In-Service Performance Evaluation of Median Cable Barriers in Iowa

Final Report
May 2018

Center for Transportation Research and Education

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Department of Transportation
(InTrans Project 15-546)

About InTrans

The mission of the Institute for Transportation (InTrans) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

About CTRE

The mission of the Center for Transportation Research and Education (CTRE) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, and reliability while improving the learning environment of students, faculty, and staff in transportation-related fields.

Disclaimer Notice

ISU Non-Discrimination Statement

Iowa DOT Statements

The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

Front Cover Images

Front cover images are median cable barrier installations on Interstates in Iowa. The images were captured from live Iowa DOT traffic cameras.

Technical Report Documentation Page

1. Report No.	**2. Government Accession No.**	**3. Recipient's Catalog No.**
InTrans Project 15-546		

4. Title and Subtitle

In-Service Performance Evaluation of Median Cable Barriers in Iowa

5. Report Date

May 2018

6. Performing Organization Code

7. Author(s)

Peter T. Savolainen (orcid.org/0000-0001-5767-9104), Trevor J. Kirsch (orcid.org/0000-0002-8163-1570), Raha Hamzeie (orcid.org/0000-0002-1335-1016), Megat Usamah Megat Johari (orcid.org/0000-0001-8446-4205), and Ellen Nightingale (orcid.org/0000-0002-9204-3977)

8. Performing Organization Report No.

InTrans Project 15-546

9. Performing Organization Name and Address

Center for Transportation Research and Education
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Organization Name and Address

Iowa Department of Transportation
800 Lincoln Way
Ames, IA 50010

13. Type of Report and Period Covered

Final Report

14. Sponsoring Agency Code

15. Supplementary Notes

Visit www.intrans.iastate.edu for color pdfs of this and other research reports.

16. Abstract

Median crossover crashes occur when errant vehicles depart from their intended lane of travel on divided roadways and traverse the median, ultimately striking a fixed roadside object or vehicle traveling in the opposite direction. These crash types are commonly associated with high-severity injuries due to the increased travel speeds and sharp impact angles experienced when a vehicle crosses the median. These crash types are caused by a wide variety of factors, including drowsiness, weather impacts, driver distractions, impaired driving, loss of control, and other factors.

A common countermeasure selected by agencies to reduce the risk of cross-median crashes is median cable barriers. These high-tension cable barrier systems are designed to absorb the impact forces when struck by errant vehicles, reducing the vehicles' speeds and containing them within the barrier system. While prior research has shown median cable barrier to be effective in various settings, Iowa has unique differences in topography, weather conditions, and other factors that motivate the need for additional research.

This study involved an in-service performance evaluation to assess the efficacy of median cable barrier systems that have been installed in Iowa to date. In addition to examining impacts on traffic crashes, injuries, and fatalities, the study also involved an economic analysis of the cable barrier systems. The results show that median cable barrier systems have significantly reduced the number of fatal and severe injury crashes across the state. While these reductions have been accompanied by significant increases in less severe crashes, particularly property damage-only collisions, the barrier systems have been shown to provide a significant return on investment. The results of this study suggest that further implementation of median cable barrier systems is warranted. As such, installation guidelines are recommended based on various combinations of median width and annual average daily traffic.

17. Key Words	**18. Distribution Statement**
benefit-cost analysis—cable barrier maintenance/repair—highway traffic safety—in-service performance evaluation—median cable barriers—safety countermeasure effectiveness	No restrictions.

19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified.	Unclassified.	63	NA

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

IN-SERVICE PERFORMANCE EVALUATION OF MEDIAN CABLE BARRIERS IN IOWA

Final Report
May 2018

Principal Investigator
Peter T. Savolainen, Safety Engineer
Center for Transportation Research and Education
Iowa State University

Research Assistants
Trevor J. Kirsch, Raha Hamzeie,
Megat Usamah Megat Johari, and Ellen Nightingale

Authors
Peter T. Savolainen, Trevor J. Kirsch,
Raha Hamzeie, Megat Usamah Megat Johari, and Ellen Nightingale

Sponsored by
Iowa Department of Transportation

Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement with the
Institute for Transportation
(InTrans Project 15-546)

A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The authors would like to thank the Iowa Department of Transportation for sponsoring this research. The authors would also like to acknowledge the technical advisory committee members for the input they provided over the course of this project.

EXECUTIVE SUMMARY

Median crossover crashes occur on divided roadways and involve an errant vehicle departing the travel lane, traversing the median, and striking either a fixed object on the roadside or an oncoming vehicle in the opposing direction of travel. These types of crashes are associated with the highest risk of fatal and severe injuries among all collision types on Interstates due to the increased travel speeds of the involved vehicle(s) and the sharp angle of vehicular impact. Median crossover crashes are caused by a variety of factors, including drowsiness, weather impacts, driver distraction, impaired driving, loss of control, and other factors.

Because of the severity of median crossover crashes, median barriers are often utilized to reduce the opportunity for cross-median collisions. Cable barriers have become a popular countermeasure implemented by a multitude of state agencies due to their lower installation costs compared to more rigid systems (such as concrete walls or steel-beam guardrail barriers), as well as the documented safety performance of these barrier types. The Iowa Department of Transportation (Iowa DOT) began installing median cable barriers in 2003 and there is currently approximately 330 miles of the barrier system located on Interstates statewide.

Anecdotal evidence from other regions in the United States suggests that cable barriers are operating as desired, and in-service performance reviews and cost-effectiveness evaluations of the systems have been well documented. However, Iowa has substantive differences in topography, weather conditions, and other salient factors that motivate the need for additional research. This project aims to determine the cost-effectiveness of the cable barrier systems in Iowa based on a comparison of the crash cost savings resulting from reductions in injury severity with the costs associated with installation, routine maintenance, and repairs. An in-depth analysis of the frequency and severity of crashes occurring in the median on both treatment and control segments was conducted for the periods before and after barrier installation for this study.

Median-related (or run-off-road left) crashes were identified through two independent review processes for this analysis: (1) utilizing Iowa DOT-recommended crash code logic functions to collect the appropriate police crash reports based on field officer documentation and (2) a manual review of all crash narratives from police crash reports collected on roadways with known cable barrier installations. Ultimately, 6,718 median-related crashes were identified through the narrative review methodology and were utilized for the nine-year (2007–2015) analysis period.

A series of severity-based statistical models were derived to evaluate the safety effectiveness associated with the installation of median cable barriers on Iowa roadways. Subsequently, benefit-cost (B/C) analyses were conducted to examine the financial benefit of the median countermeasure installations. Results from various statistical analyses demonstrated that the median cable barrier systems reduced the frequency of crashes with fatal (K), incapacitating (A), and non-incapacitating (B) injuries after installation while increasing the frequency of possible injury (C) and property damage-only crashes (PDO). These changes in injury severity are similar to those experienced in recent evaluations in other states. The median treatment was demonstrated to reduce the crash frequency the most for fatal injuries, with crash reductions decreasing for each subsequent severity level. The effects of precipitation, including rainfall and snowfall, were associated with an increase in target crash frequency. Additionally, an increase in the average median width of a segment was correlated with a decrease in crash frequency, regardless of injury severity level.

Using the observational safety effectiveness results of the median countermeasure, the installation, maintenance, and repair costs were analyzed to determine the cost-effectiveness of the median cable barrier systems currently installed throughout Iowa. A literature review of the state of the art revealed that the typical service life of a cable barrier system is between 20 and 30 years. Because of this and a recommendation by the Iowa DOT, the B/C ratio of the current Interstate installations was calculated assuming a design life of 20 years. A discount rate of 4 percent was considered during the analysis period, as well as a 1 percent annual increase in traffic volume. Crash costs estimated by the Iowa DOT were considered for the financial analysis. The resultant investigation discovered a favorable investment for the assumed design life. The B/C ratio was calculated, with a resultant 16.08 B/C ratio assuming statewide crash cost estimates at a crash-level basis.

Based on the results of the safety effectiveness analysis and the financial evaluation of the cable barrier systems currently implemented along Interstates in Iowa, it is recommended that the median treatment be further installed to reduce the risk of cross-median crashes. As such, guidelines are recommended in the report based on an aggregate composition of median width and annual average daily traffic. The reductions in fatal, incapacitating, and non-incapacitating injury crashes were significant, despite the increase in possible injury crashes and property damage-only crashes demonstrated by most frameworks. The increase in the frequency of low-severity crash types is acceptable when considering the reductions in crash severity achieved by the countermeasure.

1. INTRODUCTION

Roadway departure crashes are among the most hazardous collision types, accounting for approximately 57 percent of all traffic fatalities across the United States (Blincoe et al. 2014). On divided highways, median crossover crashes are a particular concern. These crashes occur when an errant vehicle departs its travel lane, crosses the median, and strikes either a roadside object or a vehicle traveling in the opposing direction. Such crashes are caused by a variety of factors, including adverse weather, loss of control, driver distraction, drowsiness, impairment, or other factors. On Interstate segments, where both traffic volumes and speeds are higher, the risks and potential consequences of these crashes are elevated. Table 1 notes the prevalence of median-related crashes in comparison to all crash types that occurred on statewide Interstate segments in Iowa between 2007 and 2014.

Table 1. Prevalence of median-related crashes on Iowa Interstates

Year	Median-Related Crashes	Total Crashes	Percentage of Total
2007	428	2,791	15%
2008	825	3,060	27%
2009	667	2,801	24%
2010	887	2,936	30%
2011	673	2,335	29%
2012	749	2,377	32%
2013	897	2,659	34%
2014	1,035	3,011	34%

To mitigate the potential for median crossover crashes, countermeasures such as shoulder rumble strips have been installed to reduce the likelihood of errant vehicles leaving the paved roadway surface. While such countermeasures have been shown to yield significant reductions in lane departure crashes, a considerable number of these types of crashes still occur. Considering the higher impact speeds and impact angles associated with median crossover and other lane departure crashes, other types of safety devices, such as crash cushions and roadside barriers, have been utilized to reduce the degree of injury severity sustained by vehicular occupants.

