas

Sicking et al. (2009) developed general guidelines on the use of cable median barriers along Kansas freeways. Reported crashes on Kansas freeways from 2002-2006 were reviewed. 525 cross-median events (CMEs) and 115 cross-median crashes (CMCs) were analyzed. It was found that winter driving conditions existed for less than one-eighth of the days in the study period and accounted for more than one-quarter of CME and one-third of CMC occurrences. A two-tailed chi square test confirmed that the frequencies of CMEs and CMCs were significantly overrepresented during winter driving conditions. Similar to many other studies, it was found that crash severities declined after the installations of cable median barriers. From the results, the performance of cable median barriers was found to be influenced by weather conditions.

Analyzing the influence of traffic on CMEs and CMCs, a linear relation was found to exist between AADT and CME while the relation was non-linear between AADT and CMC. The benefit-to-cost ratios for a 60-ft wide median were calculated using the following equation:

$$\frac{B}{C} = \frac{AC_0 - AC_b}{DC_b} \tag{2-6}$$

where,

B/C = benefit-to-cost ratio,
AC_o = accident cost associated with an open median,
AC_b = accident cost associated with a cable median barrier, and
DC_b = direct cost of using a cable median barrier.

The authors indicated that the average cost of cable median barrier crashes was understated in their analysis, and therefore did not recommend a cable median barrier installation when B/C < 2.0.

2.3.4 Kentucky

Agent and Pigman (2008) evaluated the effectiveness of Brifen TL-4 and Trinity CASS cable median barrier systems in preventing CMCs on specific sections of highways in Kentucky. The study also reviewed guidelines for the use of median barriers. For the review, horizontal and vertical alignment, interchange influence, median width, traffic volume, traffic composition, and side slopes were evaluated. About 325 police reported CMCs were identified over a 21-month analysis period with an average of 0.28 CMCs per mile in 5-year period and 0.05 fatal CMCs per mile in 5-year period. The results from the study show that the cable system was successful in redirecting errant vehicles as in only 0.9% of the cases had the cable system failed. It was also concluded that the struck cable system could be repaired without major disruption to traffic.

2.3.5 New Jersey

Gabler et al. (2005) evaluated the post-impact performance of a three-strand cable median barrier system installed on I-78 (1.18 miles) and a modified thrie-beam median barrier system installed on I-80 (0.91 miles) in New Jersey. A total of 12 crashes were investigated at the two sites between November 2003 and November 2004. None of these 12 crashes were penetrations. Of the 12 crashes, only one crash was reported to the police while the rest went unreported and most likely property damage only (PDO) crashes.

2.3.6 North Carolina

North Carolina has been investigating cross-median crashes since the early 1990s when cross-median crashes on high-volume, high-speed urban facilities began to be perceived as a problem (Ray et al. 2009). In 1993, Lynch et al. (1993) analyzed crashes that occurred between April 1988 and October 1991 on the North Carolina Interstate Highway System to identify and evaluate cross median crashes. Hunter et al. (2001) conducted an ISPE of three-strand cable median barriers installed in 1994. The authors developed regression models to estimate the effect of cable median barriers on crash rates by crash type. The models revealed that several types of crashes (especially run-off-the-road-left and fixed object crashes) increased after the installation of cable median barriers. However, yearly severity indices showed an encouraging trend: there were fewer number of fatal and severe injury crashes. Table 2-6 gives yearly equivalent property damage only (EPDO) values, total crash numbers, and severity indices for multiple years pre- and post-installations.

Table 2-6: Yearly EPDO and Severity Index Values Where Cable Median Barriers were Installed (Hunter et al. 2001)

Year	EPDO	Total Crashes	Severity Index
1990	925.8	90	10.3
1991	1147.2	84	13.7
1992	1016.8	131	7.8
1993	1230.2	141	8.7
1994*	1188.8	216	5.5
1995	1140.2	269	4.2
1996	1393.2	276	5.0
1997	1277.2	271	4.7

*Year when cable median barriers were installed.

In 1998, North Carolina started a three-phase project to prevent and reduce the severity of cross-median crashes on the state's freeways (Murphy 2006). The project was implemented in the following three phases:

1. Add median protection to freeways with historic crash history.
2. Systematically protect all freeways with median widths $\leq$ 70 ft.
3. Revise the design policy to protect all future freeways with median widths $\leq$ 70 ft.

As of 2005, the installation of median barriers has resulted in an estimated 90% reduction in freeway cross-median crashes and saved approximately 25 to 30 lives annually (Strasburg and Crawley 2005). Besides this evaluation, Murphy (2006) conducted a long term median barrier evaluation; Table 2-7 summarizes the results. A significant reduction in the severity of total crashes and the frequency of crossover crashes was observed after the installation of cable median barriers. However, an increase was seen in daily traffic volumes and frequency of total, minor injury, and PDO crashes. After cable median barrier installations, a few maintenance concerns were identified, of which recovery of maintenance cost from drive-away vehicles, frequency of repairs to the cable barriers, and mowing were prominent. Further, as part of the study, evaluation of cable penetrations was performed to identify common characteristics that might influence the probability of crossover collisions. This was performed through detailed investigation of all cable breaching crashes.

Table 2-7: Long-Term Median Barrier Evaluation (Murphy 2006)

	All Barrier Types			Cable Median Barrier		
	Before	After	% Change	Before	After	% Change
Mileage (miles)	428			203		
AADT (veh/day)	26,600	34,300	29%	22,000	29,400	34%
Total Crashes	2,048	3,718	82%	793	1,688	113%
Severe Injury Crashes (K and A)	120	98	-18%	47	41	-13%
Moderate and Minor Injury Crashes (B and C)	696	1,103	58%	267	448	68%
Property Damage Only (PDO)	1,232	2,517	104%	479	1,199	150%
Cross-Median Crashes	152	30	-80%	60	23	-62%
Fatal Cross-Median Crashes	13	2	-80%	4	2	-56%
Severe Injury Cross-Median Crashes (K and A)	20	3	-87%	7	2	-74%
Crashes Involving Median Barrier	-	1,218	-	-	568	-
% of Crashes Involving Median Barrier	-	33%	-	-	34%	-
Breach Rate	-	2.4%	-	-	4.0%	-

All crash numbers are crashes per year.

2.3.7 Ohio

Arnold (2006) performed a three-year ISPE on the existing high-tension Brifen cable barrier system in Ohio. About 14.5 miles of cable barrier was installed on IR-75. Even though crash frequency increased after the installation of cable median barriers, a significant number of possible crossover crashes were contained by the barrier. The three-year ISPE identified zero crossover fatal and severe injury crashes. During the two-year period prior to the installation of cable median barriers, there were 17 fatal crashes of which 9 were crossover fatal crashes. The three-year period after the installation of cable median barriers had 4 fatal crashes with no fatal crossover crashes. Descriptive statistics and trend analysis after installation of cable median barriers showed a slightly higher percentage of crossover crashes during dark conditions. Significantly higher percentage of crossover crashes occurred during wet conditions and similar trend was observed when multiple vehicles lost control.

2.3.8 Oregon

A total of 21.9 miles of three-cable barrier systems were installed in two phases (December 1996 and April 1998) on I-5 between Salem and Wilsonville, OR. Sposito and Johnston (1998) investigated the effectiveness of three-cable median barrier system in preventing median crossover crashes and concluded that the cable median barrier system is cost-effective compared to the concrete barrier system. Sposito (2000) observed a substantial increase in crash frequency post installation. However, fewer major injury and fatal crashes were observed. Based on this study, cable median barriers are recommended on locations where there is enough room for lateral deflections (up to 11.5 ft).

2.3.9 Texas

Cooner et al. (2009) recently conducted the performance evaluation of cable median barrier systems in Texas. The main objective of this project was "to perform and document an ISPE of cable median barrier systems and develop recommendations and guidelines to direct the Texas Department of Transportation (TxDOT) design, maintenance, and operations staff for future installations". The work plan for this project included performing state-of-the-practice literature review, developing an inventory of cable median barrier installations, outlining the ISPE process and study locations, collecting and analyzing data, and conducting an ISPE. While performing the ISPE, the researchers included the following elements:

- Initial installation costs.
- Routine maintenance and repair costs.
- Before-and-after crash statistics.
- Actual field performance during collisions.

Study sites were selected based on data availability, variations in roadway characteristics, existence of cable barrier, and availability of at least one year of installation, maintenance, and crash data. Assessment of the performance of cable barriers was performed on the four aforementioned elements. Geographic Information System (GIS)-based statewide barrier inventory database (GSBID) was developed to spatially locate median barrier sites along with their detailed information. A total of 192 segments (segments with 114 cable barriers and 78 concrete barriers) were successfully located in GSBID. Fifty-seven data fields were used to record barrier information such as control section job number, barrier types, barrier products, typical post spacing, typical barrier placement from inside/outside shoulder, barrier cost, route name, mile post/reference marker, project description, traffic volumes, number of lanes, median and shoulder widths, etc. Relevant conclusions from this study include:

- Cable barriers are more cost-efficient (considering capital and life-cycle cost) than concrete median barriers.
- Cable barriers are found to perform extremely well in most of the standard type collisions.
- Cable barriers are making a significant contribution to the reduction of fatal and incapacitating injuries on state roadways, effectively eliminating 96% of these injury types caused by cross-median crashes.
- The cable barrier asset management system (GSBID) successfully demonstrates the advantages of developing and maintaining such systems.

2.3.10 Washington State

Washington State has been a pioneer in cable median barrier installations and their performance assessments. By the end of 2008, the Washington State Department of Transportation (WSDOT) had 181 miles of cable median barriers with about 10 miles in construction. Hammond and Batiste (2008) evaluated the performance of cable median barriers in Washington State. The following are the relevant findings from their study:

- Analysis of 2000-2008 within and across the median collisions showed a 58% reduction in fatal and severe injury crashes.
- A 61% reduction in the annual number of cross-median crashes was observed on segments with cable median barriers.
- Comparing the performance of cable median barriers with concrete barriers, 79% of errant vehicles were contained by cable median barriers while only 34% were contained by concrete median barriers.
- Post cable median barrier installations, on locations with higher than average number of crossover collisions, concrete median barriers and shoulder widening might improve safety.

Table 2-8 gives crash statistics before and after cable barrier installation for total median-related crashes and cross-median crashes. Similar to the results from other studies, the period after the installation of cable median barriers had seen an increase in the overall crash frequency and rate, but, there was a considerable reduction in fatal and severe crashes.

Table 2-8: Collision Rate Data Before and After Cable Barrier Installations (Hammond and Batiste 2008)

	Before	After	% Change
Total Median-Related Collisions			
Annual Median Collisions	228	594	+161%
Median collision rate (per 100 million vehicle miles traveled "VMT")	7.85	15.99	+104%
Annual serious-injury median collisions	16.8	7.0	-59%
Annual fatal median collisions	8	6	-25%
Serious-injury median collision rate (per 100 million VMT)	0.58	0.21	-64%
Fatal median collision rate (per 100 million VMT)	0.27	0.15	-44%
Cross-Median Collisions			
Annual cross-median incidents	54.8	21.6	-61%
Cross-median collision rate (per 100 million VMT)	1.88	0.66	-65%
Annual serious-injury cross-median collisions	8.6	2.3	-73%
Annual fatal cross-median collision	4.8	3.5	-28%

In March 2007, Ray (2007) evaluated the WSDOT's cable median policy, and found that installation of cable median barriers resulted in the reduction of median crossover crash rates from 2.009 per 100 Million Vehicle Miles (MVM) in the before period to 0.607 per 100 MVM in the after period. Fatal crash rate reduced from 0.213 crashes per 100 MVM in the before period to 0.044 crashes per 100 MVM in the after period. Table 2-9 gives the recommendations for installing cable median barriers based on historical crash rates of all severities.

Table 2-9: Median Barrier Installation Recommendations Based on Historical Crash Rates (Ray 2007)

Cross-median Crash Rate[a] of All Severities per 100 MVM	Site Characteristics	Action
> 1.00	• No median barrier, • 30 ft or wider median, and • 6:1 or flatter slopes.	Evaluate cost benefit of using a cable median barrier.
> 2.00	• No median barrier, • 30 – 50 ft wide median, • 6:1 or flatter slopes, • ADT> 75000 veh/day, and • in rural/ urban transition area[b].	Evaluate cost benefit of using a double-run of cable, w-beam, thrie-beam or concrete median barriers.
> 0.75	• 30 – 50 ft wide median, • cable median barrier, • 6:1 or flatter slopes, • ADT> 75000 veh/day, and • in rural/ urban transition area[b].	Evaluate cost benefit of replacing a cable median barrier with w-beam, thrie-beam or concrete median barriers.

