Safety performance evaluation of cable median barriers on freeways in Florida

Priyanka Alluri, Kirolos Haleem, Albert Gan, and John Mauthner

Department of Civil and Environmental Engineering, Florida International University, Miami, Florida; AgileAssets, Inc., Austin, Texas; BasLee Engineering Solutions (BES), Inc., Tallahassee, Florida

Objective: This article aims to evaluate the safety performance of cable median barriers on freeways in Florida.

Method: The safety performance evaluation was based on the percentages of barrier and median crossovers by vehicle type, crash severity, and cable median barrier type (Trinity Cable Safety System [CASS] and Gibraltar system). Twenty-three locations with cable median barriers totaling about 101 miles were identified. Police reports of 6,524 crashes from years 2005–2010 at these locations were reviewed to verify and obtain detailed crash information. A total of 549 crashes were determined to be barrier related (i.e., crashes involving vehicles hitting the cable median barrier) and were reviewed in further detail to identify crossover crashes and the manner in which the vehicles crossed the barriers; that is, by either overriding, underriding, or penetrating the barriers.

Results: Overall, 2.6% of vehicles that hit the cable median barrier crossed the median and traversed 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. In other words, 1.9% of cars and 4.5% of light trucks that hit the barrier had crossed the median and encroached on the opposite travel lanes. There is no significant difference in the performance of cable median barrier for cars versus light trucks in terms of crossover crashes. In terms of severity, overrides were more severe compared to underrides and penetrations. The statistics showed that the CASS and Gibraltar systems performed similarly in terms of crossover crashes. However, the Gibraltar system experienced a higher proportion of penetrations compared to the CASS system. The CASS system resulted in a slightly higher percentage of moderate and minor injury crashes compared to the Gibraltar system.

Conclusions: Cable median barriers are successful in preventing median crossover crashes; 97.4% of the cable median barrier crashes were prevented from crossing over the median. Of all of the vehicles that hit the barrier, 83.6% were either redirected or contained by the cable barrier system. Barrier crossover crashes were found to be more severe compared to barrier noncrossover crashes. In addition, overrides were found to be more severe compared to underrides and penetrations.

Introduction

Median crossovers on freeways often result in fatalities or severe injuries to occupants of the errant vehicles or the road users in the opposing lanes (Federal Highway Administration [FHWA] 2014). For example, between 1990 and 1999, only 2.4% of all interstate crashes in Iowa were median crossovers; however, these crashes resulted in 32.7% of all interstate fatalities (FHWA 2014). Cable median barriers are increasingly being installed on freeways due to their lower installation costs compared to other barriers such as concrete barriers and guardrails. Similar to other barriers, cable median barriers are installed to prevent errant vehicles from striking a roadside obstacle, traversing non-recoverable terrain, or colliding with traffic from the opposite direction. Figure A1 (see online supplement) shows the 5 high-tension cable barrier systems that are currently being installed in the United States (Alberson et al. 2007; Keel 2006).

This article describes an effort by the Florida Department of Transportation (FDOT) to evaluate the safety performance of cable median barriers installed on freeways in Florida (Alluri et al. 2012). The evaluation is based on the percentages of barrier and median crossovers by vehicle type, crash severity, and cable median barrier type. In this study, 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 crosses the median and traverses into the opposite travel lanes, it becomes a median crossover crash. Barrier crossover crashes, whether they involve vehicles going into the opposite travel lanes or not, are important because they measure the actual performance of the barrier when struck by errant vehicles. A vehicle can cross over a barrier in one of the following 3 manners:

- By underriding, which involves an errant vehicle crossing the barrier by sliding under the cables.

CONTACT Priyanka Alluri palluri@fiu.edu Department of Civil and Environmental Engineering, Florida International University, 10555 W Flagler Street, EC 3680, Miami, FL 33174,
Kirolos Haleem’s present affiliation is The University of Alabama in Huntsville, Huntsville, Alabama. John Mauthner’s present affiliation is Mauthner Engineering Services, LLC, Lutz, Florida.
Associate Editor Clay Gabler oversaw the review of this article.
Supplemental data for this article can be accessed on the publisher’s website.
© 2016 Taylor & Francis Group, LLC
• By overriding, which involves an errant vehicle crossing the barrier by riding on top of the cables.
• By penetrating, which involves an errant vehicle crossing the barrier by going through the cables.

A crash is categorized as noncrossover when an errant vehicle does not cross over the cable median barrier at any point during the crash. A noncrossover crash can be classified as either redirected or contained by the cable median barrier. Again, by definition:
• A redirected noncrossover 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 noncrossover crash is classified as one when an errant vehicle hits the cable median barrier and is restrained by the cables.