The American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide* recommends median barriers as the primary countermeasure to mitigate the risk of median crossover crashes (AASHTO 2011). According to the AASHTO *Highway Safety Manual* (HSM), the installation of median barriers is associated with 43 percent and 30 percent reductions in fatal and injury crashes, respectively (AASHTO 2010). While research has consistently shown reductions in the frequency of these more severe collision outcomes, barrier systems do not come without costs. In addition to the costs required for barrier installation and maintenance, the HSM shows that the frequency of property damage-only (PDO) crashes increases by 24 percent on average following median barrier installation. This increase occurs because median barriers are often installed in close proximity to the traveled way. The amount of open median, which may have previously allowed vehicles to recover prior to being involved in a crash, is reduced, thereby increasing the likelihood of less severe collisions where vehicles are damaged when striking the barrier.

When considering the installation of a median barrier, potential alternatives include the use of concrete walls, steel-beam guardrails, or high-tension cable systems. Each type of barrier system is associated with installation, site, and cost constraints that impact their viability at specific locations. Among these barrier types, high-tension cable generally has the lowest initial installation costs (Olsen et al. 2013). A median cable barrier, an example of which is shown in Figure 1, also allows for greater flexibility than other types of barriers because it can be installed on steeper slopes (Marzougui et al. 2012). Given these benefits, median cable barriers have been installed with increasing frequency across the United States.

Figure 1. Median cable barrier treatment in Iowa

The Iowa Department of Transportation (DOT) began installing median cable barriers in 2003 and currently has approximately 330 miles of the countermeasure in place. While prior research has shown that high-tension cable systems result in significant reductions in traffic fatalities and severe injuries, the cost-effectiveness of cable barriers has varied significantly across states due to a variety of factors, including differences in topography, weather conditions, traffic volume, median width, offset from the traveled way, and other factors.

Consequently, the purpose of this study was to conduct an in-service evaluation of median cable barrier systems that have been installed in the state of Iowa. This evaluation included an in-depth investigation of the safety impacts of the systems that have been installed in Iowa to date. Based on the results of these analyses, the cost-effectiveness of the systems were estimated.

This report describes this research study. This introductory chapter provides an overview, background information, and the objectives for the study. The remainder of the report is comprised of four additional chapters, which are briefly summarized here:

- Chapter 2 presents the results of a literature review of prior research on median cable barrier systems. This review includes a synthesis of in-service evaluations of the safety impacts of median cable barrier systems, benefit-cost (B/C) evaluations conducted for several state departments of transportation (DOTs), and existing guidelines for the installation of cable barrier systems.
- Chapter 3 details the data collection processes and procedures utilized in this study. This chapter includes a summary of data obtained from resources available through the Iowa DOT, as well as additional information that was collected manually or from other publicly available resources. This chapter also outlines the process used for the identification of median-related crashes for use in the subsequent analyses.
- Chapter 4 presents the results of the statistical methods used to discern the impacts of median cable barrier installation on traffic crashes, injuries, and fatalities. The statistical methods used in these analyses are also briefly described. This chapter also includes a benefit-cost analysis that details the cost-effectiveness of the median cable barrier installations that have been erected to date.
- Chapter 5 summarizes the key findings from the research and presents conclusions and recommendations. Lastly, guidelines are presented to aid in the prioritization of candidate locations for future median cable barrier installations on the Iowa Interstate system.

2. LITERATURE REVIEW

The extant research literature includes several studies that have examined the efficacy of median cable barriers in reducing the frequency of median crossover crashes and the resultant fatalities and serious injuries. An early study in this area was conducted in South Carolina, where cable barriers were installed in the median of several narrow, unprotected Interstates after three independent cross-median crashes resulted in the death of 13 occupants within the span of three months (Zeitz 2003). The barrier systems were estimated to have been struck over 3,000 times within a three-year period; however, the majority of these strikes resulted in property damage only. At the conclusion of the analysis period, only 15 vehicles (1 percent of the total) had penetrated the barrier system.

In North Carolina, an investigation showed that cross-median crashes did not appear to occur in an identifiable pattern (Stasburg and Crawley 2005). Based on this finding, a pilot installation of median barriers occurred along five extended segments of three separate Interstate highways. In all installation locations, cable barriers were shown to reduce the number of cross-median crashes significantly. Before installation, the average cross-median crash rate per year was 5.60 crashes. Following cable barrier installation, the rate of such crashes was reduced to 0.30 per year.

Research in Missouri found cable barriers to be the most cost-effective type of median barrier when compared with concrete walls and steel-beam guardrail installations (Chandler 2007). In 2002, 24 motorists were fatally injured after crossing the median at various locations along I-70 in Missouri. Following the installation of 179 miles of median cable barrier along the Interstate, the number of fatalities resulting from cross-median crashes was reduced to two, representing a 92 percent decrease over a four-year period. After installation, the cable barrier systems were shown to prevent 95 percent of target vehicles from crossing the median.

Additional research in Kentucky examined the effectiveness of a cable median barrier system in preventing cross-median crashes (Agent and Pigman 2008). Over a five-year analysis period from 2001 to 2005, 392 target crashes occurred, which resulted in 0.28 cross-median crashes per mile during the study. A target crash is any crash in which the vehicle exits the roadway to the left and interacts with the median. An analysis indicated that 157 encroachments into the opposing lane of traffic were prevented by the cable barrier system. Of all the crashes considered, only three (1 percent) penetrated the cable barrier and continued into the opposing lanes of travel.

A synthesis of early research was prepared based upon a review of reports, articles, and the results of a survey of transportation agencies aimed at documenting the effectiveness of cable barrier systems (Ray et al. 2009). Table 2 provides a summary of these studies, which analyzed reductions in total and fatal cross-median crashes following barrier installation.

Table 2. Summary of cross-median crash reductions

State	Average Annual Crashes Before Barrier Installation	Average Annual Crashes After Barrier Installation	Percent Reduction
	Fatal Cross-Median Crashes		
Alabama	47.5	27.0	43.0
Arizona	1.7	0.7	59.0
Missouri	24.0	2.0	92.0
North Carolina	2.1	0.0	100.0
Ohio	9.4	0.0	100.0
Oklahoma	2.0	0.2	91.5
Oregon	0.6	0.0	100.0
Texas	30.0	1.0	97.0
Utah	5.9	0.0	100.0
	Total Cross-Median Crashes		
Florida	NA	NA	70.0
North Carolina	25.4	1.0	96.0
Ohio	348.3	83.0	76.0
Utah	114.0	55.0	52.0
Washington	16.0	3.8	76.0

Source: Ray et al. 2009

Aggregate results demonstrated reductions in cross-median fatal crashes between 43 percent and 100 percent. It is important to note that many of these early evaluations were based on limited data. Furthermore, several of the reductions did not consider the effects of traffic volume or other factors that may also influence the rate of cross-median crashes. These studies also generally used simplified analytical frameworks that ignored important concerns such as regression-to-the-mean (RTM), and consequently many of these initial estimates of effectiveness are likely to be overstated.

Subsequently, a series of more rigorous analyses was conducted. These analyses are summarized in Table 3.

Table 3. Summary of empirically based studies of cable median barriers

State	Year	Methodology	Number of Miles	Number of Crashes	Crash Reductions
Tennessee	2016	Empirical Bayes	14	270	K: -94% A: -92%
Michigan	2014	Empirical Bayes	300	9,640	K: -53% A: -24% C: +151% O: +163%
Wisconsin	2014	Before-After (Crash Frequency)	82	692	K/A: -59% Total: +112%
Washington	2013	Before-After (Crash Rates)	238	4,600	K: -52% A: -61% Total: +91%
Wyoming	2013	Before-After (Crash Frequency)	103	2,164	K/A: -23% O: +53%
Florida	2012	Before-After (Crash Rates)	101	8,818	K: -42% A: -20% Total: +37%

Note: K = Fatal Injury Crash, A = Incapacitating Injury Crash, C = Possible Injury Crash, O = Property Damage-Only Crash, and Total = Total Crashes

A Florida study analyzed information from 549 police crash reports at 23 locations on limited access facilities. The crashes occurred from 2003 to 2010 (Alluri et al. 2012). The crash reports were verified for accuracy and reviewed for further details as to the sequence of events leading up to the crash. Of the 549 identified target crashes, 84 percent were contained by the cable barrier. Of the 90 crashes in which the barrier was penetrated, only 14 vehicles ultimately reached the opposite direction of travel. The cable median barrier installations reduced the fatal crash rate by 42 percent, the severe injury crash rate by 20 percent, and the minor injury crash rate by 12 percent.

An analysis of the cable median barrier installation program in Washington yielded similar safety benefits (Olson et al. 2013). Due to the low initial cost, cable median barriers were installed between 2000 and 2011 in Washington along 238 miles of roadway. During this time period, there was a dramatic decline in both fatal and serious injury collisions among target crashes. The results showed a 58 percent decrease in the rate of injury collisions after cable median barriers were installed. This represents a decline from 28 fatal and serious injury crashes per year to 15. A 58 percent decline was also evident is cross-median crashes; cable installations reduced cross-median collisions from 62 per year to 26 after the countermeasure was implemented.