[a] Crash rates should be calculated on sections that are at least two miles long and where data are available such that the section has experienced at least 100 MVM. Crash rates calculated on shorter segments or where there has not yet been sufficient traffic are liable to be inaccurate and overly sensitive to a few early crashes.

[b] Rural/urban transition areas are areas that are characterized by several of the following characteristics: interchanges spaced closer than two miles apart, a change in speed limit, a large change in Average Daily Traffic (ADT) (e.g., 30 %) in a relatively short distance, or high ramp volumes in proportion to the mainline ADT.

McClanahan et al. (2004) documented Washington State's experience with cable median barrier system by analyzing installation and maintenance costs, and by performing before-and-after evaluation of the system. The research team analyzed 24.4 miles of cable median barriers along I-5. The installation cost was estimated to be $44,000 per mile. The average cost per repair was found to be $733. The average annual maintenance cost was approximately $2,570 per mile. The time required to repair the cable median barrier was approximately 30% less than that for W-beam guardrail. Figure 2-2 compares the before-and-after crash experience by crash type. Post installation, there was a significant reduction in the number of severe crashes. Also, the cable median barrier was successful in preventing cross-median crashes. This research concluded that the annual societal benefits of cable barriers were approximately $420,000 per mile.

In a 2002 research study, Glad et al. (2002) conducted benefit-cost analysis to evaluate the cost effectiveness of median barrier installation on multilane divided highways with full access control. Barriers placed in median sections up to 50 ft wide were found to be cost effective. However, the authors mentioned that this study did not take into account unreported crashes, and the benefits are not estimated based on the frequency and severity of crashes in the future.

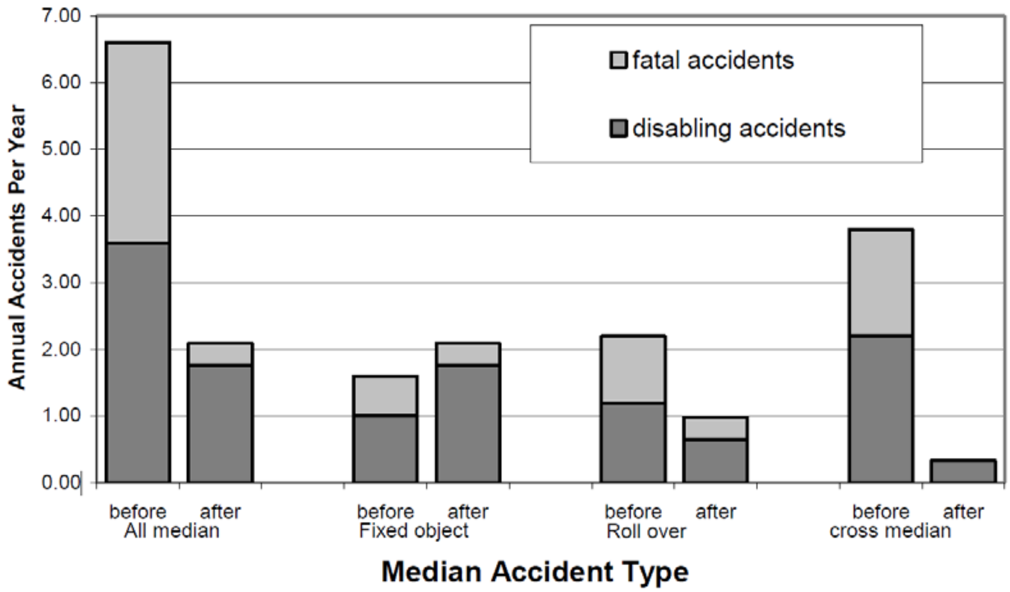

Figure 2-2: Comparison of Annual Crashes Before-and-After Cable Median Barrier Installation (McClanahan et al. 2004)

2.4 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.

High-tension cable median barrier systems have increasingly been installed along limited access facilities in a number of states. Installation of cable median barrier is found to be the most common safety improvement treatment implemented to address the problem of cross-median crashes. The general performance of the cable barrier systems at redirecting or stopping vehicles is found to be satisfactory. Most of the states documented over 90% reduction in fatal cross-median collisions after the installation of cable median barriers. Several before-and-after and ISPE studies have found that the cable median barrier systems reduce fatal and sever injury crashes, even though they often result in an increase in total, PDO, and minor injury collisions.

CHAPTER 3
DATA COLLECTION

This chapter describes the data collection and preparation efforts undertaken to identify locations with cable median barrier systems on limited access facilities in Florida. It also discusses the police reports' review process used to identify median-related crashes and crossover crash types.

3.1 Identify Study Locations

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. Specific information on begin and end mileposts of roadway sections with cable median barrier systems were obtained using ArcGIS and Google Earth. The following steps were followed to identify locations with cable median barrier systems:

1. The State Roads GIS shapefile was downloaded from the FDOT Planning and Statistics website (http://www.dot.state.fl.us/planning/statistics/gis/).
2. The GIS shapefile for state roads was imported to Google Earth. Each road was virtually driven in Google Earth to record the location of cable median barrier systems. Latitudes and longitudes of begin and end milepost locations were recorded.
3. The identified locations with cable median barriers (in ".kmz" format) were exported from Google Earth back to ArcGIS to convert latitudes and longitudes to mileposts.
4. A total of 23 locations, totaling 101 miles, were identified on limited access facilities in Florida by their begin and end mileposts.

The construction periods for installing cable median barrier systems at the 23 locations were obtained from the district offices. Table 3-1 lists the locations with construction dates and the type of cable median barrier system installed. The majority of the study locations were installed with either CASS or Gibraltar systems. A special case involves those installed on the Florida Turnpike (SR 821) in which three types of cable barrier systems (Brifen, CASS, and Safence) were installed along a 6.073-mile freeway section as part of a pilot study.

3.2 Review Police Reports

The FDOT's Crash Analysis Reporting (CAR) system was used to identify crashes that occurred at the study locations. For the periods covering 2003 to 2010, the 23 locations experienced a total of 8,818 crashes. Police reports of these crashes were available for download from the Hummingbird web system hosted on FDOT's Intranet, and were downloaded and reviewed in detail. For crossover analysis, the review focused on identifying crash consequences of vehicles hitting the barrier. For before-and-after analysis, the review focused on identifying median-related crashes. A crash where an errant vehicle leaves the designated travel lane to the left (i.e., toward the median) at any point during the crash is classified as a median-related crash.

Table 3-1: Construction Dates for Locations with Cable Median Barriers

Roadway ID	Begin MP	End MP	Segment Length (mi)	Type of Cable Barrier	State Road Name	Construction Start Date	Construction End Date
17075000	10.750	12.212	1.462	CASS	I-75	6/14/2006	5/16/2007
17075000	37.102	40.028	2.926	CASS	I-75	6/14/2006	5/16/2007
75002000	19.348	30.341	10.993	CASS	SR 528	8/7/2005	3/5/2006
87471000+	3.155	9.228	6.073	Brifen, Safence, CASS	SR 821	May-2005	July-2006
17075000	0.000	0.545	0.545	CASS	I-75	5/9/2009	11/10/2009
17075000	32.860	34.405	1.545	CASS	I-75	6/14/2006	5/16/2007
17075000	42.104	42.615	0.511	CASS	I-75	6/14/2006	5/16/2007
75301000	13.804	14.282	0.478	CASS	SR 417	5/17/2006	6/17/2006
75320000	33.784	34.480	0.696	CASS	SR 429	6/5/2006	7/20/2006
13075000	0.000	8.151	8.151	CASS	I-75	5/12/2009	4/9/2010
13075000	8.313	13.110	4.797	CASS	I-75	5/12/2009	4/9/2010
13075000	13.481	16.990	3.509	CASS	I-75	5/12/2009	4/9/2010
13075000	17.293	18.650	1.357	CASS	I-75	5/12/2009	4/9/2010
13075000	19.100	19.290	0.190	CASS	I-75	5/12/2009	4/9/2010
13075000	19.492	19.941	0.449	CASS	I-75	5/12/2009	4/9/2010
03175000	54.090	63.676	9.586	Gibraltar	I-75	10/28/2007	9/22/2010
12075000	0.000	20.767	20.767	Gibraltar	I-75	10/28/2007	9/22/2010
16320000	0.000	18.852	18.852	Gibraltar	I-4	10/13/2006	May-2007
16320000	19.913	21.870	1.957	Gibraltar	I-4	10/13/2006	May-2007
16320000	23.066	24.170	1.104	Gibraltar	I-4	10/13/2006	May-2007
16320000	25.155	27.327	2.172	Gibraltar	I-4	10/13/2006	May-2007
16320000	28.113	30.096	1.983	Gibraltar	I-4	10/13/2006	May-2007
16320000	31.133	32.022	0.889	Gibraltar	I-4	10/13/2006	May-2007

+ MP 3.155 to 5.655 is with Brifen; MP 5.655 to 6.728 is with Safence; and MP 6.728 to 9.228 is with CASS. Note that these mileposts are approximate.

3.3 Identify Manner of Barrier and Median Crossovers

Police reports of all crashes at all the 23 study locations after the installation of cable median barriers through December 2010 were reviewed. For each and every crash where the errant vehicle had hit the cable median barrier, a detailed review of the police officer's description and illustrative sketch was conducted to categorize crashes as crossover and non-crossover crashes, if a crossover crash involved vehicle encroaching into the opposite travel lanes, the type of vehicle involved, and the crash severity. As defined in Chapter 1, a crash in which an errant vehicle crosses the cable median barrier at any point during the crash is categorized as a barrier crossover crash. A barrier crossover crash could be the result of an errant vehicle under-riding, over-riding, or penetrating the cable median barrier. A barrier crossover crash is categorized as a median crossover crash when an errant vehicle traverses the opposite travel lanes. A crash is categorized as non-crossover when an errant vehicle never crosses the cable median barrier during the crash. A non-crossover crash is categorized as either redirected or contained by the cable barrier system. Figures 3-1 through 3-6 provide examples of the six different crash classifications.

V1 was traveling west on S.R. 400. The driver of V1 stated that he fell asleep at the wheel. V1 left the road and entered the median. V1 struck the cable guardrail and overturned onto its left side. V1 came to final rest on its left side facing in an westerly direction in the median of S.R. 400.