Categorization of crashes based on these detailed definitions requires information that is unavailable in typical crash summary records. Crash-specific information, such as crashes that are directly related to cable median barrier, crossover crash classification, type of vehicle that hit the cable median barrier, etc., could only be determined from a detailed review of police crash reports. As such, a major effort of this study was to manually review police reports of all crashes that occurred at the study locations.

**Existing studies**

Several studies have been conducted on the safety performance evaluation of cable barriers. A majority of these studies are based on crash tests, regression models, and software tools. For example, Donnell and Mason (2006) used regression models to develop median barrier warrant criteria. Sicking et al. (2009) used data from police reports, regression models, and a roadside safety analysis program to develop guidelines for installing cable median barriers. Marzougui et al. (2007) used finite element analysis, vehicle dynamics analysis, and full-scale crash testing to evaluate the performance of low-tension 3-strand cable median barriers. Davis and Pei (2005) used Markov chain Monte Carlo and Bayesian methods to reconstruct 2 cross-median crashes to verify that simulation could be used to estimate impact severity of crashes involving cable median barriers.

Hu and Donnell (2010) predicted the severity of median barrier crashes using a nested logit model. The analysis was based on 3,691 median barrier crashes that occurred from 2000 to 2004 on 453 miles of rural highways in North Carolina that were installed with cable, guardrail, and concrete barriers. In addition to the commonly used roadway, vehicle, driver, and median cross-section variables and less-common variables including median barrier placement and median cross-slope were included in the model. The authors concluded that crashes involving a cable median barrier result in an increase in the probability of less-severe crash outcomes relative to crashes involving a concrete or guardrail median barrier.

Although roadside safety features are designed and crash tested as per the Manual for Assessing Safety Hardware (FHWA 2012; previously tested using National Cooperative Highway Research Program Report 350), it is difficult to determine their actual performance on field without effective in-service evaluations (Ray et al. 2003; Ross et al. 1993), the process of assessing the performance of roadside safety hardware under real-world service conditions (Fitzpatrick et al. 1999).

Since the early 1970s, state departments of transportation (DOTs) have been performing in-service performance evaluations (ISPEs) of several roadside safety hardware. Cooner et al. (2009) evaluated the safety performance of a total of 114 cable barriers and 78 concrete barriers and concluded that cable barriers were making significant contributions to the reduction in fatal and incapacitating injuries on state roadways, effectively eliminating 96% of these injury types caused by cross-median crashes. Compared to concrete median barriers, cable barriers were most cost-efficient when capital and life cycle costs were considered. Cable barriers were also found to perform extremely well in most of the standard type collisions. Sicking et al. (2009) reviewed reported crashes on Kansas freeways from 2002 to 2006. The authors reviewed a total of 525 cross-median events and 115 cross-median crashes (CMCs) in the study period. The authors further developed median barrier warrants that could be applicable to a number of states in the midwestern region.

Graham et al. (2014) provided improved guidelines for designing median cross sections (i.e., median width, median slope, and median barrier) on rural divided highways. A before-and-after evaluation using the empirical Bayes method was conducted to estimate crash modification factors (CMFs) for flexible (i.e., cable), semiflexible (i.e., steel guardrail), and rigid (i.e., concrete) barriers. Table A1 (see online supplement) provides the CMFs for cable median barrier (i.e., flexible barrier) installations.

These CMFs are suitable for planning of roadside design policies that would be applied over many sites, or to analyses conducted with a combination of a Safety Performance Function (SPF) for median-related crashes and the application of the EB [empirical Bayes] method. (Graham et al. 2014, p. 105)

Agent and Pigman (2008) evaluated the effectiveness of 2 types of cable median barriers, Brien TL-4 and Trinity Cable Safety System (CASS), in preventing CMCs on Kentucky highways. About 325 police-reported CMCs were identified over a 21-month analysis period with an average of 0.28 CMCs per mile and 0.05 fatal CMCs per mile in a 5-year period. The authors concluded that the cable system was successful in redirecting errant vehicles; in only 0.9% of the cases had the cable system failed.