Another large-scale evaluation of median cable barrier installations was conducted in Michigan, where 317 miles of cable barrier were installed between 2008 and 2013 (Savolainen et al. 2014). A comprehensive evaluation determined that fatal and serious injuries were reduced by 33 percent after installation while cross-median crash rates were reduced by 87 percent. With road and weather conditions having a profound impact on the severity and frequency of crashes, the researchers also noted that cable barriers were 97 percent effective in preventing barrier penetration.

One of the most recent in-service evaluations of median cable barriers was conducted in Tennessee, where barriers were installed on 14 miles of divided highway (Chimba et al. 2013). At least three years of crash data before and after barrier installation were utilized for the analysis. The safety impacts of the barrier were examined through an empirical Bayes evaluation. On the sections analyzed, fatal and incapacitating injury crashes were both reduced by more than 90 percent.

Cable barriers have also been shown to be an effective alternative for occupant protection. For example, research in Indiana compared the degree of occupant injury sustained in crashes involving concrete, steel-beam guardrail, and cable barrier systems (Zou et al. 2014). Each barrier type was tested with varying offsets from the edge of the roadway. In total, 2,124 single-vehicle crashes were analyzed on 517 pair-matched barrier and non-barrier segments. The results showed that striking any barrier type was associated with a lower risk of injury than striking a fixed object. Furthermore, the analysis showed that the odds of injury are 43 percent lower when a vehicle strikes a steel-beam guardrail rather than a concrete barrier. Additionally, the odds of injury when a vehicle strikes a near-side cable median barrier are 75 percent lower than when a vehicle strikes a concrete barrier and 57 percent lower than when a vehicle strikes a steel-beam guardrail.

Vehicle containment is also an important metric when determining the effectiveness of a median barrier. Containment of rogue vehicles prevents two types of high-severity crashes from occurring: (1) a vehicle penetrating the barrier system and striking oncoming traffic and (2) a vehicle striking the barrier and being redirected back into the travel lane from which they departed. Vehicles that penetrate the barrier and cross into oncoming traffic are at a much higher risk of a severe injury than those contained by the countermeasure. Also, vehicles that strike a barrier and are redirected back into traffic by the countermeasure have a greater probability of experiencing more severe outcomes. Research in Washington showed that cable median barriers had an 83 percent containment rate compared to only 38 percent for concrete barriers (Ray 2007).

A common anecdotal concern about median cable barriers is the risk posed by the system to motorcyclists. Research in Washington (Ray 2007) and Michigan (Savolainen et al. 2014) did not substantiate this concern. In addition, a detailed investigation analyzed 951 motorcycle-barrier crashes involving 1,047 riders (Daniello and Gabler 2011). The level of occupant injury after a barrier was struck (steel-beam guardrail or cable) was observed. Of the motorcyclists involved in steel-beam guardrail collisions, 40.1 percent were fatally or severely injured, while 40.3 percent had the same injury outcome after colliding with a cable barrier. The study determined that, regardless of helmet use, the odds of sustaining a severe injury when colliding with a cable or steel-beam guardrail barrier were not significantly different.

2.1 Policies and Guidelines for Installation

Although cable median barriers have been demonstrated to be very effective in preventing cross-median crashes, limited guidance is available as to the roadway characteristics that are most appropriate for cable median barrier installation. The *Roadside Design Guide* (AASHTO 2011) provides national guidance for the installation of any type of barrier based on median width and annual average daily traffic (AADT), as shown in Figure 2.

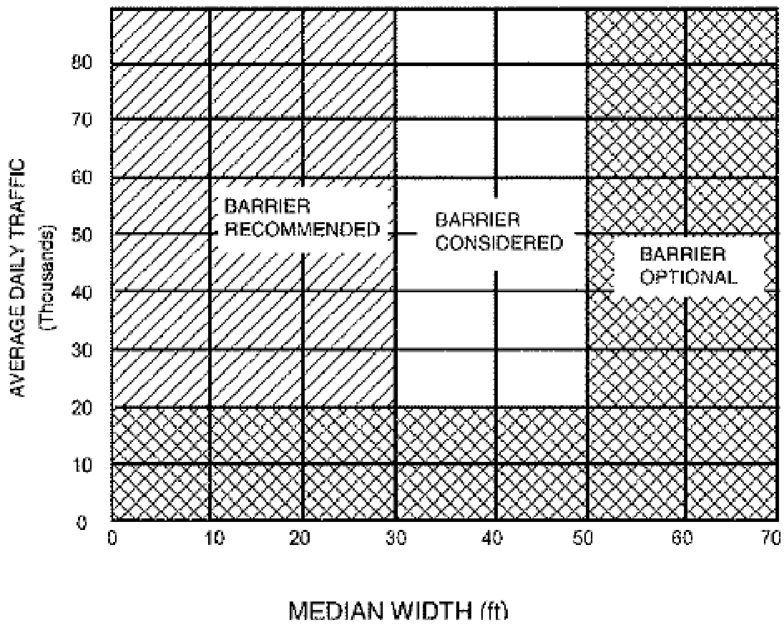

Figure 2. AASHTO *Roadside Design Guide* barrier guidance

It should be noted these recommendations were derived based on older types of barrier systems. Because modern structures have been designed to be more crashworthy, a Wisconsin study sought to establish more refined installation recommendations (Noyce 2006). Data were analyzed from 631 median crossover crashes that led to more than 600 injuries and 53 fatalities during a three-year study period. Because 82 percent of these crashes occurred on roadways where median barriers were not recommended based on previous warrants, it was recommended that the past national barrier standards be refined for state use in Wisconsin to prevent these crash types. A similar Pennsylvania study found that cross-median crashes still occurred on roadways for which a median treatment was not recommended by the existing installation policy. Consequently, additional policy guidelines were recommended following a survey and Delphi focus group (Donnell et al. 2002).

Similar recommendations were proposed based on a Texas study in which cross-median crash risk models were developed (Bligh et al. 2006). Similar to the recommendations from the *Roadside Design Guide*, the guidelines are a function of AADT and median width. Because cable median barriers are much more flexible than traditional barrier types, a wider median is required for installation in order to prevent vehicles from striking the barrier and still reaching the opposing lanes of traffic. Figure 3 displays the combination matrix created from this analysis for traversable medians.

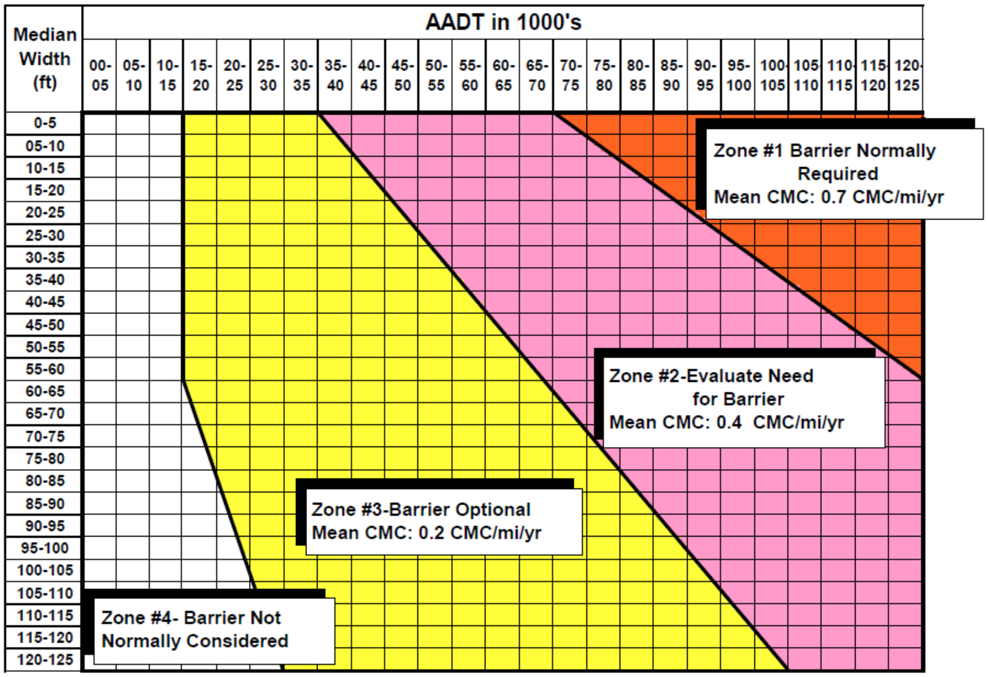

Figure 3. Texas-specific guidelines for installing median barriers

Further analysis by researchers from George Washington University utilized computer simulations to investigate the key factors associated with the performance and installation of cable barrier systems (Marzougui et al. 2012). As a roadside device, cable barriers need sufficient space to accommodate lateral deflections when struck. Because of this, design guidance must be researched and analyzed often because new cable barrier systems have different performance characteristics than previously developed models. Ultimately, a warrant-based system was crafted by the researchers to determine when cable barriers should be implemented in a cost-effective manner. The policies were based on median cross-slopes, shoulder characteristics, and super-elevation; end anchor requirements and post embedment recommendations were also generated.

2.2 Performance Degradation

While cable median barriers have demonstrated valuable safety effectiveness, occasional cross-median crashes still occur due to barrier penetration. Because of this, some research has persuaded agencies to select other alternatives to prevent traffic from entering unintended lanes. After installing cable median barrier systems, the New Jersey Department of Transportation (NJDOT) elected to discontinue the use of median cable barriers for this reason (Ray et al. 2009). The most common reason for avoiding the use of median cable barrier installations is that more low-severity and property damage-only crashes occur because the barrier is often close to the lane of travel. This is necessary due to the inherent flexibility in the cable system, which slows errant vehicles over a longer distance than the more rigid alternatives (i.e., concrete barriers and steel-beam guardrails). Also, the barrier of interest does not prevent every crash from traversing the median; therefore, public disapproval may diminish interest in continuing the use of cable barriers. Other external factors often impact the performance of cable barriers, including weather, roadway conditions, speed, impact angle, vehicle size, driver behavior, and other factors (Ray 2007). Although these reasons have deterred agencies from continuing cable barrier installation programs, the well-documented benefits and updated installation guidelines justify the installation of cable median barrier systems.