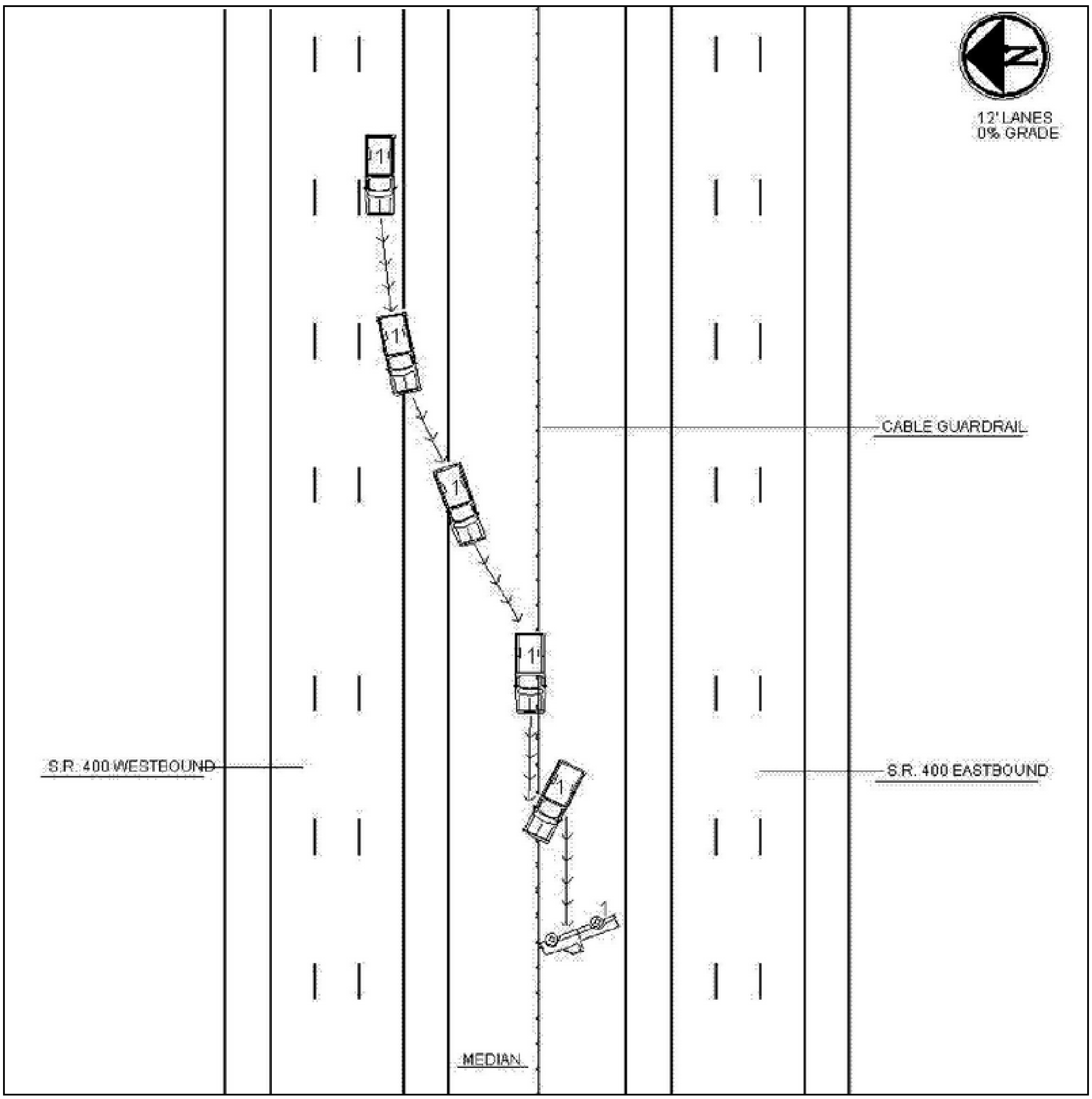

Figure 3-1: Example of a Barrier Crossover Over-ride Crash (Crash # 776721690)

V-1 was eastbound on State Road 400 in the inside lane. A vehicle that was eastbound on State Road 400 in the middle lane, alongside V-1, changed lanes toward V-1. D-1 swerved to her left and slid off the roadway into the grass median. V-1 rotated in a counterclockwise manner, sliding into the cable rail in the median. The left side of V-1 struck a cable support. V-1 traveled partially through the cable rail, continuing to rotated counterclockwise. V-1 slid down the cable rail, underneath the cables, making contact with the rail supports with the rear and left side of V-1, before rotating out, traveling backward, into the median, coming to rest. V-1 was a non-contact vehicle that left the scene.

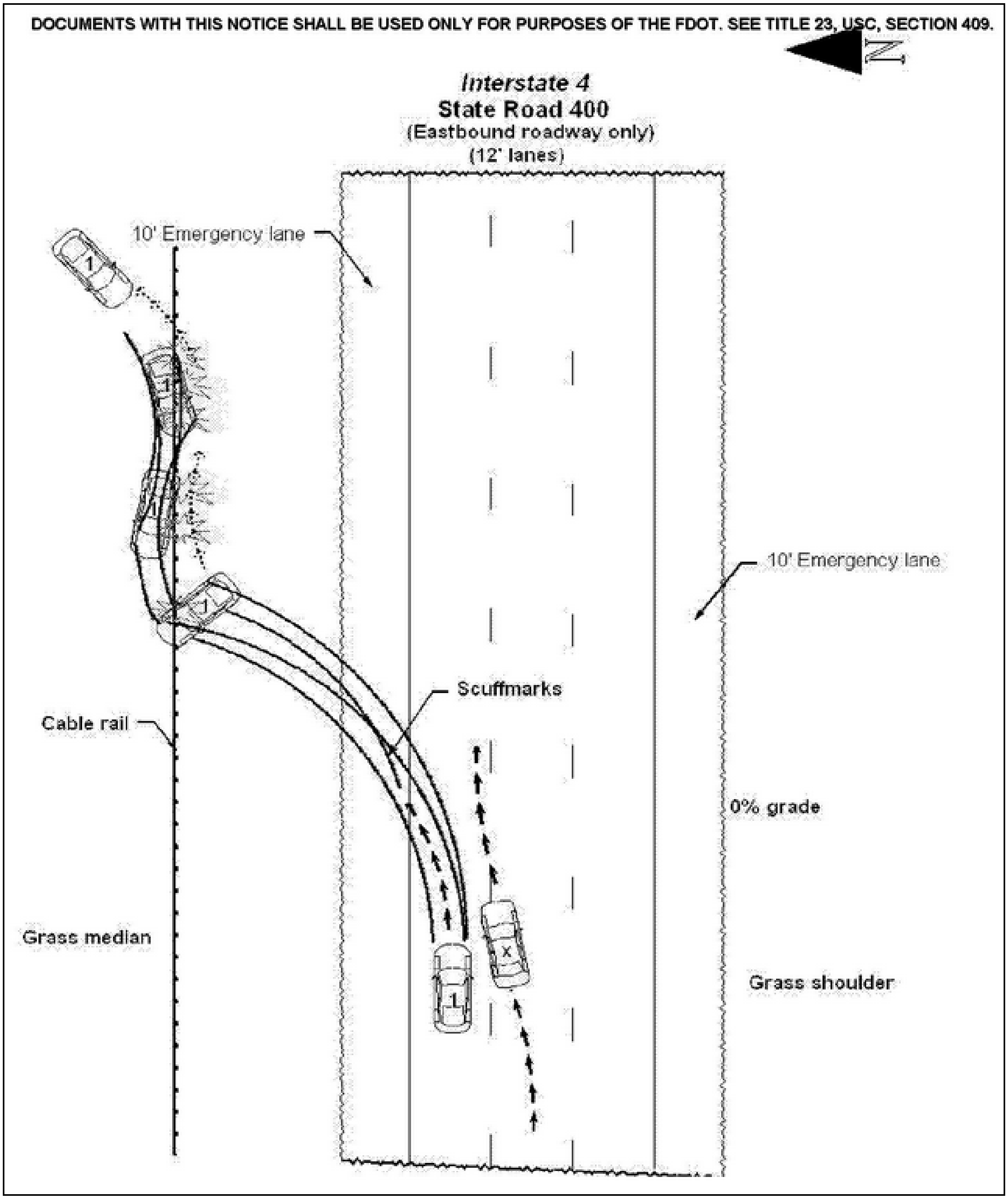

Figure 3-2: Example of a Barrier Crossover Under-ride Crash (Crash # 776553840)

V-1 was eastbound on SR 400 in the outside lane. V-1's right side tires entered the south edge of the roadway. D-1 over corrected to the left causing V-1 to travel across the eastbound lanes rotating counterclockwise. V-1 entered the median striking the cable guard rail with V-1's right side. V-1 traveled through the guard rail. V-1's front rotated to face eastbound. V-1 traveled eastbound toward the guard rail. V-1 traveled through the guard rail a second time rotating counterclockwise coming to final rest on the south side of the guard rail facing northwest. D-1 stated that she was originally in the center lane and was operating her GPS. When she looked up again she was close to a truck. She then traveled into the outside lane and onto the south edge of the roadway and lost control of her vehicle.

Code 24 Contributing Causes Driver distractions V-1: Driver operating GPS system.

Damage to the cable guard rail west of the 40.3 mile marker. Approximately 125 feet damaged.

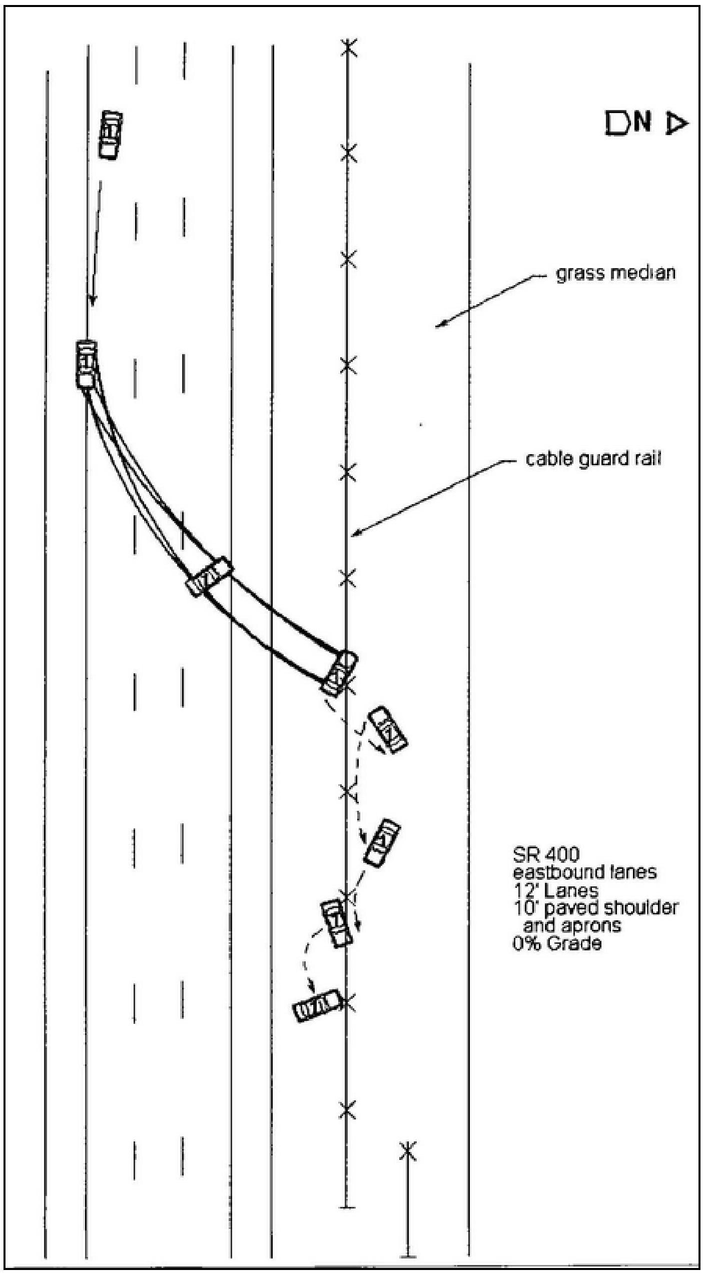

Figure 3-3: Example of a Barrier Crossover Penetration Crash (Crash # 771491090)

V1 WAS TRAVELING WEST ON SR 528 IN THE RIGHT LANE NEAR THE 22 MILE MARKER V1 DRIVER STATED THAT SHE ATTEMPTED TO PASS A DUMP TRUCK, SHE WENT FROM THE RIGHT TO THE LEFT LANE, THEN TRIED TO GO BACK TO THE RIGHT LANE, RAN UPON THE UNEVEN PAVEMENT, LOST CONTROL OF HER STEERING HIT HER BRAKES, WENT INTO A COUNTER CLOCKWISE SPIN, RAN BACK ACROSS THE LEFT LANE INTO THE CENTER GRASS MEDIAN STRIKING THE METAL ROPE GUARDRAIL WITH THE LEFT SIDE OF HER VEHICLE, OVERTURNED HER VEHICLE CROSSING THE GUARDRAIL, CROSSING THE EASTBOUND LANES AND PAVED SHOULDER ONTO THE GRASS SHOULDER WHERE IT CAME TO FINAL REST CRASHING INTO SOME SMALL TREES, AND SHRUBBERIES * ROAD CONDITION LEFT LANE HAD BEEN NEWLY PAVED / UNEVEN LANES.