Murphy (2006) compared the long-term safety performance of cable median barriers with other barrier types including W-beam and weak-post barriers. 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 no-injury 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.
Stolle (2012) evaluated cable median barrier crashes in 12 states that occurred between 1996 and 2010 to determine containment failure causality, design improvements, placement guidelines, and improved full-scale testing procedures to improve safety. He also evaluated the performance of different cable barrier systems in terms of penetrations, rollovers, and severe crashes, and these results are provided in Table A2 (see online supplement). Stolle (2012) concluded that the lowest rate of severity of high-tension systems occurred on the Safence 4-cable median barrier. Of the TL-3 high-tension cable median barriers evaluated, Brifen had the lowest frequency of severe injury crashes, whereas Nucor had the highest frequency of severe injury crashes. Both Nucor and Brifen systems were involved in fewer fatal crashes compared to the Trinity CASS system.

A nationwide state-of-the-practice survey of cable median barriers was conducted and the following are relevant excerpts from the survey (Sheikhet al. 2008):

- There was a decrease in the severity of crashes at locations where wire rope median barriers have been installed and total crashes have increased.
- Although some states continued to use nonproprietary low-tension systems, usage of proprietary high-tension systems continued to increase.
- Horizontal curvature had 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 have to be conducted to improve the system.

A scanning tour of the locations with cable median barriers in Ohio, Oklahoma, and Texas found that high-tension cable barriers have been successfully used for median crossover protection on highways with wide medians and flat median slopes, and the general performance of the cable barriers at redirecting or stopping vehicles seemed to be excellent (Medina and Beneko-hal 2006).

Before-and-after safety evaluations have been conducted as part of the ISPEs to assess the safety performance of cable barriers. Sposito and Johnston (1998) conducted a simple before-and-after evaluation of cable median barriers installed on a 9-mile stretch along I-5 in Oregon. The before period included data from 1987 to 1996 and the after period included data from December 1996 through March 1998. Fatality rates were found to have dropped from 0.6 per year to 0 per year, whereas the injury crash rate increased from 0.7 per year to 3.8 per year. Based on the review of barrier maintenance records and police crash reports of barrier crashes, the authors concluded that the cable median barriers prevented 21 potential crossovers at the study locations. Monsere et al. (2003) also conducted a simple before-and-after evaluation of cable median barriers on a 21.9-mile stretch along I-5 in Oregon. The before data were from December 1993 to December 1996 and the after data were from May 1998 to May 2001. The authors estimated that 105 potential median crossovers were prevented by the cable median barriers.

Hunter et al. (2001) conducted before-and-after evaluation of 3-strand cable median barriers installed on an 8.5-mile section along I-40 in North Carolina. The authors compared the performance of the locations with barriers to the freeways with no cable median barriers. They concluded that total crash frequencies increased after median installation but only at a level equivalent to the freeways with no cable barriers. On the other hand, fatal and severe injury crashes decreased during the cable barrier installation year and continued to decrease after the cable barrier installation. Hit-fixed-object-in-median crashes increased significantly after median construction, and this is expected because cable median barriers reduce the effective clear recovery width in the median.

Arnold (2006) performed a 3-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. Although crash frequency increased after the installation of cable median barriers, a significant number of possible crossover crashes were contained by the barrier. The 3-year ISPE identified zero crossover fatal and severe injury crashes. During the 2-year period prior to the installation of cable median barriers, there were 17 fatal crashes, of which 9 were crossover fatal crashes. The 3-year period after the installation of cable median barriers had 4 fatal crashes with no fatal crossover crashes. Descriptive statistics and trend analysis after the installation of cable median barriers showed a slightly higher percentage of crossover crashes during dark conditions. A significantly higher percentage of crossover crashes occurred during wet conditions and a similar trend was observed when multiple vehicles lost control.

Hammond and Batiste (2008) conducted a before-and-after safety evaluation of cable median barrier installations for both median-related and cross-median collisions. The authors found that although total crashes increased in the after period, both fatal and severe injury crashes reduced significantly. Further, an overall reduction in the frequency and severity of cross-median crashes was observed. A similar evaluation by crash type was conducted in Washington State. The study concluded that the annual societal benefits of cable barriers were approximately $420,000 per mile (McClanahan et al. 2004).

In summary, the general performance of cable barriers at redirecting or stopping vehicles is found to be satisfactory. Several before-and-after and ISPE studies have found that the cable median barriers reduce fatal and severe injury crashes, although they often result in an increase in total, minor injury, and no-injury collisions.

**Data preparation**

This section discusses the data collection and preparation efforts undertaken to identify locations with cable median barriers on freeways in Florida. This section also discusses the process used to review police reports of crashes that occurred at the study locations.