Further research on cable barrier performance has considered the cable median barrier as another fixed object on the roadside. Research from the Nebraska Transportation Center analyzed more than 6,000 crashes in 12 US states in an attempt to optimize barrier design, installation procedures, and crash testing metrics (Stolle and Sicking 2012). Recommendations from the analysis included implementing low-tension cables with low-strength posts to prevent occupant injury in smaller vehicles and reducing cable tension at high-angle installation locations to reduce the risk of vehicular rollover upon impact. Lastly, full-scale crash testing on a wide variety of slopes was also recommended based on the frequency of override and underride penetrations at field installations of the barrier.

Another issue with cable barrier systems is the degradation in performance over time due to inadequate soil conditions in some locations. Research conducted for the Texas Department of Transportation (TxDOT) determined that several districts within the state of Texas have experienced issues with post installations and terminal anchors uprooting due to poor soil performance in the region (Cooner et al. 2009). This performance degradation is common when the countermeasure is installed in an area with high-plasticity clay soils, as commonly noted by manufacturers. Improper installation can lead to quick degradation over time, including significant anchor movement within the system. Other states, such as Arizona, Florida, and Indiana, have generated additional requirements and reactive installation guidelines when cable barrier placement on high-plasticity clay soils is unavoidable.

2.3 Cost-Effectiveness

Several economic analyses have been conducted to examine the cost-effectiveness of median cable barrier systems. Research in Wisconsin considered the number of cable collisions and the associated maintenance costs that were necessary to restore the barrier to its previous working state (Qin and Wang 2010). An in-service performance evaluation of installed cable barriers was conducted by comparing the benefit of the reduced injury severity with the installation costs for the system. The routine maintenance costs (due to nuisance strikes) and restoration costs were included. The study determined that although a total average cost of $5,906,048 was incurred by the Wisconsin Department of Transportation (WisDOT) for the installation of cable median barriers, with an average societal benefit of $332,855 each year, the B/C ratio for the cable median barrier installations was about 8 considering its design life. Research conducted under the National Cooperative Highway Research Program (NCHRP) has also determined that cable median barriers are cost-effective for extended sections of justified medians (Graham et al. 2014).

Additional economic research in Texas compared concrete and cable median barriers to determine when the installation of cable barrier was more economically favorable (Miaou et al. 2005). Results showed that as AADT decreased and median width increased, the favorability of cable systems over concrete systems increased. Of the 525 combinations of AADT and median width tested for the study, only 32 percent favored the installation of concrete median barriers. Additionally, the average B/C ratio for the cable installations was greater than those for their concrete counterparts. Similar research on the Washington cable median barrier program also generated favorable results (McClanahan et al. 2003). The study considered 24 miles of cable median barrier installations at three separate locations along Interstate 5 in Washington. After reviewing the appropriate documentation, the installation cost was found to be $44,000 per mile for the countermeasure. On average, repairs were completed within two days of notification, with a typical cost of $733 per repair. The time needed to repair the system was 30 percent less than the time needed to repair an equivalent length of steel-beam guardrail. Lastly, due to the reduction in severity for median-related crashes, the average societal benefit from the installations was about $420,000 per mile annually.

3. DATA COLLECTION AND INTEGRATION

This analysis of current cable median barrier installations in Iowa involved extensive collection and integration of a diverse range of data, including roadway characteristics, traffic information, and historical weather measurements, among others. While portions of the data were obtained through the Iowa DOT's geographic information management system (GIMS), a substantial amount of manual data collection was conducted to enhance the analysis. This chapter outlines each of the data sources utilized for this study, as well as the necessary processes used to obtain disaggregate information when appropriate.

3.1 Roadway Information

The baseline Interstate roadway network was provided by the Iowa DOT through the online GIMS portal. This portal contains annually updated operational and geometric characteristics for roadways within the state. All of the roadway management resources are maintained in a georeferenced format. Figure 4 displays a sample georeferenced segment collected from the GIMS database (in orange) as it relates to aerial imagery from this Interstate.

Image © 2016 Google (from Google Earth)

Figure 4. GIMS georeferencing example

In order to effectively analyze the safety performance of the known cable barrier installations, various roadway and traffic characteristics were obtained. The TRAFFIC_2015 file from the GIMS portal was the most current database available that contained the AADT for the roadway segments of interest. Based on this file, installations of median cable barrier were manually collected using up-to-date Google Earth imagery for all Interstates within Iowa. Additionally, because the relevant GIMS information for each segment is averaged directionally (i.e., there is one measurement for both directions of travel), manual data collection was necessary to collect greater disaggregate information along each segment. At each mile point, the median width and shoulder width measurements were collected for the roadway. A sample of the collected information at mile marker 148 is displayed in Figure 5.

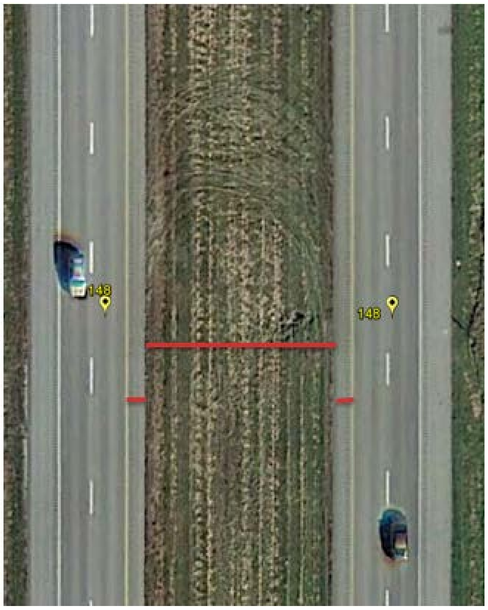

Image © 2016 Google (from Google Earth)

Figure 5. Roadway measurements manually collected at each mile marker

For Interstate locations with median cable barrier installations, the offset of the system from either edge of the roadway was also measured using Google Earth measurement tools. The starting point and stopping point of each cable barrier installation was also documented to provide more refined information about the roadway characteristics. A snapshot of this data collection procedure, containing the starting and stopping points of a brief cable barrier installation, is displayed in Figure 6.

Image © 2016 Google (from Google Earth)

Figure 6. Roadway measurements collected at cable barrier installations

Based on the duration and frequency of these cable barrier systems, the Interstate network within Iowa was divided into 897 independent analysis segments, which included 362 segments on which cable barriers were installed during the analysis period (2007 to 2015) and 535 control segments that did not have any median barriers installed during the study period. These analysis segments (i.e., those with median cable barrier installations) covered the entire Interstate network within Iowa, excluding segments with known concrete and guardrail barrier installations. The segmentation was diligently completed such that each segment with a cable barrier treatment was between 0.25 and 1 miles in length. The remaining segments (i.e., the control segments, those with no median cable barrier installations) were split as evenly as possible while considering consistency among roadway geometrics and characteristics such as the number of lanes and posted speed limit.

3.2 Crash Information

A statewide crash database is maintained by the Iowa DOT that includes detailed information regarding all crashes reported to law enforcement on an annual basis. Due to the analysis period utilized for the known cable barrier installations within the state, crashes that occurred between 2007 and 2015 were collected for this study. The location of each crash was provided in a georeferenced format similar to that used for the GIMS data. Additionally, vehicular information, roadway characteristics, and environmental factors present during the crash, as described by the responding police officer, were included. A total of 85 individual data elements related to the scene of the incident were either collected or derived and matched with each crash as appropriate. Because the purpose of this analysis was to determine the safety effectiveness of median cable barrier treatments, only crashes that were considered median-related (i.e., run-off-road left) were included. This information was collected using two independent methods:

1. Application of a series of logic functions provided by the Iowa DOT to identify target crashes based on the sequence of events coded from police-reported crash forms
2. A manual review of relevant crash narratives using a keyword search based on a police officer’s description of the crash events

3.2.1 Crash Code Logic Methodology

The Iowa DOT has developed a logic function, based upon various code combinations from the police crash report form, to identify potential median-related crashes. This same logic function method was applied to all of the crashes that occurred on Iowa Interstates between 2007 and 2015. The script for identifying potential median-related crashes uses a series of logic functions to determine if a vehicle in any documented crash was involved in a median-related incident based solely on the crash coding provided by the responding officer through the crash report form. Figure 7 contains a flow chart that is representative of the provided logic function.