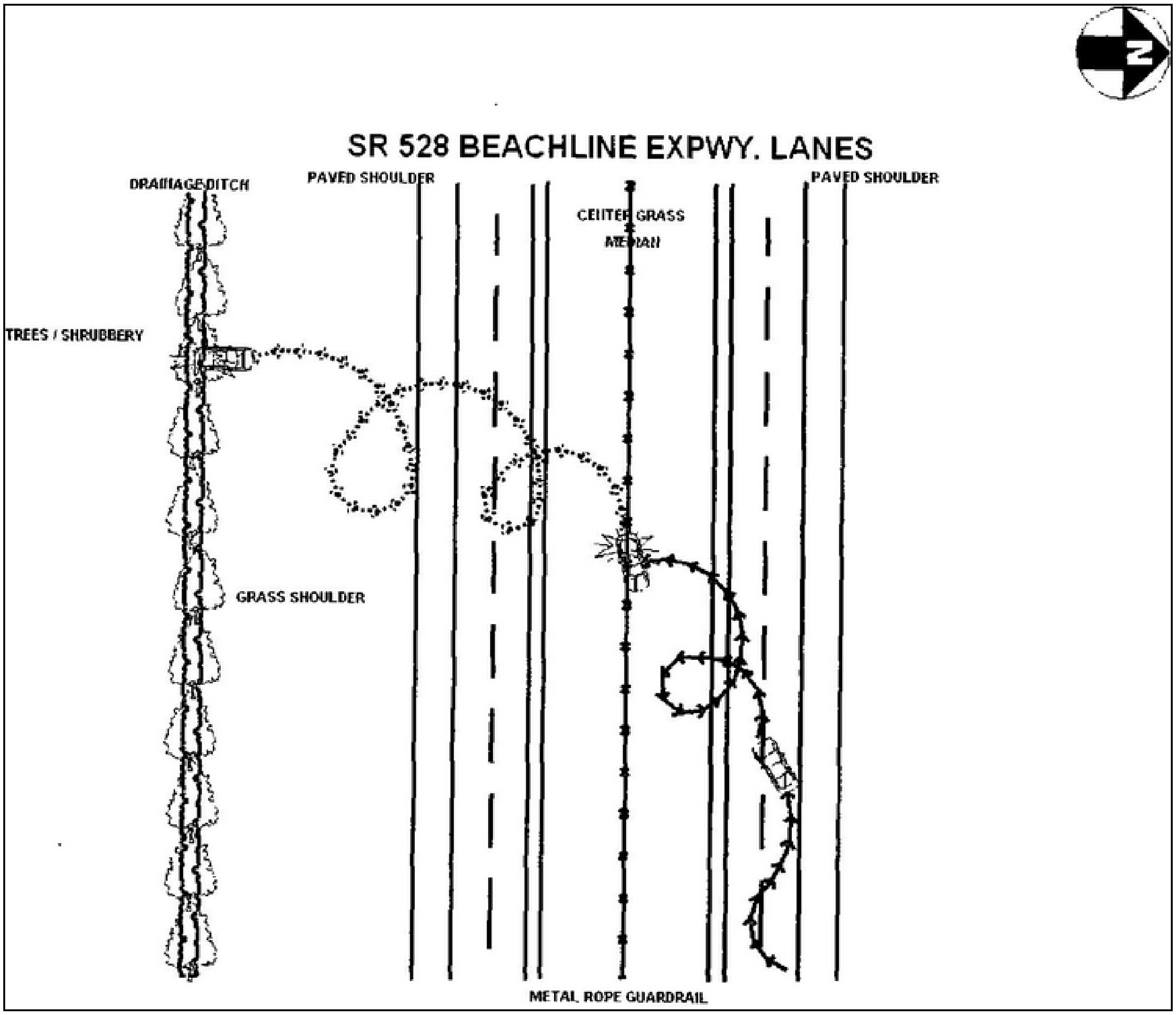

Figure 3-4: Example of a Median Crossover Crash (Crash # 771887130)

V1 was westbound on SR-400 in the inside lane. For an unknown reason, the driver of V1 lost control of the vehicle. V1 continued in a westerly direction onto the median. V1 then started to rotate clockwise and struck a cable wire with it's left front. V1 came to final rest at this time without further incident. V1 came to final rest facing south.Contributing Causes-Careless Driving-V1 failed to maintain control of vehicle.Cable wire stopped the vehicle movement.

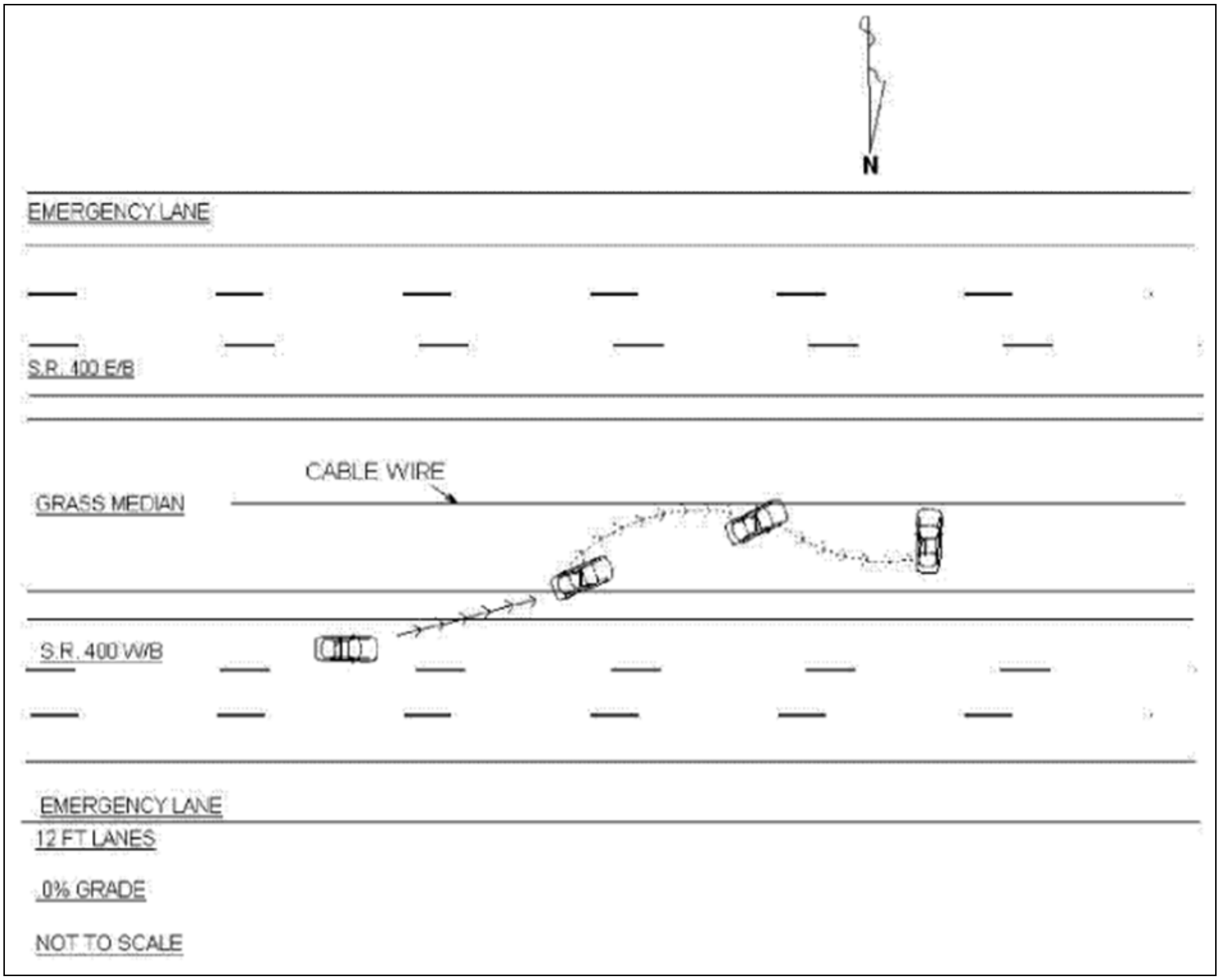

Figure 3-5: Example of a Non-Crossover Redirected Crash (Crash # 773972380)

V1 WAS TRAVELING WESTBOUND ON SR-528 IN THE OUTSIDE LANE. THE TIRE TREAD ON V1'S LEFT REAR TIRE SEPARATED CAUSING D1 TO LOSE CONTROL OF THE VEHICLE. V1 ROTATED CLOCKWISE AS V1 SLID ACROSS THE WESTBOUND TRAVEL LANES AND INTO THE MEDIAN. THE RIGHT REAR OF V1 THEN COLLIDED WITH THE WIRE GUARDRAIL. V1 CONTINUED TO SLIDE TO THE SOUTHWEST AS THE WIRE GUARDRAIL SLOWED V1 TO A STOP. V1 CAME TO FINAL REST FACING NORTHEAST IN THE MEDIAN AND WAS ENTANGLED IN THE WIRE GUARDRAIL. NOTE: 2 OF THE 3 GUARDRAIL WIRES TRAVELED OVER THE ROOF OF V1 CAUSING ADDITIONAL DAMAGE.

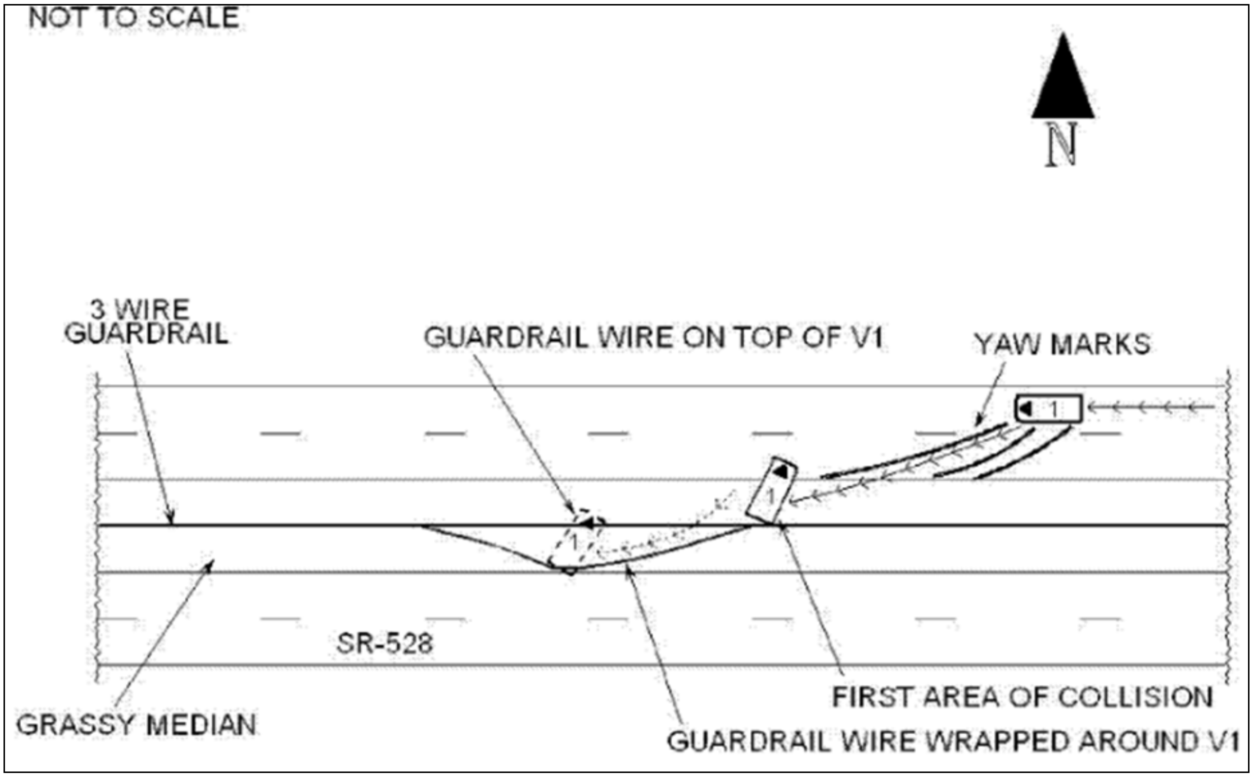

Figure 3-6: Example of a Non-Crossover Contained Crash (Crash # 776779740)

CHAPTER 4
CROSSOVER ANALYSIS

This chapter presents an analysis based on the percentages of vehicles prevented from crossing over a cable median barrier. The statistics are given for different site locations, vehicle types, crash severity levels, and cable median barrier types. The analysis includes both barrier and median crossover crashes. As defined in Chapter 1, a crash in which an errant vehicle crosses the cable median barrier at any point during the crash is categorized as a barrier crossover crash. If the errant vehicle reaches the opposite travel lane after crossing the barrier, it becomes a median crossover crash.