The FDOT Roadway Characteristics Inventory database does not provide detailed information on the location and type of roadside safety feature. Therefore, other options to collect this information were explored. Freeway segments with roadside safety features for the entire state were first identified and extracted from the 2010 Roadway Characteristics Inventory database. The extracted segments were then visually reviewed to identify freeway locations installed specifically with cable median barriers. A total of 101 miles of freeways (23 locations
in total) with cable median barriers were identified and used in the analysis, as shown in Table A3 (see online supplement). From 2005 to 2010, the 23 study locations experienced a total of 6,524 crashes. Police reports of all 6,524 crashes were downloaded from the Hummingbird web system hosted on FDOT’s Intranet and reviewed in detail. For every crash where the errant vehicle had hit the cable median barrier, a detailed review of the police officer’s description and crash report scene diagram was conducted to categorize crashes as crossover and noncrossover crashes, whether a crossover crash involved a vehicle encroaching on the opposite travel lanes, the type of vehicle involved, and the crash severity. Crossovers were further categorized as under-ride, override, or penetrations; noncrossovers were categorized as either redirected or contained by cable barriers. Figures A2-a through A2-f (see online supplement) provide examples of the different crash classifications (i.e., crash report scene diagrams and excerpts from the police reports).

**Safety performance evaluation of cable median barriers**

The evaluation was conducted based on (1) type of vehicle that hit the barrier, (2) severity of barrier-related crashes, and (3) type of cable median barriers. As part of the analysis, police reports of over 6,500 potential barrier-related crashes were downloaded and reviewed. It should be noted that the analysis is based on the entire freeway network with cable median barriers and not on a sample. Further, the analysis is based on the performance of cable median barriers when hit by vehicles, resulting in conservative statistics. In other words, the crossover statistics are based on barrier-related crashes (i.e., crashes involving vehicles hitting the cable median barrier) and not on all crashes that occurred at the study locations.

**Performance by vehicle type**

For this analysis, the vehicle types include cars, light trucks, medium and heavy trucks, motorcycles, unknown vehicle types, and others. Light trucks include vans and pickup trucks with 2 or 4 rear tires; medium and heavy trucks include vehicles with 4 rear tires, vehicles with 2 or more rear axles, and truck tractors. The “others” category includes buses and other vehicles. Five vehicles were coded as unknown because of insufficient information in the police reports. When a crash involved multiple vehicles, the vehicle that actually hit the cable median barrier was used in the analysis. This approach is believed to be more accurate because the first vehicle identified in the crash report is not necessarily the vehicle that hit the barrier.

Barrier crossover crash statistics by vehicle type are given in Table A4 (see online supplement). Of the 549 barrier-related crashes (i.e., crashes involving vehicles hitting the cable median barrier), 90 were identified as barrier crossover crashes and the remaining 459 were barrier noncrossover crashes. Overall, 83.6% of all barrier-related crashes were noncrossover 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 did not cross the barrier. Medium and heavy trucks were found to have a lower non-crossover rate of 64.3. This is expected because the cable median barrier was not designed for these vehicle types.

Median crossover crash statistics by vehicle type are given in Table A5 (see online supplement). As discussed earlier, 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 vehicles crossing the median and traversing into the opposite travel lane. Of these 14 crashes, 8 were due to overrides, 3 were due to 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, 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. None of the other vehicle types traversed into the opposite travel lane. Overall, 97.4% of vehicles that hit the cable median barrier were prevented from crossing over the median and traversing into the opposite lane.

In addition to the crossover analysis for different vehicle types, the performance of cable median barriers in terms of cars and light trucks is of additional value because they are the 2 most common vehicle types. A chi-square test of independence is used to determine whether there is a significant difference in the performance of cable median barriers for cars versus light trucks in terms of barrier and median noncrossover crashes on freeways in Florida. Table 1 summarizes the chi-square test results for both barrier and median noncrossover crashes involving cars and light trucks. There is sufficient evidence to support the conclusion that at a 5% significance level, there is no significant difference in the performance of cars and light trucks in terms of noncrossover crashes. It should be noted that the percentage of noncrossover crashes for light trucks could be closer to that for cars. This is because the light truck category used in this study includes vans and larger pickup trucks with 4 rear

**Table 1. Significance tests for noncrossover crashes involving cars and light trucks.**

| Type of noncrossover | Car statistics | Light truck statistics |
|----------------------|----------------|-----------------------|
|                      | Noncrossover  | Total barrier-related | Noncrossover  | Total barrier-related | Percentage of |
|                      | crashes (a)   | crashes (b)           | crashes (c)   | crashes (d)           | noncrossover  |
| Barrier noncrossover  | 315           | 369                   | 85.4          | 123                   | 154          |
| Median noncrossover   | 362           | 369                   | 98.1          | 147                   | 154          |

\[ \chi^2 = 2.41 < \chi^2_{Crit(0.05)} = 3.84. \]  
\[ \chi^2 = 2.93 < \chi^2_{Crit(0.05)} = 3.84. \]

a) \( \chi^2 = 2.41 < \chi^2_{Crit(0.05)} \)

b) \( \chi^2 = 2.93 < \chi^2_{Crit(0.05)} \)
tires, which, on average, are heavier than the standard P2000 and P2270 design vehicles used in National Cooperative Highway Research Program Report 350 (Ross et al. 1993) and Manual for Assessing Safety Hardware (FHWA 2012), respectively.