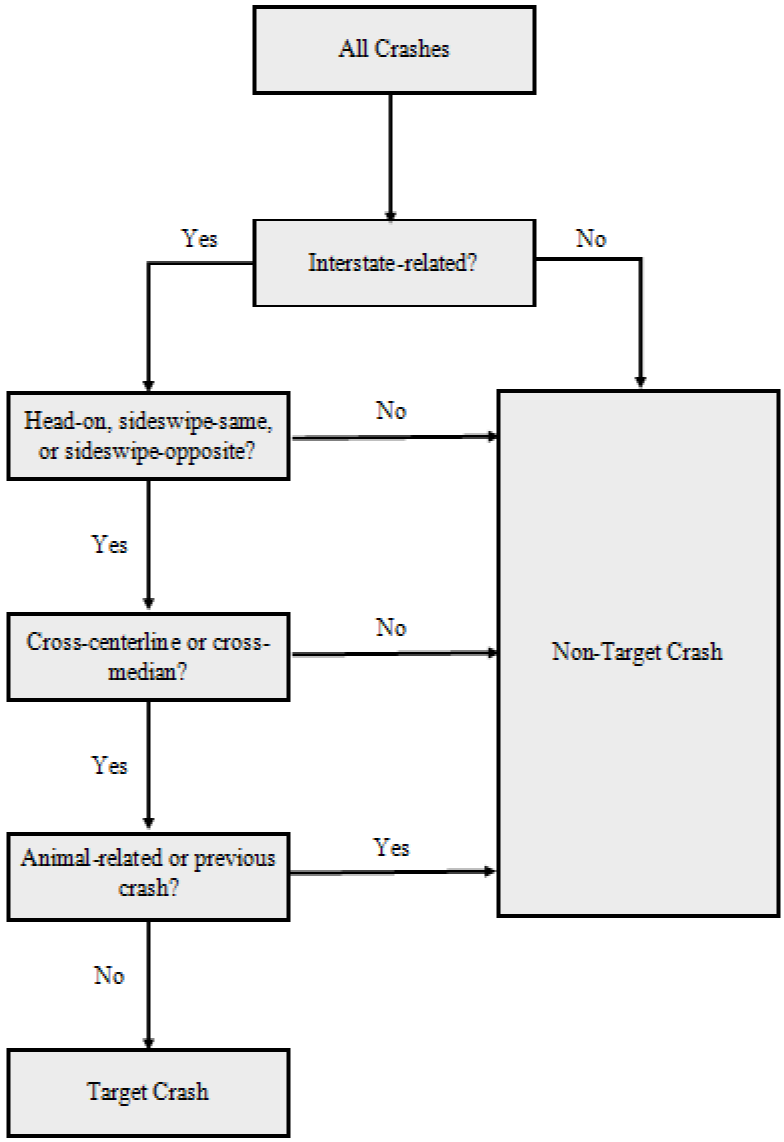

Figure 7. Flowchart of logic provided by Iowa DOT staff member

Note that the statements on the left side of Figure 7 are associated with variables in the statewide crash database maintained by the Iowa DOT. The script first collects all of the Interstate crashes, regardless of severity. Next, a filter is applied that only retains those crashes coded as head-on or sideswipe (same direction or opposite direction). Next, crashes whose major cause is classified as “cross centerline” are retained, and lastly crashes that involved animals or a previous crash are removed from the selected data. From this data collection method, a total of 8,148 crashes were identified as median-related.

3.2.2 Crash Narrative Review Methodology

The crash narrative review methodology involved reading the crash narratives provided by responding officers at the scene of the crash and determining if any vehicle involved in the collision ran off the road to the left (i.e., towards the median). The crash narratives were provided along with the crash coding by the Iowa DOT after personally identifiable information was removed. Before narrative analysis began, the crashes were filtered to include only those incidents that occurred on Interstates.

At the onset of the review process, 1,000 narratives were analyzed for each year within the analysis period. During this procedure, common keywords related to target crashes (i.e., median, center, shoulder, ditch, and inside) were identified. As mentioned previously, a target crash is any type of crash in which a vehicle exits the roadway to the left and enters the median. For those segments where median cable barrier was installed, these crashes may have involved a vehicle striking the barrier. The sample also included any crashes on these segments where a vehicle entered the median but did not strike the barrier. For control segments (i.e., segments without any median barrier), these same types of crashes were identified as target crashes if they involved a vehicle entering the median during the event. These crashes are included in the analysis because median barrier installation guidelines are based on the frequency and severity of all median-involved crashes. Based on these findings, the remaining crash narratives were filtered using the common keywords previously mentioned to accelerate the manual review process. All narratives that contained the listed common keywords were analyzed to determine if the incident was a target crash. Quality assurance was also performed by reading 10 percent of those crashes not identified through the keyword process to ensure that median-related crashes were not excluded by the procedure. Using the crash narrative review method, 6,718 crashes were identified as median-related.

3.2.3 Database Construction

Ultimately, there were substantial differences between the two datasets. A total of only 3,570 crashes were identified using both the crash code logic and the crash narratives. Table 4 provides summary statistics for the crashes identified using the crash code and crash narrative methodologies. The minimum, maximum, mean, and standard deviation are provided for each severity level, as well as the overall frequency of crashes.

Table 4. Summary statistics of crash data for individual Interstate segments by dataset

Dataset	Severity Level	Min	Max	Mean	Std Dev
Identified by Crash Codes	K (Fatal)	0	2	0.013	0.113
	A (Incapacitating)	0	2	0.031	0.178
	B (Non-incapacitating)	0	3	0.093	0.311
	C (Possible Injury)	0	4	0.114	0.352
	O (No Injury)	0	11	0.636	1.081
	Total Crashes	0	13	0.886	1.275
Identified by Crash Narratives	K (Fatal)	0	2	0.016	0.128
	A (Incapacitating)	0	2	0.036	0.196
	B (Non-incapacitating)	0	3	0.105	0.336
	C (Possible Injury)	0	4	0.132	0.384
	O (No Injury)	0	12	0.720	1.168
	Total Crashes	0	15	1.009	1.394

There are a variety of reasons for these discrepancies, which include incorrect and inconsistent coding on the crash report form. For example, various non-target crashes were incorrectly identified by the crash code logic, such as those crashes involving wrong-way driving. Other crashes were missed by the logic, such as cases where run-off-road-left was not indicated in the sequence of events but was identified in the narrative. Based upon an evaluation of the available information, the target crashes identified by the crash narrative review were utilized for this evaluation.

Once all target crashes were identified, various crash characteristics, such as vehicle type, level of injury severity, and weather conditions were added to the database. All of the crashes were georeferenced to the developed segmentation system and joined to the nearest segment to avoid crash duplication based on proximity. Furthermore, although the crash report form (and thus the crash coding framework) was adjusted by the Iowa DOT in 2015, the old crash code framework was utilized in this study, with appropriate adjustments created for the 2015 crash data to ensure database consistency. More details about the target crashes, specifically the vehicle type and roadway surface conditions at the time of the crash, are included in Table 5.

Table 5. Details of median-related target crashes

Variable	Count	Percentage
Vehicle Type		
Passenger Car	3,491	52.0%
Pick Up Truck	927	13.8%
Sport Utility Vehicle (SUV)	1,150	17.1%
Van	284	4.2%
Single Unit Truck	131	1.9%
Tractor Trailer	619	9.2%
Other	116	1.7%
Surface Condition		
Dry	2,873	42.8%
Wet	893	13.3%
Ice/Frost	1,543	23.0%
Snow	1,057	15.7%
Other	352	5.2%
Total	6,718	100.0%

3.3 Weather Data

The National Weather Service Cooperative Observer Program (NWS COOP) provides an open source platform that contains weather, precipitation, and temperature data from designated weather stations across 13 states in the Midwestern region of the US. Through this cooperative program, historical weather data are available for 115 stations in Iowa at daily intervals. These data include highly disaggregate information regarding various weather-related measures, such as rain depth, snowfall, temperature measurements, and solar radiation samples. For this analysis, the precipitation and snowfall data were queried from the open source portal. Each segment that was generated for the analysis was assigned to the nearest weather station to ensure accuracy. A buffer radius around each weather measurement station was utilized to encapsulate each segment. In the event that a segment was covered by multiple weather station buffers, the precipitation estimates were averaged for the duration of the segment. The weather stations, buffers, and analysis segments are displayed in Figure 8.

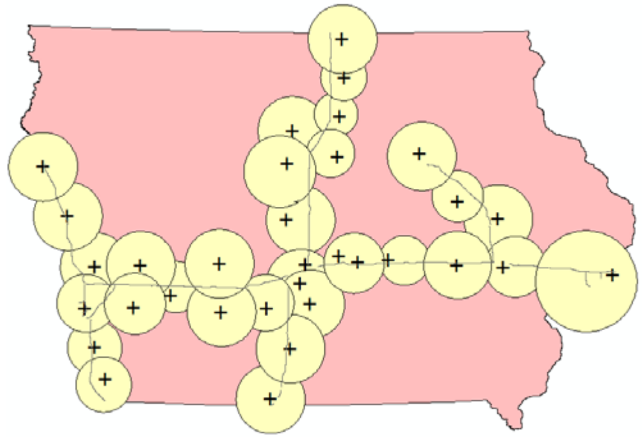

Figure 8. NWS COOP weather stations with buffers and analysis segments

3.4 Cable Barrier System Installation, Maintenance, and Repair Data

The Iowa DOT divides the state into six districts, as shown in Figure 9. Figure 9 also shows the locations of the Interstates in Iowa as well as the locations of current cable barrier installations, noted in pink.

Figure 9. Median cable barrier installations by district and county

Currently, four districts (District 1, District 4, District 5, and District 6) have median cable barrier systems installed along their respective Interstates. These jurisdictions were contacted to obtain detailed information regarding their cable barrier installation, maintenance, and repair costs. Out of these four districts, Districts 1, 5, and 6 provided the requested maintenance and repair data from 2011 to 2015. The installation data were provided by the Iowa DOT through contractor letting plans for the installation of 28 unique cable barrier projects. Each cable barrier system had costs specific to the installation of the barrier treatment only (i.e., there were no additional project costs included), and the installations were located within the four districts previously mentioned, as displayed in Figure 9. In summary, the installation, maintenance, and repair data included information regarding the initial installation cost of the system, the number of posts that were repaired after an incident, the cost of post replacement, any anchor costs, any turnbuckle costs, and repair mobilization costs. Ultimately, the summation of the district-level information resulted in 2,682 repairs that occurred on the cable barrier systems between 2011 and 2015.