4.1 Individual Segments

Table 4-1 shows the percentage of barrier crossover and non-crossover crashes at each of the 23 cable median barrier locations in Florida. The table also gives statistics on the number of vehicles that traversed into the opposite travel lane after hitting the cable median barrier. A total of 549 crashes were identified to be cable median barrier related, i.e., 549 crashes resulted in vehicles hitting the cable median barrier. Of these 549 crashes, 90 were identified as barrier crossover crashes and the remaining 459 were non-crossover crashes.

It can be seen from Table 4-1 that the majority of cable median barrier crashes at each of the 23 study locations were non-crossover crashes. The overall effective rate of installing cable median barrier to prevent barrier crossover crashes is 83.6%. This implies that 83.6% of all vehicles that hit the cable median barrier were either redirected or contained by the cable barrier system. Of the 549 crashes that involved errant vehicles hitting the cable median barrier, 14 resulted in the vehicle traversing into the opposite travel lane, giving the median crossover rate of 2.6%. In other words, only 2.6% of vehicles that hit the cable median barrier traversed into the opposite travel lane. This result is consistent with those from other studies, including McClanahan et al. (2004), Arnold (2006), Murphy (2006), and Hammond and Batiste (2008), which found relatively low median crossover percentages after cable median barrier installation.

Table 4-1: Barrier and Median Crossover Crash Statistics by Individual Locations

Roadway ID	Begin MP	End MP	Segment Length (miles)	Road Name	Mean AADT	Barrier Crossover Crashes (a)	Barrier Non-Crossover Crashes (b)	Total Crashes (c)=(a)+(b)	Percent of Barrier Non-Crossover Crashes (b)/(c)	Median Crossover Crashes (d)	Percent of Median Crossover Crashes (d)/(c)
17075000	0.000	0.545	0.545	I-75	45357	0	1	1	100.0%	0	0.0%
17075000	10.750	12.212	1.462	I-75	54195	1	6	7	85.7%	0	0.0%
17075000	32.860	34.405	1.545	I-75	80743	0	3	3	100.0%	0	0.0%
17075000	37.102	40.028	2.926	I-75	108300	5	20	25	80.0%	2	8.0%
17075000	42.104	42.615	0.511	I-75	110984	0	4	4	100.0%	0	0.0%
13075000	0.000	8.151	8.151	I-75	98840	6	12	18	66.7%	0	0.0%
13075000	8.313	13.110	4.797	I-75	87023	0	5	5	100.0%	0	0.0%
13075000	13.481	16.990	3.509	I-75	65151	0	4	4	100.0%	0	0.0%
13075000	17.293	18.650	1.357	I-75	60348	0	3	3	100.0%	0	0.0%
13075000	19.100	19.290	0.190	I-75	61107	0	0	0	---	0	---
13075000	19.492	19.941	0.449	I-75	62857	0	0	0	---	0	---
03175000	54.090	63.676	9.586	I-75	61962	1	2	3	66.7%	0	0.0%
12075000	0.000	20.767	20.767	I-75	74769	0	5	5	100.0%	0	0.0%
16320000	0.000	18.852	18.852	I-4	70385	47	182	229	79.5%	7	3.1%
16320000	19.913	21.870	1.957	I-4	66213	2	29	31	93.5%	0	0.0%
16320000	23.066	24.170	1.104	I-4	70492	1	13	14	92.9%	0	0.0%
16320000	25.155	27.327	2.172	I-4	69582	7	19	26	73.1%	0	0.0%
16320000	28.113	30.096	1.983	I-4	76917	5	21	26	80.8%	0	0.0%
16320000	31.133	32.022	0.889	I-4	84597	0	10	10	100.0%	0	0.0%
75002000	19.348	30.341	10.993	SR 528	39671	8	45	53	84.9%	3	5.7%
87471000	3.155	9.228	6.073	SR 821	57877	6	73	79	92.4%	2	2.5%
75301000	13.804	14.282	0.478	SR 417	26500	0	0	0	---	0	---
75320000	33.784	34.480	0.696	SR 429	25713	1	2	3	66.7%	0	0.0%
					Total	**90**	**459**	**549**	**83.6%**	**14**	**2.6%**

4.2 Individual Roadways

Table 4-2 provides the percentages of barrier crossover and non-crossover crashes at individual roadways (e.g., I-75, I-4, SR 528, etc.). An individual roadway combines one or more individual segments on the same facility. Table 4-2 indicates that there were no crashes related to cable median barrier along the 0.478-mile section on SR 417, while SR 821 experienced the highest percentage (92.4%) of non-crossover crashes. On the contrary, SR 429 experienced the lowest percentage (66.7%) of non-crossover crashes; however, it is recognized that the sample size is too small to yield any reliable results. It can also be seen that the three roadways, i.e., I-75, I-4, and SR 528, that were installed with significant lengths of cable median barrier experienced comparable percentages of non-crossover crashes, at 83.3%, 81.5%, and 84.9%, respectively.

Table 4-2: Barrier Crossover Crash Statistics by Individual Roadways

Roadway	Total Roadway Length (miles)	Barrier Crossover Crashes (a)	Barrier Non-Crossover Crashes (b)	Total Crashes (c) = (a) + (b)	Percent of Non-Crossover Crashes (b)/(c)
I-75	55.795	13	65	78	83.3%
I-4	26.957	62	274	336	81.5%
SR 528	10.993	8	45	53	84.9%
SR 821	6.073	6	73	79	92.4%
SR 417	0.478	0	0	0	---
SR 429	0.696	1	2	3	66.7%
Total	**100.992**	**90**	**459**	**549**	**83.6%**

4.3 Vehicle Type

This section focuses on the safety performance of cable median barriers by vehicle type. When a crash involved multiple vehicles, the vehicle that actually hit the cable median barrier 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. Five vehicles were coded as unknown since these vehicles fled the crash site prior to the arrival of law enforcement.

Table 4-3 gives the crash performance statistics of cable median barriers in terms of barrier crossover and non-crossover crashes by vehicle type. Of the 549 cable median barrier crashes, 90 were identified as barrier crossover crashes and 459 were non-crossover crashes. Of the 90 crossover crashes, 34 were over-rides, 29 were penetrations, and only 2 were under-rides. The barrier crossover type of 25 crashes could not be determined due to insufficient information in the police reports. Of the 459 non-crossover crashes, 285 were redirected while the rest (i.e., 174) were contained by the cable median barrier. Overall, 83.6% of all crashes were non-crossover crashes, and 85.4% of cars that hit the cable median barrier were either redirected or contained by the cable median barrier (i.e., non-crossover). Likewise, 79.9% 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 50.0% and 66.7%, respectively. This is expected as the cable median barrier has not been designed for these vehicle types. Further, lower sample sizes of these vehicle types make it difficult to come to reliable conclusions.

Table 4-4 gives the median crossover crash statistics by vehicle type. As discussed in Chapter 1, median crossover crashes are defined as the barrier crossover crashes that resulted in vehicle traversing into the opposite travel lane. Of the 549 cable median barrier related crashes, 14 resulted in vehicle traversing into the opposite travel lane. Of these 14 crashes, 8 were due to over-rides, 3 were because of penetrations, and the crossover category of the remaining 3 was unknown because of insufficient information in the police reports. Seven out of the 14 median crossover crashes were cars, and the remaining 7 were light trucks. Overall, a high 98.1% of cars that hit the cable median barrier were prevented from traversing into the opposite travel lane. Likewise, 95.5% of light trucks were preventing from crossing over the median. None of the other vehicle types traversed into the opposite travel lane. Overall, a relatively high 97.4% of the cable median barrier crashes were prevented from crossing over the median.

Table 4-3: Barrier Crossover Crash Statistics by Vehicle Type

Vehicle Type	Barrier Crossover Crashes					Barrier Non-Crossover Crashes			Total Crashes (i) = (e)+(h)	Percent of Barrier Non-Crossover Crashes (h)/(i)
	Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Crossover (e) = (a)+(b)+(c)+(d)	Redirected (f)	Contained (g)	Total Non-Crossover (h) = (f)+(g)		
Car	2	16	18	18	54	193	122	315	369	85.4%
Light Truck[1]	0	17	7	7	31	81	42	123	154	79.9%
Medium Truck[2]	0	0	1	0	1	0	1	1	2	50.0%
Heavy Truck[3]	0	1	3	0	4	3	5	8	12	66.7%
Motorcycle	0	0	0	0	0	1	1	2	2	100.0%
Unknown	0	0	0	0	0	4	1	5	5	100.0%
Other	0	0	0	0	0	3	2	5	5	100.0%
Total	**2**	**34**	**29**	**25**	**90**	**285**	**174**	**459**	**549**	**83.6%**

[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.

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

Vehicle Type	Median Crossover Crashes					Median Non-Crossover Crashes (f)	Total Crashes (g) = (e)+(f)	Percent of Median Non-Crossover Crashes (f)/(g)
	Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Crossover (e) = (a)+(b)+(c)+(d)			
Car	0	4	2	1	7	362	369	98.1%
Light Truck[1]	0	4	1	2	7	147	154	95.5%
Medium Truck[2]	0	0	0	0	0	2	2	100.0%
Heavy Truck[3]	0	0	0	0	0	12	12	100.0%
Motorcycle	0	0	0	0	0	2	2	100.0%
Unknown	0	0	0	0	0	5	5	100.0%
Other	0	0	0	0	0	5	5	100.0%
Total	**0**	**8**	**3**	**3**	**14**	**535**	**549**	**97.4%**

[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.

4.4 Crash Severity

This section focuses on the safety performance of cable median barriers 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 retrieved from the police reports:

- K – Fatal Injury
- A – Incapacitating Injury
- B – Non-Incapacitating Injury
- C – Possible Injury
- O – Property Damage Only

Table 4-5 identifies barrier crossover and non-crossover crashes by crash severity. Of the 549 cable median barrier related crashes, 8 were fatal crashes, 24 resulted in incapacitating injury, 55 resulted in non-incapacitating injury, 105 involved possible injury, 322 resulted in only property damage (PDOs), and the rest (i.e., 35) were of unknown severity. 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 90 barrier crossover crashes, 3.3% were fatal; of the 459 barrier non-crossover crashes, 1.1% were fatal. Slightly over one-third (35.6%) of the barrier crossover crashes were PDOs, while about two-thirds (63.2%) of non-crossovers were PDOs. From these statistics, it could be inferred that barrier crossover crashes, as expected, are more severe compared to barrier non-crossover crashes. In addition, over-rides are more severe compared to under-rides and penetrations.

Table 4-6 gives median crossover crash statistics by crash severity. Of the 14 median crossover crashes, 1 was a fatal crash, 1 resulted in an incapacitating injury, 4 were non-incapacitating injury crashes, 3 were possible injury, and 4 were PDOs. These numbers show that the median crossover crashes are slightly more severe compared to barrier crossover crash statistics.

Table 4-5: Barrier Crossover Crash Statistics by Crash Severity

Crash Severity[a]	Barrier Crossover Crashes						Barrier Non-Crossover Crashes			
	Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Crossover (e) = (a)+(b)+(c)+(d)	Percent of Total Crossover Crashes (e)/90	Redirected (f)	Contained (g)	Total Non-Crossover (h) = (f)+(g)	Percent of Total Non-Crossover Crashes (h)/459
K	0	2	1	0	3	3.3%	3	2	5	1.1%
A	0	5	3	1	9	10.0%	9	6	15	3.3%
B	0	13	4	2	19	21.1%	26	10	36	7.8%
C	0	7	8	8	23	25.6%	49	33	82	17.9%
O	2	6	10	14	32	35.6%	178	112	290	63.2%
Unknown[b]	0	1	3	0	4	4.4%	20	11	31	6.8%
Total	**2**	**34**	**29**	**25**	**90**	**100.0%**	**285**	**174**	**459**	**100.0%**

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

[b] 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	Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Median Crossover (e) = (a)+(b)+(c)+(d)	Percent of Total Median Crossover Crashes (e)/14
Fatal (K)	0	1	0	0	1	7.1%
Incapacitating (A)	0	0	0	1	1	7.1%
Non-Incapacitating (B)	0	3	1	0	4	28.6%
Possible (C)	0	3	0	0	3	21.4%
PDO (O)	0	1	1	2	4	28.6%
Unknown[+]	0	0	1	0	1	7.1%
Total	**0**	**8**	**3**	**3**	**14**	**100.0%**

[+] 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.