**Performance by crash severity**

The crash performance statistics of cable median barriers in terms of barrier crossover and median crossover crashes by crash severity are given in Tables 2 and 3, respectively. Data from the police crash reports were used to identify crash severity using the following codes: K = fatal injury; A = incapacitating injury; B = nonincapacitating injury; C = possible or minor injury; PDO = property damage only. The severity of a crash is unknown when the driver fled the crash site prior to the arrival of law enforcement officials or when a discrepancy exists between the coded crash severity in the crash summary database and that in the actual police report.

Based on the statistics shown in Table 2, barrier crossover crashes, as expected, were more severe compared to barrier noncrossover crashes. In addition, overrides were found to be more severe compared to underrides and penetrations. The statistics in Tables 2 and 3 show that the median crossover crashes were slightly more severe compared to barrier crossover crashes. However, this observation is not statistically significant because the median crossover crashes are too few to yield meaningful conclusions.

**Performance by cable median barrier type**

The 23 study locations were installed with one of the 4 types of cable barrier systems: Brifen, CASS, Safence, or Gibraltar systems. The Florida Turnpike (SR 821) was considered as a location for pilot study, and Brifen, CASS, and Safence systems were installed along the approximately 6-mile stretch. The rest of the study locations were installed with either the Gibraltar system or CASS. Barrier-related crashes along SR 821 were considered as a “mixed” type because the section was installed with 3 types of cable barrier systems and it was difficult to accurately associate crashes to each cable barrier type. This section therefore focuses on a comparison of the performance of CASS and Gibraltar systems. Because all of the study locations are on limited access facilities in Florida, no major differences are expected in crash reporting thresholds, weather conditions, etc., at locations with CASS and Gibraltar barrier systems. However, other roadway geometric and crash consequences such as median slope, lateral offset, impact angle, impact speed, etc., might vary. The two data sets (i.e., crashes involving vehicles hitting CASS and Gibraltar systems) might not be similar because of the variations in these characteristics. The comparison of the safety performance of CASS and Gibraltar systems was based on the assumption that the 2 data sets are similar.

The crash performance statistics of CASS and Gibraltar systems in terms of barrier crossover crashes are given in Table A6 (see online supplement). A total of 37.61 miles of freeway was installed with the CASS (excluding the section with CASS on SR 821) and 57.31 miles was installed with Gibraltar system. The CASS was hit 126 times and the Gibraltar system was hit 344 times. Of all vehicles that hit the CASS, 83.3% were barrier noncrossover crashes. Similarly, the barrier noncrossover percentage was 81.7% for Gibraltar. However, based on the chi-square test of independence, at a 5% significance level, there is no significant difference in the performance of CASS and Gibraltar systems in terms of barrier noncrossover crashes. Note that this conclusion is based on the assumption that the 2 data sets (i.e., crashes involving vehicles hitting CASS and Gibraltar systems) are similar.

Of the 126 crashes that hit the CASS, 21 were barrier crossovers. Three of the 21 CASS barrier crossover crashes (14.3%) were penetrations, 16 (76.2%) were overrides, and 2

**Table 2. Barrier crossover crash statistics by crash severity.**

| Crash severity | Underride (a) | Override (b) | Penetration (c) | Unknown crossover (d) | Total crossover (e) = (a) + (b) + (c) + (d) | Percentage of total barrier crossover crashes (e)/90 | Redirected (f) | Contained (g) | Total noncrossover (h) = (f) + (g) | Percentage of total barrier noncrossover crashes (h)/459 |
|----------------|--------------|--------------|----------------|------------------------|---------------------------------------------|------------------------------------------------|----------------|----------------|----------------------------------|---------------------------------------------------|
| K+A           | 0            | 7            | 4              | 1                      | 12                                          | 13.3                                          | 12             | 8              | 20                               | 4.4                                               |
| B+C           | 0            | 20           | 12             | 10                     | 42                                          | 46.7                                          | 75             | 112             | 198                              | 25.7                                              |
| O             | 2            | 6            | 10             | 14                     | 32                                          | 35.6                                          | 178            | 112             | 290                              | 62.3                                              |
| Unknown       | 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                                             |