3.5 Data Summary

As mentioned previously, a total of 897 segments across four districts in the state of Iowa were identified for the purpose of this study. Table 6 provides the summary statistics for these segments, including both the sections with cable barrier installations and those without (i.e., control segments).

Table 6. Summary statistics for the study segments (N=897 segments)

Analysis Segments				
Variable	**Min**	**Max**	**Mean**	**Std Dev**
AADT (veh)	11,700.00	85,176.92	31,473.14	10,809.68
Length (mi.)	0.23	0.95	0.76	0.13
Annual Rain (in.)	23.21	57.77	41.06	7.85
Annual Snow (in.)	14.16	61.53	35.88	10.63
Average Median (ft)	36.19	273.26	52.29	14.13
Minimum Median Width (ft)	34.59	125.48	51.04	6.97
Maximum Median Width (ft)	36.34	381.37	53.66	22.36
Average Minimum Barrier Offset (ft)	6.69	37.49	12.40	2.61
Average Maximum Barrier Offset (ft)	13.38	263.55	39.58	13.56
Average Shoulder Width (ft)	4.91	12.49	6.67	1.07

Control Segments				
Variable	**Min**	**Max**	**Mean**	**Std Dev**
AADT (veh)	4,792.00	43,000.00	17,077.94	5,282.99
Length (mi.)	0.22	0.95	0.69	0.14
Annual Rain (in.)	20.50	57.65	37.51	8.15
Annual Snow (in.)	8.78	69.46	34.27	11.73
Average Median (ft)	28.46	326.86	60.12	16.62
Minimum Median Width (ft)	19.72	104.99	58.67	12.98
Maximum Median Width (ft)	36.31	107.29	59.97	12.86
Average Minimum Barrier Offset (ft)	NA	NA	NA	NA
Average Maximum Barrier Offset (ft)	NA	NA	NA	NA
Average Shoulder Width (ft)	4.15	14.58	6.50	0.87

The cross-sectional roadway characteristics, including the cable barrier offset and the shoulder and median widths, were collected manually at each mile point, as previously mentioned. It should be noted that in cases where these attributes changed along a study segment, the minimum, maximum, and the average of each variable along each segment was included in the datasets for further analysis. Also, because the GIMS data does not allow for any directional analysis, the shoulder widths were averaged across opposing directions of travel.

This study utilized crash data over a nine-year period from 2007 to 2015. However, the segments with cable barriers had known barrier installation dates occurring anytime throughout this period. In order to properly investigate the barriers' effectiveness, the year in which the cable barrier was installed along a segment was removed for the purpose of analysis. As such, each segment may have had a combination of different before and after installation periods. This made a direct comparison of the before-after installation crash frequencies impossible. Consequently, such a comparison was made based on the crash frequencies per one hundred million vehicle miles of travel (HMVMT) and is shown in Table 7.

Table 7. Simple before-after comparison of the crash rates

	Before Installation		After Installation		
Severity Level	**Crashes per HMVMT**	**Percentage of Total Crashes**	**Crashes per HMVMT**	**Percentage of Total Crashes**	**Percent Change**
K (Fatal)	0.32	2.37%	0.11	0.46%	-65.63%
A (Incapacitating)	0.65	4.81%	0.40	1.68%	-38.46%
B (Non-incapacitating)	1.69	12.52%	1.37	5.77%	-18.93%
C (Possible Injury)	2.03	15.04%	2.27	9.55%	11.82%
O (No Injury)	8.81	65.26%	19.61	82.53%	122.59%
Total Crashes	13.50	100.00%	23.76	100.00%	76.00%

Note that the rate of target crashes per HMVMT decreased after barrier installation for the first three severity levels (i.e., K, A, and B). The percentage of the total crashes for each of these severity levels decreased as well, with non-incapacitating injuries experiencing the greatest percentage reduction, from 13 percent to only 6 percent of total crashes. A slight increase in the rate of possible injury crashes was evident following barrier installation, while the rate of PDO crashes increased significantly. The percentage of total crashes for the PDO subset of collisions increased greatly, from 65 percent of the total crashes experienced to 83 percent. Similar results have been documented in previous literature. Despite the overall reductions in the most severe crash rates, the total crashes experienced after cable barrier installation increased, mainly due to the large increase in the PDO crash rate. This finding is similar to the results of prior research and is likely due to two factors. First, with the median cable barrier system in place, the injuries sustained as a result of a crash are likely to be less severe. For example, a crash that may have resulted in a fatal or incapacitating injury without the barrier system may only result in property damage due to the efficacy of the barrier. A second reason for the increase in PDO crashes is that a large number of the barrier strikes can be classified as nuisance strikes. In these instances, the driver may have been able to recover and avoid a crash during the pre-installation period. However, these events are likely to result in a PDO crash given the proximity of the barrier to the edge of the traveled way.

4. STATISTICAL METHODS AND RESULTS

The data described previously were used to quantify the safety impacts of the Iowa median cable barrier installation program, as well as to investigate the associated cost-effectiveness of the currently installed median treatments. As stated previously, target crashes were identified using a series of logic functions to analyze crash codes that were extracted from relevant crash reports as well as a manual review of crash narratives to determine if a vehicle had departed the roadway and entered the median during a crash event. Once the target crashes were identified, the Iowa DOT crash database was utilized to extract detailed information about each incident, including the level of severity, weather conditions, and the types of vehicles involved.

For the purpose of this study, the effectiveness of the cable barrier installation program was evaluated through two means: a naïve before-after comparison and a cross-sectional comparison, both of which included control locations where barriers were not installed during the study period. These study designs, each of which is discussed in this chapter, allowed for a determination of the relative change in crash frequencies for each level of injury severity following barrier installation.

4.1 Statistical Methodology

To properly examine the safety performance of the barrier treatments, a series of negative binomial (NB) regression models was developed to examine the safety impacts of median cable barrier installations on crashes, particularly at each severity level. The NB framework provides an appropriate model structure for crash data, which commonly exhibit overdispersion (i.e., the variance is greater than the mean when considering crash counts on a segment-by-segment basis).

The NB model specification estimates the probability $P(n_{it})$ of n_{it} crashes occurring on segment i during year t as follows:

$$P\ (n_{it}) = (\frac{1/\alpha}{(1/\alpha)+\lambda_{it}})^{1/\alpha} \frac{\Gamma[(1/\alpha)+n_{it}]}{\Gamma(1/\alpha)n_{it}!} (\frac{\lambda_{it}}{(1/\alpha)+\lambda_{it}})^{nit} \qquad (1)$$

where $\Gamma(.)$ is a gamma function, and the mean number of crashes on segment i in year t, λ_{it} , is a linear function of the covariates, as follows:

$$\lambda_{it} = EXP\ (\beta X_{it} + \varepsilon_{it}) \qquad (2)$$

where β is the vector of estimated coefficients, X_{it} is the vector of variables associated with segment i during year t (e.g., segment length, AADT, and median width), and ε_{it} is the error term with a mean of one and variance of α, which is known as the overdispersion parameter.

4.2 Estimating Impacts of Median Cable Barrier Installations

4.2.1 Naïve Before-After Analysis

The naïve before-after analysis used a subset of the prepared dataset that included only the segments that had a cable barrier installed at some point during the study period, meaning that all control segments were excluded from the analysis dataset. A binary variable was introduced to identify the presence of a cable barrier in order to distinguish between the before and after periods. A series of NB regression models was developed to identify the contributing factors at each severity level. The results of this analysis are presented in Table 8 in tabular form and graphically in Figure 10.

Table 8. Results of the naïve before-after analysis

Severity	Parameter	Estimate	Std Error	Pr (>|Z|)
K	Intercept	-10.265	4.422	0.020
	Natural logarithm of AADT	0.562	0.430	0.191
	Cable present (1 if yes; 0 otherwise)	-1.161	0.371	0.002
	Overdispersion parameter	0.003		
A	Intercept	-11.318	2.964	<0.001
	Natural logarithm of AADT	0.728	0.288	0.012
	Cable present (1 if yes; 0 otherwise)	-0.459	0.2051	0.025
	Overdispersion parameter	0.690		
B	Intercept	-10.461	1.700	<0.001
	Natural logarithm of AADT	0.745	0.165	<0.001
	Cable present (1 if yes; 0 otherwise)	-0.273	0.114	0.016
	Overdispersion parameter	0.125		
C	Intercept	-11.546	1.469	<0.001
	Natural logarithm of AADT	0.869	0.142	<0.001
	Cable present (1 if yes; 0 otherwise)	0.055	0.094	0.558
	Overdispersion parameter	0.279		
O	Intercept	-8.307	0.685	<0.001
	Natural logarithm of AADT	0.707	0.067	<0.001
	Cable present (1 if yes; 0 otherwise)	0.670	0.042	<0.001
	Overdispersion parameter	0.318		