4.5 Cable Median Barrier Type

As identified in Table 3-1, the 23 study locations were installed with one of the four types of cable barrier systems: Brifen, CASS, Safence, or Gibraltar systems. Florida Turnpike (SR 821) is considered as a location for pilot study, and Brifen, CASS, and Safence were installed along the approximate 6-mile stretch. I-4 and I-75 in Collier and Lee counties (Roadway IDs: 03175000 and 12075000) were installed with Gibraltar while the rest of the study locations were installed with the CASS system. Cable median barrier crashes along SR 821 are considered as a "mixed" type since the section was installed with three types of cable barrier systems and it is difficult to accurately associate crashes to each cable barrier system due to potential incorrect crash locations. This section, therefore, focuses on the comparison of the performance of CASS and Gibraltar systems.

Table 4-7 gives the crash performance statistics of CASS and Gibraltar cable barrier systems in terms of barrier crossover and non-crossover crashes. A total of 37.609 miles of limited access facilities were installed with the CASS system and 57.31 miles were installed with Gibraltar cable barriers. The CASS system was hit 129 times and the Gibraltar system was hit 345 times. Of all crashes that hit the CASS system, 83.3% were non-crossover crashes. Similarly, the barrier non-crossover percentage was 81.7% for Gibraltar. This implies that 81.7% of all vehicles that hit the Gibraltar system were either redirected or contained by the system. The location on SR 821 was installed with the three types of cable barrier systems, and this location had a high non-crossover percentage of 92.4%.

Of the 129 crashes that hit the CASS barrier system, 21 were barrier crossovers. Three of the 21 CASS barrier crossover crashes (14.3%) were penetrations; 16 (76.2%) were over-rides and 2 (9.5%) were unknown. In contrast, of the 345 crashes that hit the Gibraltar system, 63 were barrier crossover crashes. Of these 63 crashes, 24 (38.1%) were penetrations; 17 (27.0%) were over-rides; 20 (31.7%) were unknown; and 2 (3.2%) were under-rides. The statistics show that the Gibraltar system experienced greater proportion of penetrations compared to the CASS system.

Table 4-8 gives the barrier crossover crash statistics of CASS and Gibraltar systems by vehicle type. For cars, 86.8% that hit the CASS system were either redirected or contained by the barrier; the percentage was a little lower at 82.6% for Gibraltar system. The CASS system prevented 78.4% of light trucks from crossing the barrier; while a similar percentage (79.6%) of light trucks were prevented by the Gibraltar system. For heavy trucks, the Gibraltar system was more successful in preventing barrier crossovers as the non-crossover percentage was 80.0% compared to 57.1% for the CASS system; however, these percentages are unreliable due to small sample size. Also, medium trucks and motorcycles were too few to yield meaningful results.

Table 4-7: Barrier Crossover Crash Statistics by Cable Median Barrier Type

Type of Cable Median Barrier	Total Section Length (miles)	Barrier Crossover Crashes					Barrier Non-Crossover Crashes			Total Crashes (i) = (e)+(h)	Percent of Barrier Non-Crossover Crashes (h)/(i)
		Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Crossover (e) = (a)+(b)+(c)+(d)	Redirected (f)	Contained (g)	Total Non-Crossover (h) = (f)+(g)		
CASS	37.609	0	16	3	2	21	55	50	105	126	83.3%
Gibraltar	57.310	2	17	24	20	63	186	95	281	344	81.7%
Mixed[+]	6.073	0	1	2	3	6	44	29	73	79	92.4%
Total	**100.992**	**2**	**34**	**29**	**25**	**90**	**285**	**174**	**459**	**549**	**83.6%**

[+]Three types of cable median barrier systems (i.e., CASS, Safence, and Brifen) were installed along SR 821.

Table 4-8: Barrier Crossover Crash Statistics of CASS and Gibraltar Systems by Vehicle Type

Vehicle Type	Barrier Crossover Crashes					Barrier-Non-Crossover			Total Crashes (i) = (e)+(h)	Percent of Barrier Non-Crossover Crashes (h)/(i)
	Under-ride (a)	Over-ride (b)	Penetration (c)	Unknown Crossover (d)	Total Crossover (e) = (a)+(b)+(c)+(d)	Redirected (f)	Contained (g)	Total Non-Crossover (h) = (f)+(g)		
CASS										
Car	0	8	1	1	10	35	31	66	76	86.8%
Light Truck[1]	0	7	0	1	8	16	13	29	37	78.4%
Medium Truck[2]	0	0	0	0	0	0	0	0	0	---
Heavy Truck[3]	0	1	2	0	3	1	3	4	7	57.1%
Motorcycle	0	0	0	0	0	0	0	0	0	---
Unknown	0	0	0	0	0	1	1	2	2	100.0%
Other	0	0	0	0	0	2	2	4	4	100.0%
Total	**0**	**16**	**3**	**2**	**21**	**55**	**50**	**105**	**126**	**83.3%**
Gibraltar										
Car	2	7	16	15	40	124	66	190	230	82.6%
Light Truck[1]	0	10	6	5	21	56	26	82	103	79.6%
Medium Truck[2]	0	0	1	0	1	0	0	0	1	0.0%
Heavy Truck[3]	0	0	1	0	1	2	2	4	5	80.0%
Motorcycle	0	0	0	0	0	1	1	2	2	100.0%
Unknown	0	0	0	0	0	3	0	3	3	100.0%
Other	0	0	0	0	0	0	0	0	0	---
Total	**2**	**17**	**24**	**20**	**63**	**186**	**95**	**281**	**344**	**81.7%**

[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 4-9 gives the performance of different types of cable barrier systems by crash severity. In this analysis, the severity was divided into fatal and severe injury (K+A) crashes, moderate and minor injury (B+C) crashes, PDO crashes, and “Unknown” crashes. 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 4-9: Performance of Different Cable Median Barrier Types by Crash Severity

Type of Cable Median Barrier	K+A		B+C		O		Unknown		Total	
	Number (a)	% (a)/(e)	Number (b)	% (b)/(e)	Number (c)	% (c)/(e)	Number (d)	% (d)/(e)	Number (e)= (a)+(b)+(c)+(d)	%
CASS	7	5.6%	48	38.1%	62	49.2%	9	7.1%	126	100%
Gibraltar	20	5.8%	89	25.9%	214	62.2%	21	6.1%	344	100%
Mixed	5	6.3%	23	29.1%	46	58.2%	5	6.3%	79	100%
Total	**32**	**5.8%**	**160**	**29.1%**	**322**	**58.7%**	**35**	**6.4%**	**549**	**100%**

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

Table 4-9 shows that 5.8% of all crashes that hit the cable median barrier were either fatal or incapacitating injury crashes, 29.1% resulted in moderate or minor injury, 58.7% were PDOs, and the rest (6.4%) were of unknown severity. The CASS and Gibraltar systems performed similarly in terms of fatal and severe injury crashes; the proportion of K+A crashes were 5.6% and 5.8% for CASS and Gibraltar systems, respectively. Less than half of total crashes (i.e., 49.2%) that hit the CASS system were PDOs, while 62.2% of the crashes that hit the Gibraltar system were PDOs. From these statistics, it could be concluded that the CASS system resulted in a slightly higher percentage of moderate and minor injury crashes compared to the Gibraltar system.

4.6 Summary

This chapter focused on the barrier and median crossover statistics by site location, vehicle type, crash severity, and cable median barrier type. The 23 study locations experienced a total of 549 cable barrier related crashes, i.e., crashes in which the errant vehicles hit the cable median barrier at any point during the crash. Police reports of these 549 crashes were 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 classified as under-ride, over-ride, or penetration. Non-crossover crashes were classified as either redirected or contained. Crashes that resulted in vehicles traversing the opposite travel lane (i.e., median crossover crashes) were also identified and analyzed.

Overall, 83.6% of vehicles that hit the cable median barrier were prevented from crossing over. Of all cars that hit the cable median barrier, 85.4% were either redirected or contained by the cable median barrier. Likewise, 79.9% of light trucks were barrier non-crossover crashes. Fewer medium and heavy trucks that hit the barrier were prevented from crossing the barrier. This is expected as the cable median barrier has not been designed for these vehicle types.

The 23 study locations were installed with one of the four types of cable barrier systems: Brifen, CASS, Safence, or Gibraltar systems. Three types of cable barrier systems (Brifen, CASS, and Safence) were installed along the approximate 6-mile stretch on Florida Turnpike (SR 821). A total of 37.609 miles of limited access facilities in Florida were installed with the CASS system (excluding the section with CASS on SR 821) and 57.310 miles were installed with Gibraltar cable barriers. The CASS system was hit 129 times and the Gibraltar system was hit 345 times. The statistics show that the Gibraltar system experienced a greater proportion of penetrations compared to the CASS system.

Of all the crashes that hit the CASS system, 83.3% were barrier non-crossover crashes. Similarly, the barrier non-crossover percentage was 81.7% for Gibraltar. For cars, 86.8% that hit the CASS system were either redirected or contained by the barrier; the percentage was a little lower at 82.6% for Gibraltar system. The CASS system prevented 78.4% of light trucks from crossing the barrier; while a similar percentage (79.6%) of light trucks were prevented by the Gibraltar system. For heavy trucks, the Gibraltar system was more successful in preventing barrier crossovers as the non-crossover percentage was 80.0% compared to 57.1% for the CASS system.

Of all the crashes that hit the cable median barrier, 5.8% were either fatal or incapacitating injury crashes, 29.1% resulted in moderate or minor injury, 58.7% were PDOs, and the rest (6.4%) were of unknown severity. The CASS and Gibraltar systems performed very similarly in terms of K+A crashes; however, the CASS system resulted in a slightly higher percentage of moderate and minor injury crashes compared to the Gibraltar system.

Of the 549 crashes that involved errant vehicles hitting the cable median barrier, 14 (2.6%) resulted in vehicle traversing into the opposite travel lane. In other words, 97.4% of all cable median barrier crashes were prevented from crossing over the median. A high 98.1% of cars that hit the cable median barrier were prevented from traversing into the opposite travel lane. Likewise, 95.5% of light trucks were preventing from crossing over the median. None of the other vehicle types traversed into the opposite travel lane.

CHAPTER 5
BEFORE-AND-AFTER ANALYSIS

This chapter includes a before-and-after analysis of cable median barriers based on median-related crashes. As defined in Chapter 3, a crash where an errant vehicle leaves the designated travel lane to the left (i.e., toward the median) at any point during the crash is classified as a median-related crash. The focus on median-related crashes allows the study to more precisely evaluate the safety impacts of cable median barrier installation and ensure that the results are not affected by other unrelated crashes. The analysis evaluates crash statistics for all study locations combined as well as for individual locations. In addition, CMFs and CRFs for different severity levels are also developed.

5.1 Study Locations and Crash Data

The study locations were selected from the list of 23 locations listed in Table 3-1. It can be seen from the table that cable median barriers were installed in 2010 on 8 of the 23 locations; these locations were excluded from the analysis since there was no sufficient data in the after period. Of the remaining 15 locations, it was determined that any location shorter than 3 miles would be excluded, leaving a total of 3 relatively long segments measuring a total of approximately 36 miles. The exclusion of short segments was done to minimize the negative impact from freeway crash mileposts that are known to be imprecise. Table 5-1 lists the three study locations used in this analysis.

Table 5-1: Before-and-After Study Locations

Road Name	Roadway ID	Beg MP	End MP	Segment Length (mi)	Construction Start Date	Construction End Date
SR 528	75002000	19.348	30.341	10.993	8/7/2005	3/5/2006
Florida Turnpike (SR 821)	87471000	3.155	9.228	6.073	May 2005	July 2006
I-4	16320000	0.000	18.852	18.852	October 2006	May 2007

Police reports for up to three years of before and after periods for each of these locations were extracted and reviewed. They included a total of 1,171 crashes occurred in the before periods and 1,103 crashes occurred in the after periods, for a total of 2,274 total crashes. Out of these crashes, 917 (or 40.3%) were first classified as median-related crashes. Of the 917 crashes, a total of 153 crashes were determined to be hitting the concrete barriers at several bridge locations and were excluded. Additionally, 20 median-related crashes were excluded because of insufficient information in the police reports. Finally, 744 crashes were identified as median-related, of which 279 occurred in the before period and 465 occurred in the after period. In other words, median-related crashes increased after the installation of cable median barriers. This observation is consistent with Hunter et al. (2001).