**Table 3. Median crossover crash statistics by crash severity.**

| Crash severity | Underride (a) | Override (b) | Penetration (c) | Unknown crossover (d) | Total median crossover (e) = (a) + (b) + (c) + (d) | Percentage of total median crossover crashes (e)/14 |
|----------------|--------------|--------------|----------------|------------------------|---------------------------------------------|---------------------------------------------------|
| K+A           | 0            | 1            | 0              | 1                      | 2                                           | 14.3                                             |
| B+C           | 0            | 6            | 1              | 0                      | 7                                           | 50.0                                             |
| O             | 0            | 1            | 1              | 2                      | 4                                           | 28.6                                             |
| Unknown       | 0            | 0            | 1              | 0                      | 1                                           | 7.1                                              |
| Total         | 0            | 8            | 3              | 3                      | 14                                          | 100.0                                             |

*aSample size is too small to yield reliable results.*
Table 4. Barrier crossover crash statistics of CASS and Gibraltar systems by vehicle type.

| Vehicle type          | Underride (a) | Override (b) | Penetration (c) | Unknown crossover (d) | Total crossover (e) = (a) + (b) + (c) + (d) | Redirected (f) | Contained (g) | Total noncrossover (h) = (f) + (g) | Total crashes (i) = (e) + (h) | Percentage of barrier noncrossover crashes (h)/(i) |
|-----------------------|---------------|--------------|-----------------|-----------------------|---------------------------------------------|----------------|----------------|----------------------------------|-----------------------------------------------|--------------------------------------------------|
| Car                   | 0             | 8            | 1               | 1                     | 10                                          | 35             | 31             | 66                               | 76                                            | 86.8%                                            |
| Light truck           | 0             | 7            | 0               | 1                     | 8                                           | 16             | 13             | 29                               | 37                                            | 78.4%                                            |
| Medium and heavy trucks* | 0         | 1            | 2               | 0                     | 3                                           | 1              | 3              | 4                                | 7                                             | 57.1%                                            |
| Motorcycle*           | 0             | 0            | 0               | 0                     | 0                                           | 0              | 0              | 0                                | —                                             | —                                                |
| Unknown               | 0             | 0            | 0               | 0                     | 0                                           | 0              | 0              | 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%                                            |

Table 5. Performance of different cable median barrier types by crash severity.

| Type of cable median barrier | Crash severity | K+A | % (a)/(e) | B+C | % (b)/(e) | O | % (c)/(e) | Unknown | % (d)/(e) | Total | % |
|-----------------------------|----------------|-----|-----------|-----|-----------|---|-----------|---------|-----------|-------|----|
| CASS                        | Number (a)     | 7   | 5.6       | 48  | 38.1      | 62| 49.2      | 9       | 7.1       | 126   | 100|
| Gibraltar                   | 20             | 5.8 | 89        | 25.9| 214       | 14| 62.2      | 21      | 6.1       | 344   | 100|
| Mixed*                      | 5              | 6.3 | 23        | 29.1| 46        | 54| 58.2      | 5       | 6.3       | 79    | 100|
| Total                       | 32             | 5.8 | 160       | 29.1| 322       | 52| 58.7      | 35      | 6.4       | 549   | 100|

*Sample size is too small to yield reliable results.

(9.5%) were unknown. In contrast, of the 344 crashes that hit the Gibraltar system, 63 were barrier crossover crashes. Of these 63 crashes, 24 (38.1%) were penetrations, 17 (27.0%) were overrides, 20 (31.7%) were unknown, and 2 (3.2%) were underridges. The statistics show that the Gibraltar system experienced a greater proportion of penetrations compared to the CASS.

Table 4 provides the barrier crossover crash statistics for CASS and Gibraltar systems by vehicle type. For cars, 86.8% that hit the CASS were either redirected or contained by the barrier; the percentage was a little lower, at 82.6%, for the Gibraltar system. The CASS prevented 78.4% of light trucks from crossing the barrier; a similar percentage (79.6%) of light trucks was prevented by the Gibraltar system. Based on the chi-square test of independence, at a 5% significance level, there is no significant difference in the performance of CASS and Gibraltar systems in terms of barrier noncrossover crashes for cars and light trucks.