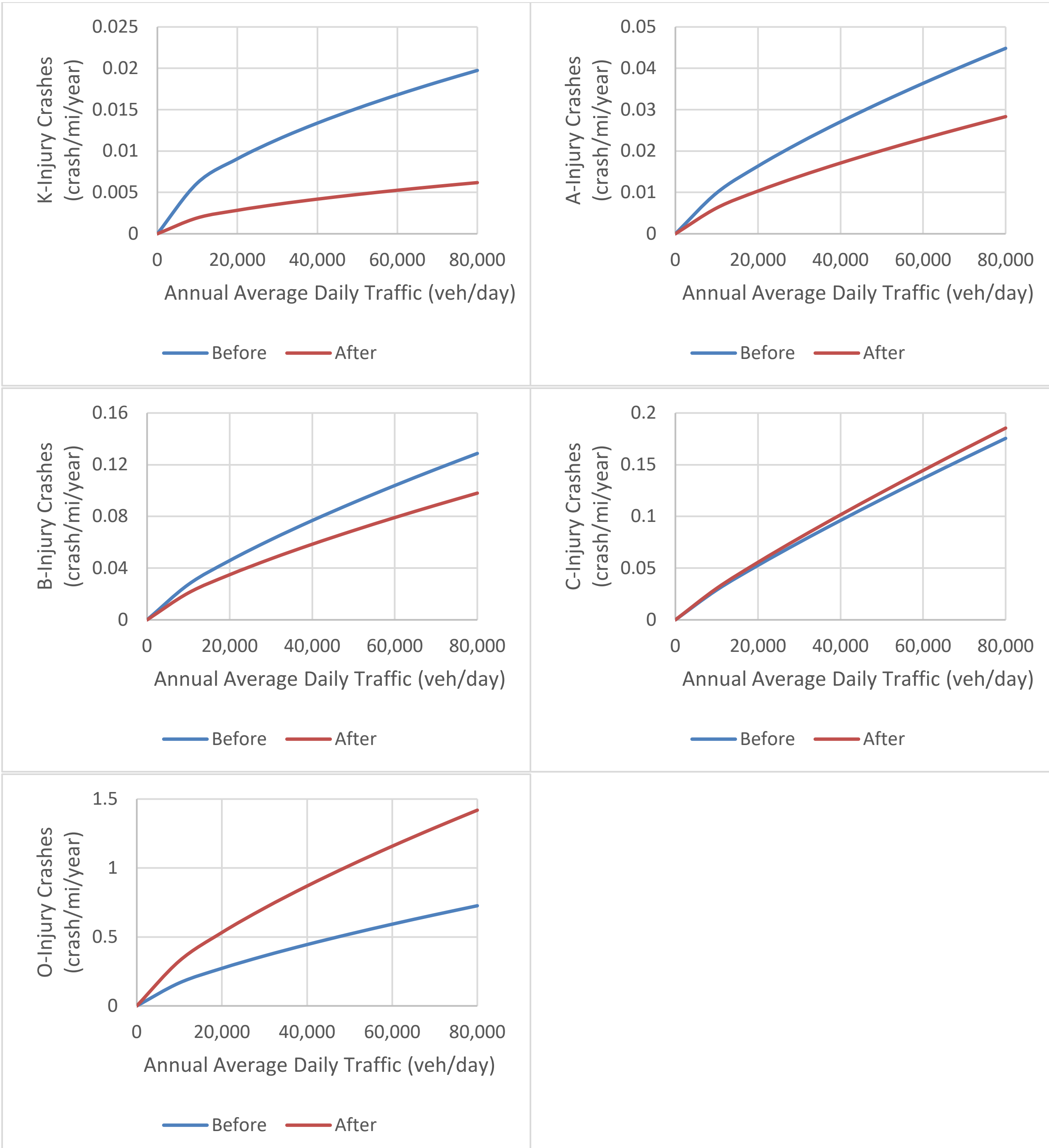

Figure 10. Results of before-after crash comparison by severity level

In these model results, positive coefficients indicate variables that are associated with an increase in the dependent variable (i.e., crash frequency), whereas negative estimates reflect a decrease in the dependent variable. In these models, AADT was used as an exposure factor, and segment lengths were treated as an offset variable (i.e., crashes were assumed to increase proportionately with respect to length).

The results from the naïve before-after analysis show that those segments with installed cable barrier systems are associated with lower crash frequencies within the first three severity levels (i.e., K, A, and B). This is similar to the observed crash rate per HMVMT for the entire dataset, as shown above in Table 7. The effect of the barrier systems was the most pronounced for the most severe injuries (i.e., fatal crashes), with a decreasing effectiveness for lower severity crashes. The presence of a cable barrier was associated with an increase in C-level (i.e., possible injury) crashes, while PDO crashes experienced a significant increase following cable barrier installation. As noted previously, similar results were found in the reviewed literature, and this finding is reflective of the following: (1) a reduction in the severity of crashes that involve a vehicle departing the roadway at a high travel speed or large departure angle and (2) nuisance strikes given the proximity of the barrier to the traveled way.

The naïve before-after analysis provided some useful insights regarding the safety impacts of the cable barrier program. The underlying assumption of this methodology was that the segments retained consistent characteristics during the before and after periods, and any changes in the crash frequencies were solely due to the median treatment. However, this logic could potentially result in biased estimates because characteristics were likely to change during the nine-year analysis period. Because of this, a cross-sectional analysis framework was also employed.

4.2.2 Cross-Sectional Analysis

In addition to the naïve before-after analysis, the effectiveness of the cable barrier program was investigated through a cross-sectional analysis. Unlike the previous method, which solely utilized the segments on which, at some point, a cable barrier was installed, the cross-sectional method considered such segments in combination with the no-barrier (i.e., control) segments. In this case, two binary variables were introduced (1) to distinguish between the study segments and the control segments and (2) to identify the segments with cable barrier present in each study year. Similar to the previous method, NB regression models were developed for each severity level. The results of this analysis are presented in Table 9 in tabular form and graphically in Figure 11.

Table 9. Results of the cross-sectional analysis

Severity	Parameter	Estimate	Std Error	Pr (>|Z|)
K	Intercept	-5.163	3.795	0.174
	Natural logarithm of AADT	0.763	0.260	0.003
	Cable present (1 if yes; 0 otherwise)	-0.958	0.371	0.010
	Natural logarithm of median width (ft)	-1.887	0.606	0.002
	Overdispersion parameter	0.004		
A	Intercept	-12.335	2.481	<0.001
	Natural logarithm of AADT	0.886	0.173	<0.001
	Cable present (1 if yes; 0 otherwise)	-0.369	0.201	0.066
	Natural logarithm of median width (ft)	-0.186	0.363	0.609
	Overdispersion parameter	0.513		
B	Intercept	-11.446	1.464	<0.001
	Natural logarithm of AADT	1.015	0.1005	<0.001
	Cable present (1 if yes; 0 otherwise)	-0.299	0.112	0.007
	Natural logarithm of median width (ft)	-0.463	0.220	0.036
	Overdispersion parameter	0.339		
C	Intercept	-12.412	1.342	<0.001
	Natural logarithm of AADT	1.081	0.092	<0.001
	Cable present (1 if yes; 0 otherwise)	0.106	0.092	0.250
	Natural logarithm of median width (ft)	-0.359	0.201	0.075
	Overdispersion parameter	0.329		
O	Intercept	-12.376	0.655	<0.001
	Natural logarithm of AADT	1.203	0.046	<0.001
	Cable present (1 if yes; 0 otherwise)	0.734	0.042	<0.001
	Natural logarithm of median width (ft)	-0.299	0.097	0.002
	Overdispersion parameter	0.391		