5.2 All Study Locations

Table 5-2 gives the before-and-after statistics of median-related crashes at the three locations. The table shows that, after the installation of cable median barriers, SR 528 experienced a 3.5%

reduction in median-related crash rate, while SR 821 and I-4 experienced an increase of 26.6% and 47.6%, respectively. Overall, the median-related crash rate increased by 37.8% after cable median barrier installation. This increase is consistent with previous studies, e.g., Sposito (2000), Murphy (2006), Arnold (2006), and Sheikh et al. (2008), as the presence of a barrier usually increases the number of crashes involving property damage and minor injury as a result of vehicles hitting the barrier.

Table 5-3 shows the summary statistics of median crossover crashes in the before and after periods at each of the three locations. As discussed in Chapter 1, median crossover crashes are defined as the crashes in which any of the involved vehicles crosses the median and traverses into the opposite travel lane. After the installation of cable median barriers, all three study locations experienced an overall reduction of 78.8% in median crossover rate. Specifically, the median crossover crash rate was reduced from 1.93 crashes/100MVM/year in the before period to 0.41 crashes/100MVM/year in the after period; SR 821 experienced the highest reduction at 88.8%, followed by SR 528 at 85.0%, and I-4 at 69.5%.

Table 5-2: Changes in Crash Rates of Median-Related Crashes

Road Name	Roadway ID	Beg MP	End MP	Segment Length (mi)	Before				After				Percent Change in Crash Rate
					Period (months)	No. of Crashes	AADT	Crash Rate[a]	Period (months)	No. of Crashes	AADT	Crash Rate[a]	
SR 528	75002000	19.348	30.341	10.993	31	42	37429	10.83	36	52	41325	10.45	-3.5%
SR 821	87471000	3.155	9.228	6.073	28	45	43218	20.13	36	104	61390	25.48	26.6%
I-4	16320000	0.000	18.852	18.852	36	192	68044	13.67	36	309	74191	20.18	47.6%
Overall Median-Related Crash Rate					**---**	**279**	**---**	**13.84**	**---**	**465**	**---**	**19.08**	**37.8%**

[a] Crash rate is in 100 MVM/year.

Table 5-3: Changes in Crash Rates of Median Crossover Crashes

Road Name	Roadway ID	Beg MP	End MP	Segment Length (mi)	Before			After			Percent Change in Crash Rate
					Period (months)	No. of Median Crossover Crashes	Median Crossover Crash Rate[a]	Period (months)	No. of Median Crossover Crashes	Median Crossover Crash Rate[a]	
SR 528	75002000	19.348	30.341	10.993	31	16	4.12	36	3	0.60	-85.0%
SR 821	87471000	3.155	9.228	6.073	28	5	2.23	36	1	0.25	-88.8%
I-4	16320000	0.000	18.852	18.852	36	18	1.28	36	6	0.39	-69.5%
Overall Median Crossover Crash Rate					**---**	**39**	**1.93**	**---**	**10**	**0.41**	**-78.8%**

[a] Crash rate is in 100 MVM/year.

Table 5-4 provides the overall changes in crash severity for all locations for each of the following six severity levels: fatal injury (K), incapacitating injury (A), non-incapacitating injury (B), possible or minor injury (C), PDO (O), and "Unknown" severity. 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 5-4: Changes in Crash Rates for All Locations by Crash Severity

Crash Severity	Before		After		Percent Change in Crash Rate
	Crash Number	Crash Rate[b]	Crash Number	Crash Rate[b]	
Fatal (K)	13	0.64	9	0.37	-42.2%
Incapacitating Injury (A)	31	1.54	30	1.23	-20.1%
Non-Incapacitating Injury (B)	59	2.93	63	2.59	-11.6%
Possible Injury (C)	55	2.73	102	4.18	53.1%
PDO (O)	114	5.65	259	10.63	88.1%
Unknown[a]	7	0.35	2	0.08	-77.1%
Total	**279**	**13.84**	**465**	**19.08**	**37.8%**

[a] 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.
[b] Crash rate is in 100 MVM/year.

It can been seen from Table 5-4 that after cable median barrier installation, there was an increase in the PDO crash rate (88.1%) and possible injury crash rate (53.1%). This is expected as more vehicles hit the cable median barrier due to reduction in the effective clear-recovery width in the median. Reductions of 42.2%, 20.1%, and 11.6% were observed in fatal, incapacitating, and non-incapacitating crash rates, respectively. The reduction in fatal crash rates is consistent with Arnold (2006), Hammond and Batiste (2008), Sheikh et al. (2008), and Cooner et al. (2009).

Table 5-5 gives the distribution of fatal and severe injury (K+A) crash rates by vehicle type in the before and after periods. For this analysis, 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. Vehicles were coded as unknown when vehicles fled the crash site prior to the arrival of law enforcement.

In the after period, a reduction in fatal and severe injury (K+A) crash rates was observed for all vehicle types. The overall K+A crash rates were reduced by 26.6%. The highest reduction was experienced by motorcycles at 73.3%, followed by light trucks at 35.6%, and cars at 10.8%. It is recognized that the very small sample sizes for medium and heavy trucks made it difficult to reach reliable conclusions.

Table 5-5: Changes in K+A Crash Rates for All Locations by Vehicle Type

Vehicle Type	Before		After		Percent Change in (K+A) Crash Rate
	(K+A) Crash Number	(K+A) Crash Rate[d]	(K+A) Crash Number	(K+A) Crash Rate[d]	
Car	26	1.29	28	1.15	-10.8%
Light Truck[a]	9	0.45	7	0.29	-35.6%
Medium Truck[b]	1	0.05	0	0.00	-100.0%
Heavy Truck[c]	1	0.05	1	0.04	-20.0%
Motorcycle	6	0.30	2	0.08	-73.3%
Others	1	0.05	1	0.04	-20.0%
Total	**44**	**2.18**	**39**	**1.60**	**-26.6%**

[a] Light Trucks include vans and pickup trucks with two or four rear tires.
[b] Medium Trucks are vehicles with four rear tires.
[c] Heavy Trucks include truck tractors.
[d] Crash rate is in 100 MVM/year.

5.3 Individual Study Locations

Table 5-6 gives the before-and-after statistics of median-related crashes by crash severity and vehicle type on SR 528. The 10.993-mile segment on SR 528 experienced a total of 52 crashes in the 36-month after period and 42 crashes in the 31-month before period. Even though the crash frequency increased in the after period, the location experienced a 3.5% reduction in median-related crash rate. In the after period, PDO and possible injury crash rates were increased by 64.7% and 90.0%, respectively; while the fatal, incapacitating, and non-incapacitating injury crash rates reduced by 55.5%, 80.6%, and 44.3%, respectively.

Before and after the cable median barrier installations, the location had no change in the median-related crash rate of cars. On the other hand, crash rate of light trucks was increased by 21.6%. Crash rates of medium trucks, heavy trucks, and motorcycles decreased in the after period.

Table 5-6: Changes in Crash Rates Along SR 528 by Crash Severity and Vehicle Type

SR 528, Roadway ID: 75002000, BMP: 19.348, EMP: 30.341, Segment length: 10.993 miles					
	Before (31 months)		**After (36 months)**		**Percent Change in Crash Rate**
	Crash Number	**Crash Rate[c]**	**Crash Number**	**Crash Rate[c]**	
Crash Severity					
Fatal (K)	7	1.80	4	0.80	-55.5%
Incapacitating Injury (A)	4	1.03	1	0.20	-80.6%
Non-Incapacitating Injury (B)	14	3.61	10	2.01	-44.3%
Possible Injury (C)	7	1.80	17	3.42	90.0%
PDO (O)	9	2.32	19	3.82	64.7%
Unknown[a]	1	0.26	1	0.20	-23.1%
Total	**42**	**10.83**	**52**	**10.45**	**-3.5%**
Vehicle Type					
Car	25	6.44	32	6.44	0.0%
Light Truck	9	2.32	14	2.82	21.6%
Medium Truck	1	0.26	0	0.00	-100.0%
Heavy Truck	4	1.03	1	0.20	-80.6%
Motorcycle	3	0.77	0	0.00	-100.0%
Others	0	0.00	3	0.60	---
Unknown[b]	0	0.00	2	0.40	---
Total	**42**	**10.83**	**52**	**10.45**	**-3.5%**

[a] Severity level is unknown because the driver fled the crash site prior to the arrival of law enforcement or a discrepancy exists between the coded severity level in the CAR system and the severity level in the police report.
[b] Vehicles fled the crash site prior to the arrival of law enforcement.
[c] Crash rate is in 100 MVM/year.

Table 5-7 gives the median-related crash statistics by crash severity and vehicle type on Florida Turnpike (SR 821). The 6.073-mile segment experienced a total of 104 crashes in the 36-month after period and 45 crashes in the 28-month before period. Unlike SR 528, SR 821 experienced a 26.6% increase in crash rate after the installation of cable median barriers. At this location, both fatal and severe injury crash rates reduced by 44.9% and 56.1%, respectively. A slight 3.1% increase in non-incapacitating injury crash rate was observed. Both PDO and possible injury crash rates increased by 154.6% and 28.0%, respectively.

After the installation of cable median barriers, crash rates of cars and light trucks increased by 36.4% and 21.9%, respectively. On the other hand, a reduction of 59.2% was observed in motorcycle crash rate. Other vehicle types were very few to come to reliable conclusions.

Table 5-7: Changes in Crash Rates Along SR 821 by Crash Severity and Vehicle Type

SR 821, Roadway ID: 87471000, BMP: 3.155, EMP: 9.228, Segment length: 6.073 miles					
	Before (28 months)		**After (36 months)**		**Percent Change in Crash Rate**
	Crash Number	**Crash Rate[b]**	**Crash Number**	**Crash Rate[b]**	
Crash Severity					
Fatal (K)	2	0.89	2	0.49	-44.9%
Incapacitating Injury (A)	10	4.46	8	1.96	-56.1%
Non-Incapacitating Injury (B)	8	3.57	15	3.68	3.1%
Possible Injury (C)	12	5.36	28	6.86	28.0%
PDO (O)	11	4.91	51	12.50	154.6%
Unknown[a]	2	0.89	0	0.00	-100.0%
Total	**45**	**20.13**	**104**	**25.48**	**26.6%**
Vehicle Type					
Car	31	13.83	77	18.87	36.4%
Light Truck	9	4.02	20	4.90	21.9%
Medium Truck	0	0.00	2	0.49	---
Heavy Truck	0	0.00	1	0.25	---
Motorcycle	4	1.79	3	0.73	-59.2%
Others	1	0.45	1	0.25	-44.4%
Total	**45**	**20.13**	**104**	**25.48**	**26.6%**

[a] Severity level is unknown because the driver fled the crash site prior to the arrival of law enforcement or a discrepancy exists between the coded severity level in the CAR system and the severity level in the police report.
[b] Crash rate is in 100 MVM/year.

Table 5-8 gives the median-related crash statistics by crash severity and vehicle type on I-4. The 18.852-mile section experienced a total of 309 crashes in the 36-month after period and 192 crashes in the 36-month before period. Similar to SR 821, I-4 experienced a 47.6% increase in crash rate after the installation of cable median barriers. At this location, fatal crash rate reduced by 32.1%. Both PDO and possible injury crash rates increased by 84.5% and 45.3%, respectively. Unlike the other two locations, the crash rate of incapacitating injury crashes increased by 13.2%.

After the installation of cable median barriers, crash rates of cars and light trucks increased by 65.8% and 55.8%, respectively. On the other hand, a reduction of 54.1% was observed in heavy truck crash rate. Other vehicle types were very few to come to reliable conclusions.