Table 5 gives the performance of CASS and Gibraltar 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 CASS and Gibraltar systems performed similarly in terms of fatal and severe injury crashes; the proportion of K+A crashes was 5.6 and 5.8% for CASS and Gibraltar systems, respectively. The odds ratio is used to compare the effect of barrier type (i.e., CASS and Gibraltar) on crash severity. The odds of severe injury when a vehicle hits a CASS system are 0.964 times lower (95% confidence interval, 0.397 to 2.342) than the odds of severe injury when a vehicle hits a Gibraltar system. However, this difference is not statistically significant.

As can be observed from Table 5, less than half of total vehicles (i.e., 49.2%) that hit the CASS system were PDOs, whereas 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.

Safety performance evaluation of cable median barriers on freeways in Florida was performed based on the percentages of barrier and median crossover crashes as they relate to vehicle type, crash severity, and cable median barrier type. Unlike previous studies that evaluated the performance of cable median barriers based on specific crash types such as run-off-the-road and fixed object crashes (Hunter et al. 2001), median crossover...
crashes (Agent and Pigman 2008; Ray et al. 2009), severity of total crashes (Murphy 2006; Sposito and Johnston 1998), etc., this study focuses on crashes that involved vehicles hitting the barrier. In addition, this study provides separate percentages of median and barrier crossovers to more precisely measure the performance of cable median barriers independent of other variables such as median width. Although the available lateral offset (i.e., the clear distance between the inside travel lane and the barrier) influences the impact angle of the crash and thereby the consequences of errant vehicles after hitting the cable barrier, this variable was not investigated in this study due to data limitations. Furthermore, median slope and mounting height of the barrier also affect the safety performance of median barriers; however, this information was also not available and therefore these variables could not be studied. Investigating the impact of these variables on the safety performance of cable median barriers is recommended for future research.

A total of 23 locations totaling about 101 miles experienced 549 cable median barrier-related crashes (i.e., crashes involving vehicles hitting the cable median barrier). Police reports of these 549 crashes were reviewed in detail to identify crossover and noncrossover crashes. Based on the descriptions and crash report scene diagrams in the police reports, crossover crashes were further classified as underride, override, or penetration. Noncrossover crashes were classified as either redirected or contained. Crashes that resulted in vehicles traversing into 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 the barrier. 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 noncrossover crashes. Fewer medium and heavy trucks that hit the barrier were prevented from crossing the barrier. This was expected because the cable median barrier was not designed for these vehicle types. Further, of the 549 crashes that involved vehicles hitting the cable median barrier, 14 traversed into the opposite travel lane. In other words, 97.4% of vehicles that hit the cable median barrier were prevented from crossing over the median. Although the noncrossover percentages for cars and light trucks are quite different, at a 5% significance level, there is no significant difference in the performance of light trucks and cars in terms of both barrier and median noncrossover percentages. Barrier crossover crashes were found to be more severe compared to barrier noncrossover crashes. In addition, overrides were found to be more severe compared to underrides and penetrations.

The performance of CASS and Gibraltar systems was compared. There is no significant difference in barrier crossover percentages for cars and light trucks for the 2 systems. Additionally, the CASS and Gibraltar systems performed very similarly in terms of fatal and 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, this study focuses on evaluating the safety performance of cable median barriers in terms of barrier and median crossover crashes. These crash statistics provide the most accurate estimates of the performance of the cable median barriers because they are based on vehicles hitting the barrier, unlike previous studies that are based on total crashes. The study results provide evidence that cable median barriers successfully prevent a majority of median crossover crashes in real-world scenarios. Because barrier crossover crashes are more severe compared to barrier noncrossover crashes, efforts to minimize barrier failures could improve safety. Furthermore, the manner in which barrier crossover crashes occur is of interest to the practitioners; in particular, measures to minimize the more severe override crossover crashes would result in a better safety performance of cable median barriers.

Acknowledgments

We are thankful to Dr. Kaiyu Liu and Hai Feng Wang for software support and to graduate research assistants Andres Diaz, Shanghong Ding, Erik Echezabal, Katrina Meneses, Stephanie Miranda, and Anita Pourji for their assistance in reviewing the police reports.

Funding

This research was funded by the Research Center of the Florida Department of Transportation (FDOT).

References

Agent K, Pigman J. Evaluation of Median Barrier Safety Issues. Lexington, KY: Kentucky Transportation Center; 2008. Research Report KTC-08-14/SPR329-06-1F.

Alberson D, Sheikh N, Chatham L. Guidelines for the Selection of Cable Barrier Systems: Generic Design vs. High-Tension Design. Washington, DC: American Association of State Highway and Transportation Officials; 2007. NCHRP Project 20-7(210).