Table 5-8: Changes in Crash Rates Along I-4 by Crash Severity and Vehicle Type

I-4, Roadway ID: 16320000, BMP: 0.000, EMP: 18.852, Segment length: 18.852 miles					
	Before (36 months)		After (36 months)		Percent Change in Crash Rate
	Crash Number	Crash Rate[b]	Crash Number	Crash Rate[b]	
Crash Severity					
Fatal (K)	4	0.28	3	0.19	-32.1%
Incapacitating Injury (A)	17	1.21	21	1.37	13.2%
Non-Incapacitating Injury (B)	37	2.63	38	2.48	-5.7%
Possible Injury (C)	36	2.56	57	3.72	45.3%
PDO (O)	94	6.69	189	12.34	84.5%
Unknown[a]	4	0.28	1	0.07	-75.0%
Total	**192**	**13.67**	**309**	**20.18**	**47.6%**
Vehicle Type					
Car	120	8.54	217	14.16	65.8%
Light Truck	47	3.35	80	5.22	55.8%
Medium Truck	5	0.36	3	0.20	-44.4%
Heavy Truck	12	0.85	6	0.39	-54.1%
Motorcycle	3	0.21	2	0.13	-38.1%
Others	5	0.36	1	0.07	-80.6%
Total	**192**	**13.67**	**309**	**20.18**	**47.6%**

[a] Severity level is unknown because the driver fled the crash site prior to the arrival of law enforcement or a discrepancy exists between the coded severity level in the CAR system and the severity level in the police report.
[b] Crash rate is in 100 MVM/year.

5.4 Crash Reduction Factors and Crash Modification Factors

A Crash Reduction Factor (CRF) is a measure of the percentage reduction in crash rate that might be expected after implementing a given countermeasure. A CRF based on a simple before-and-after analysis can thus be calculated as:

$$CRF = \frac{Crash\ Rate_B - Crash\ Rate_A}{Crash\ Rate_B} \times 100 \qquad (5\text{-}1)$$

where $Crash\ Rate_B$ is the crash rate in the before period (i.e., before installing the cable median barrier) and $Crash\ Rate_A$ is the crash rate in the after period (i.e., after installing the cable median barrier).

The CRFs associated with cable median barrier installation for median-related crashes for different injury severity levels can be obtained directly from before and after crash rates in Table 5-4.

A variation of CRF that is increasingly being used is the Crash Modification Factors (CMFs), which is the complement of CRF and can be calculated as follows:

$$CMF = 1 - CRF(\%)/100 \quad (5\text{-}2)$$

A CMF less than 1 for a countermeasure indicates a potential reduction in crash rate after the countermeasure's implementation, while a CMF greater than 1 indicates a potential increase. Table 5-9 lists the CRFs and CMFs for median-related crashes for installing cable median barriers on limited access facilities as a countermeasure. The factors indicate that cable median barrier installation could reduce 42.2% of median-related fatal crash rates (K), 20.1% of incapacitating median-related injury crash rates (A), and 11.6% of non-incapacitating median-related crash rates (B), but increase the median-related crash rates involving possible injury and property damage by 53.1% and 88.1%, respectively, for an overall crash rate increase of 37.8%. These factors can be used in the economic analysis of cable median barrier installation to estimate its monetary benefit from potential crash reduction.

Table 5-9: CRFs and CMFs for Cable Median Barrier Installation

Crash Severity	**Crash Reduction Factor (CRF)**	**Crash Modification Factor (CMF)**
Fatal (K)	42.2%	0.578
Incapacitating Injury (A)	20.1%	0.799
Non-Incapacitating Injury (B)	11.6%	0.884
Possible Injury (C)	-53.1%	1.531
PDO (O)	-88.1%	1.881
Total	**-37.8%**	**1.378**

5.5 Summary

This chapter focused on the before-and-after analysis by evaluating the changes in median-related crashes and median crossovers. It also included the analysis of median-related crashes by crash severity and vehicle type. Three locations on SR 821, SR 528, and I-4 were used in the analysis; the three locations together had 744 median-related crashes (279 and 465 in the before and after periods, respectively).

After the installation of cable median barriers, the overall median-related crash rate was increased by 37.8%; overall median crossover rate was decreased by 78.8%. SR 821 experienced the highest reduction of 88.8% in median crossover rate even though it experienced an increase of 26.6% in median-related crash rate. Similarly, a 69.5% reduction in median crossover rate was observed on I-4 while the median-related crash rate increased by 47.6%. Unlike these two locations, SR 528 experienced an 85.0% reduction in median crossover rate and a 3.5% reduction in median-related crash rate.

The installation of cable median barriers resulted in an increase in the PDO crash rate (88.1%) and possible injury crash rate (53.1%). This is expected as more vehicles hit the cable median barrier due to reduction in the effective clear-recovery width in the median. Reductions of 42.2%, 20.1%, and 11.6% were observed in fatal, incapacitating, and non-incapacitating crash rates, respectively. The overall fatal and severe injury (K+A) crash rate was reduced by 26.6%.

The highest reduction in K+A crash rate was experienced by motorcycles at 73.3%, followed by light trucks at 35.6%, and cars at 10.8%. Small sample sizes of medium and heavy trucks made it difficult to reach reliable conclusions. At each of the three locations, crash rate of light trucks increased in the after period. Crash rates of cars increased at two of the three locations, and stayed the same on SR 528.

Finally, CRFs and CMFs were calculated to estimate the expected reduction in median-related crash rate after installing cable median barriers. The results show that cable median barrier installation reduced fatal crash rate by 42.2%, severe injury crash rate by 20.1%, and minor injury crash rate by 11.6%, but increased the crash rates involving possible injury and property damage by 53.1% and 88.1%, respectively, for an overall crash rate increase of 37.8%.

CHAPTER 6
SUMMARY AND CONCLUSIONS

The main objective of this project is to evaluate the safety performance of cable median barrier systems installed on limited access facilities (i.e., freeways and expressways) in Florida. This safety performance evaluation was conducted using the following two types of analysis:

1. Percentages of barrier and median crossovers by site location, vehicle type, crash severity, and cable barrier type.
2. Comparisons of median-related crash statistics before and after cable median barrier installations by crash severity and vehicle type.

In this study, the effectiveness of cable median barrier is measured by the percentages of errant vehicles prevented from: (1) crossing the cable median barrier, i.e., barrier crossover; and (2) crossing the median, i.e., median crossover. A crash in which an errant vehicle crosses the cable median barrier at any point during the crash is categorized as a barrier crossover crash. If the errant vehicle reaches the opposite travel lane after crossing the barrier, it becomes a median crossover crash. A barrier can be crossed over by under-riding, over-riding, or penetrating the cable median barrier. A crash is categorized as non-crossover when an errant vehicle does not cross over the cable median barrier at any point during the crash. A non-crossover crash can be classified as either redirected or contained by the cable barrier system.

A total of 23 locations totaling about 101 miles with cable median barriers were identified and verified using the state's roadway database and Google Earth. The construction periods for cable median barrier installation at the 23 locations were obtained from the district offices. In the years 2003-2010, a total of 8,818 crashes occurred at these locations. Police reports of these 8,818 crashes were downloaded and reviewed in detail. For before-and-after analysis, the review focused on identifying median-related crashes. A crash where an errant vehicle leaves the designated travel lane to the left (i.e., toward the median) at any point during the crash is classified as a median-related crash. For crossover analysis, the review focused on identifying crossover crashes and identifying crash consequences of vehicles hitting the barrier.

6.1 Crossover Analysis

The 23 study locations experienced a total of 549 cable barrier related crashes, i.e., crashes in which the errant vehicles hit the cable median barrier at any point during the crash. Of the 549 crashes that hit the cable median barrier, 90 were barrier crossover crashes and 459 were non-crossover. Of the 90 barrier crossover crashes, 34 were over-rides, 29 were penetrations, and only 2 were under-rides. The barrier crossover type of 25 crashes could not be determined due to insufficient information in the police reports. Of the 459 non-crossover crashes, 285 were redirected while the rest (i.e., 174) were contained by the cable median barrier.

The overall effective rate of installing cable median barrier to prevent barrier crossover crashes is high at 83.6%. Of all the cars that hit the barrier, 85.4% were either redirected or contained by the cable median barrier. Likewise, 79.9% of light trucks were barrier non-crossover crashes. Fewer medium and heavy trucks that hit the barrier were prevented from crossing the barrier.

This is expected as the cable median barrier has not been designed for these vehicle types. Further, lower sample sizes of these vehicle types make it difficult to come to reliable conclusions.

The 23 study locations were installed with one of the four types of cable barrier systems: Brifen, CASS, Safence, or Gibraltar systems. Three types of cable barrier systems (Brifen, CASS, and Safence) were installed along the approximate 6-mile stretch on Florida Turnpike (SR 821). A total of 37.609 miles of limited access facilities in Florida were installed with the CASS system (excluding the section with CASS on SR 821) and 57.31 miles were installed with Gibraltar cable barriers. The CASS system was hit 129 times and the Gibraltar system was hit 345 times.

The statistics show that the Gibraltar system experienced greater proportion of penetrations compared to the CASS system. When the performance of the two cable barrier systems was compared for different vehicle types, it was observed that the barrier crossover percentages for cars and light trucks were very similar for the two systems. However, for heavy trucks, the Gibraltar system was more successful in preventing barrier crossovers as the non-crossover percentage was 80.0% compared to 57.1% for the CASS system; these percentages are unreliable due to small sample size and have to be used with caution.

Of all crashes that hit the cable median barrier, 5.8% were either fatal or incapacitating injury crashes; 29.1% resulted in moderate or minor injury; 58.7% were PDOs and the rest (6.4%) were of unknown severity. The CASS and Gibraltar systems performed similarly in terms of severe injury crashes; however, the CASS system resulted in a slightly higher percentage of moderate and minor injury crashes compared to the Gibraltar system.

Of the 549 crashes that involved errant vehicles hitting the cable median barrier, 14 (2.6%) resulted in vehicle traversing into the opposite travel lane. Of these 14 crashes, 8 were due to over-rides, 3 were because of penetrations, and the crossover category of the remaining 3 was unknown because of insufficient information in the police reports. A relatively high 98.1% of cars that hit the cable median barrier were prevented from traversing into the opposite travel lane. Likewise, 95.5% of light trucks were preventing from crossing over the median. None of the other vehicle types traversed into the opposite travel lane.

In summary, cable median barriers are successful in preventing median crossover crashes; a relatively high 97.4% of the cable median barrier crashes were prevented from crossing over the median. Of all the vehicles that hit the barrier, 83.6% were either redirected or contained by the cable barrier system.

6.2 Before-and-After Analysis

A before-and-after safety evaluation of cable median barriers was conducted based on median-related crashes. Cable median barriers were installed in 2010 on eight of the 23 locations; these locations were excluded from the analysis since there is no sufficient data in the after period. Further, locations shorter than 3 miles were also excluded from this analysis to minimize the bias of incorrect crash locations. The before-and-after analysis was conducted based on the following

three relatively long segments measuring a total of approximately 36 miles: Florida Turnpike, SR 528, and I-4.
The before-and-after analysis was based on the identified 744 median-related crashes (279 and 465 in the before and after periods, respectively). The analysis focused on evaluating the change in crash rate of median-related crashes, median crossovers, and site-specific evaluation by crash severity and vehicle type.

After the installation of cable median barriers, the overall median-related crash rate was increased by 37.8%; overall median crossover rate was decreased by 78.8%. SR 821 experienced the highest reduction of 88.8% in median crossover rate even though it experienced an increase of 26.6% in median-related crash rate. Similarly, a 69.5% reduction in median crossover rate was observed on I-4 while the median-related crash rate increased by 47.6%. Unlike these two locations, SR 528 experienced an 85.0% reduction in median crossover rate and a 3.5% reduction in median-related crash rate.

The installation of cable median barriers resulted in an increase in the PDO crash rate (88.1%) and possible injury crash rate (53.1%). This is expected as more vehicles hit the cable median barrier due to reduction in the effective clear-recovery width in the median. Reductions of 42.2%, 20.1%, and 11.6% were observed in fatal, incapacitating, and non-incapacitating crashes, respectively. The overall fatal and severe injury (K+A) crash rate was reduced by 26.6%.

The highest reduction in K+A crash rate was experienced by motorcycles at 73.3%, followed by light trucks at 35.6%, and cars at 10.8%. Small sample sizes of medium and heavy trucks made it difficult to reach reliable conclusions. At each of the three locations, crash rate of light trucks increased in the after period. Crash rates of cars increased at two of the three locations, and stayed the same on SR 528.

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