Alluri P, Haleem K, Gan A. In-service Performance Evaluation (ISPE) for G4 (1S) Type of Strong-Post W-Beam Guardrail System and Median Cable Barrier. Volume II. Tallahassee, FL: Florida Department of Transportation; 2012.

Arnold E. Proprietary Tensioned Cable System: Results of a Three Year In-service Evaluation. Columbus, OH: Ohio Department of Transportation; 2006.

Cooner S, Rathod Y, Alberson D, Bligh R, Ranft S, Sun D. Performance Evaluation of Cable Median Barrier Systems in Texas. College Station, TX: Texas Transportation Institute; 2009. FHWA/TX-09/0-5609-1.

Davis G, Pei J. Bayesian reconstruction of median-crossing crashes and potential effectiveness of cable barriers. Transp Res Rec. 2005;1908:141–147.

Donnell E, Mason J Jr. Methodology to develop median barrier warrant criteria. J Transp Eng. 2006;132(4):269–281.

Federal Highway Administration. Manual for Assessing Safety Hardware (MASH). 2012. Available at: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/crm/pd_mash/mash/. Accessed July 2012.

Federal Highway Administration. Cable median barriers. 2014. Available at: http://www.fhwa.dot.gov/research/deployment/cable.cfm. Accessed August 2015.

Fitzpatrick M, Hancock K, Ray M. Videolog assessment of vehicle collision frequency with concrete median barriers on an urban highway in Connecticut. Transp Res Rec. 1999;1690:59–67.

Graham J, Harwood D, Richard K, O’Laughlin M, Donnell E, Brennan S. Median Cross-section Design for Rural Divided Highways. Washington, DC: American Association of State Highway and Transportation Officials; 2014. NCHRP Project 22–21A.

Hammond P, Batiste J. Cable Median Barrier: Reassessment and Recommendations Update. Olympia, WA: Washington State Department of Transportation; 2008.

Hu W, Donnell E. Median barrier crash severity: some new insights. Accid Anal Prev. 2010;42:1697–1704.
Hunter W, Stewart J, Eccles K, Huang H, Council F, Harkey D. Three-strand cable median barrier in North Carolina: in-service evaluation. Transp Res Rec. 2001;1743:97–103.
Keel A. High tension cable barriers. Paper presented at: FICE/FDOT Design Conference; 2006; Orlando, FL.
Marzougui D, Mohan P, Kan CD, Opiela K. Performance evaluation of low-tension three-strand cable median barriers. Transp Res Rec. 2007;2025:34–44.
McClanahan D, Albin R, Milton J. Washington State cable median barrier in-service study. Paper presented at: Transportation Research Board 83rd Annual Meeting; 2004; Washington, DC.
Medina J, Benekohal R. High Tension Cable Median Barrier: A Scanning Tour Report. Urbana, IL: Illinois Department of Transportation; 2006.
Monsere C, Sposito B, Johnston S. Safety effectiveness and operating performance of a three-cable median barrier on Interstate 5 in Oregon. Paper presented at: Institute of Transportation Engineers 2003 Annual Meeting and Exhibit; 2003; Seattle, WA.
Murphy B. Median barriers in North Carolina—long term evaluation. Paper presented at: Missouri Traffic and Safety Conference; 2006.
Ray M, Silvestri C, Conron C, Mongiardini M. Experience with cable median barriers in the United States: design standards, policies, and performance. J Transp Eng. 2009;135:711–720.
Ray M, Weir J, Hopp J. In-service Performance of Traffic Barriers. Washington, DC: Transportation Research Board; 2003. National Cooperative Highway Research Program Report 490.
Ross H, Sicking D, Zimmer R, Michie J. Recommended Procedures for the Safety Performance Evaluation of Highway Features. Washington, DC: Transportation Research Board; 1993. National Cooperative Highway Research Program Report 350.
Sheikh N, Alberson D, Chatham L. State of the practice of cable barrier systems. Transp Res Rec. 2008;2060:84–91.
Sicking D, De Albuquerque F, Lechtenberg K, Stolle C. Guidelines for implementation of cable median barrier. Transp Res Rec. 2009;2120:82–90.
Sposito B, Johnston S. Three-cable Median Barrier Final Report. Salem, OR: Oregon Department of Transportation; 1998. Report No. OR-RD-99-03.
Stolle C. Cable Median Barrier Failure Analysis and Remediation [PhD dissertation]. Lincoln, Nebraska: University of Nebraska–Lincoln; 2012.