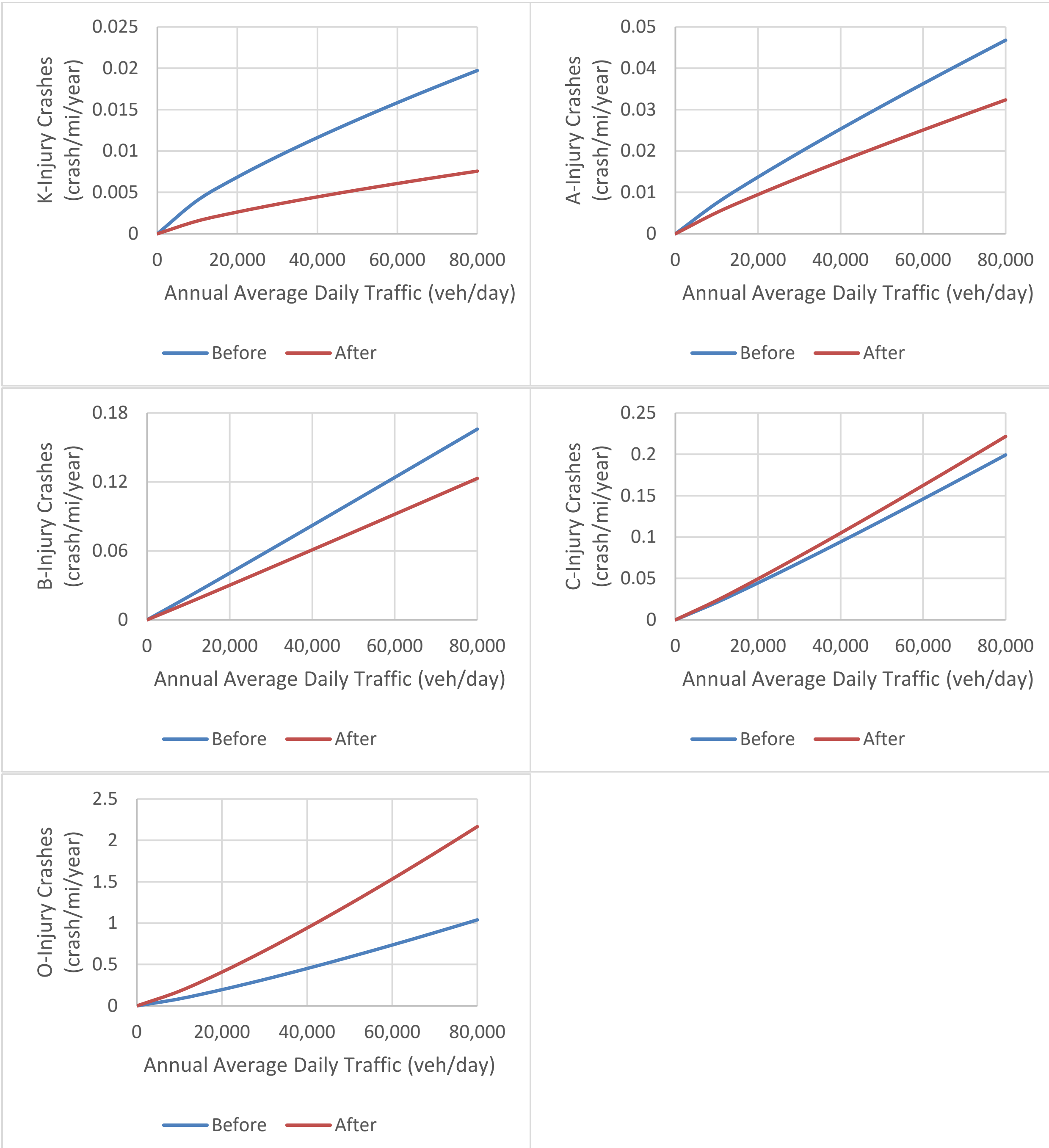

Figure 11. Results of cross-sectional crash comparison by severity level

Because the cross-sectional analysis also utilized a NB framework, the coefficients indicate results similar to those found in the previous analysis. As such, positive coefficients are associated with an increase in crash frequency, while negative coefficients are correlated with a decrease in crash frequency. Similar to the previous analysis, the results are categorized by injury severity. Each segment's AADT for both the control and non-control segments was characterized as an exposure factor, while segment length was treated an offset variable.

The results from this analysis again indicated that the presence of a median cable barrier system decreased the crash frequencies associated with K, A, and B injury-level crashes. Again, possible injury and PDO crashes increased after the treatment had been installed due to a reduction in higher severity crashes due to the effectiveness of the median cable barrier as well as an increase in nuisance strikes. This result is similar to the trend in crash rate per HMVMT found by evaluating the entire dataset (Table 7) and the results from the naïve before-after analysis (Table 8). The effectiveness of the median treatment was the greatest for fatal injury crashes, with a reduction in effectiveness for less severe crashes. This finding is also similar to the results of the naïve before-after analysis.

Unlike in the naïve before-after analysis, average median width was shown to have a significant impact on crashes across various injury severity levels. As expected, for each severity level, an increase in the average median width was associated with a decrease in crash frequency. In other words, as the amount of physical space between the opposite directions of travel increased, the less likely motorists were to be involved in a collision. This was particularly true during the pre-installation period when the median barrier was open. Even during the post-installation period, a wider median provides greater space for vehicular recovery, therefore reducing the chance of nuisance strikes.

4.2.3 Analysis Comparison

Both the naïve before-after comparison and the cross-sectional analysis indicated that the frequencies of K-, A-, and B-level crashes declined following the installation of cable barrier systems. Both of these analyses also indicated that the frequencies of C and PDO crashes increased after the installation of median cable barrier systems. The resultant effectiveness of the current cable barrier system is similar between these two frameworks as shown in Table 10. In general, the cross-sectional analysis showed a less pronounced reduction in K- and A-level crashes, which is likely reflective of the regression-to-the-mean phenomenon. Because they consider data from similar control locations in the cross-sectional analysis, these estimates are likely to be more accurate when estimating the performance of future installations.

Table 10. Effects of cable barrier presence on crashes by severity

Severity Level	Naïve Before-After	Cross-Sectional
K (Fatal)	-68.7%	-61.6%
A (Incapacitating)	-36.8%	-30.8%
B (Non-incapacitating)	-23.9%	-25.8%
C (Possible injury)	+5.7%	+11.2%
O (No injury)	+95.4%	+108.3%

The percentages of reductions and increases in Table 10 are derived from the statistical models developed during the three analyses. The models utilized the variables and parameters noted in Table 8 and Table 9.

Overall, median cable barriers were found to be most effective at reducing fatal crashes, reducing these crashes by approximately 61.6 percent according to the cross-sectional analysis. A-level crashes were also significantly reduced (by 30.8 percent), as were B-level crashes (by 25.8 percent). In contrast, the crash frequencies for the two categories for which no injuries were apparent both increased. The number of C-level (possible injury) crashes increased by 11.2 percent, while PDO crashes increased by 108.3 percent.

4.3 Economic Analysis of Median Cable Barrier Installations

In order to discern the cost-effectiveness of the median cable barriers that have been installed in in Iowa to date, a benefit-cost analysis was conducted. In this analysis, the benefits were comprised of the crash cost savings realized through the reductions in fatal, incapacitating, and non-incapacitating injury crashes. In contrast, the increases in possible injury crashes and property damage-only crashes represent costs to the public. These costs and the annual maintenance costs were added to the initial installation costs of the barrier systems.

4.3.1 Maintenance and Repair Cost Analysis

As noted previously, installation and repair information was provided by the Iowa DOT. Currently, four of the six Iowa DOT districts have median cable barriers installed along Interstates within their jurisdictions. Note that each district is responsible for administering a repair contract with a private contractor to maintain and replace the barrier systems. Consequently, there is significant variability in costs across districts and within individual districts over time. An aggregate summary of the maintenance information received can be found in Table 11.

Table 11. Maintenance and repair data summary

Year	District	Number of Repairs	Post Repair Count	Mobilization Cost	Total Cost	Average Cost Per Repair	Average Mobilization Cost per Repair
2011	1	26	133	$ 24,000	$ 45,817	$ 1,762	$ 923
	6	40	277	$ 15,000	$ 48,962	$ 1,224	$ 375
2012	1	348	1,583	$ 112,600	$ 310,942	$ 894	$ 324
	6	469	2,274	$ 97,245	$ 387,622	$ 826	$ 207
2013	1	298	1,867	$ 82,249	$ 315,746	$ 1,060	$ 276
	6	538	3,387	$ 46,389	$ 530,691	$ 986	$ 86
2014	1	41	185	$ 10,846	$ 28,270	$ 690	$ 265
	5	11	53	$ 6,000	$ 25,025	$ 2,275	$ 545
	6	642	2,506	$ 118,995	$ 714,597	$ 1,113	$ 185
2015	1	272	2,536	$ 106,154	$ 437,142	$ 1,607	$ 390
	5	16	205	$ 18,650	$ 74,307	$ 4,644	$ 1,166
Total	-	2,701	15,006	$ 638,128	$ 2,919,122	-	$ 431

This information is presented by district and year for all cases where such data were provided. The summary information includes the annual number of repairs, the number of posts repaired, the mobilization cost, the total cost, the average cost per repair, and the average mobilization cost per repair.

According to the information in Table 11, the factor that most affected the total repair cost was the count of required post replacements needed to return the barrier to an operational state. The mobilization costs incurred for each repair were also notable. Table 12 shows the percentage of the total repair cost that is directly related to the mobilization of the maintenance staff for each district that provided documentation annually.

Table 12. Comparison of mobilization and total repair costs

Year	District	Mobilization Cost	Total Cost	Percent Mobilization Cost of Total Cost
2011	1	$ 24,000	$ 45,817	52%
	6	$ 15,000	$ 48,962	31%
2012	1	$ 112,600	$ 310,942	36%
	6	$ 97,245	$ 387,622	25%
2013	1	$ 82,249	$ 315,746	26%
	6	$ 46,389	$ 530,691	9%
2014	1	$ 10,846	$ 28,270	38%
	5	$ 6,000	$ 25,025	24%
	6	$ 118,995	$ 714,597	17%
2015	1	$ 106,154	$ 437,142	24%
	5	$ 18,650	$ 74,307	25%
Average	-	$ 58,012	$ 265,375	-
Total	-	$ 638,128	$ 2,919,121	-

It is interesting to note that mobilization costs as a percentage of the total costs impacted each district independently during the study period. In District 1, the percentage of mobilization costs decreased almost every year throughout the study period, except for 2014. Meanwhile, District 6 experienced a dramatic decline in mobilization costs between 2012 and 2013; however, the percentage of mobilization costs increased significantly for the final year of the provided data. Note that maintenance and repair costs were not provided from District 6 for 2015. Although District 5 only provided two years of repair information, it is evident that the change in the percentage of mobilization costs was relatively insignificant because financial records from both 2014 and 2015 demonstrate that mobilization costs are about a quarter of the total costs spent on median cable barriers. The significant variability in mobility costs is likely due to the manner in which each district chooses to group its repairs into a single repair order for the contractor. Repair orders with a greater number of locations are likely to result in a lower mobility cost per order. However, the underlying objective is to repair the barriers in a timely manner.

Because a majority of barrier strikes are often low severity or property damage-only, some studies have considered the resilient effectiveness of a barrier following a lesser severity strike. The intent of these types of analyses is to reduce the amount of maintenance conducted on the barrier systems by only repairing the barrier after more significant collisions have occurred. Limited research is available to quantify the amount of nuisance strikes a median cable barrier may sustain before it is no longer an effective countermeasure, but past literature has determined that the system can remain effective even after being struck lightly in a property damage-only incident (Ray et al. 2009). Alternatively, the increasing number of repairs may be attributed to the greater mileage of barrier present in these regions of the state.

4.3.2 Benefit/Cost Analysis

Using the disaggregate-level information collected for this analysis, a comprehensive B/C examination of the median cable barrier installation program in Iowa was conducted. This analysis considered initial installation costs provided by the Iowa DOT, annual maintenance and repair costs obtained from district-level on-call repair contracts, and the cost savings due to reductions in injury severity, described in the safety effectiveness section of this report.

To associate a financial benefit with a reduction in crash severity, values for crash costs were obtained from the Iowa DOT Transportation Safety Improvement Program (TSIP) Benefit/Cost Worksheet. These crash cost values are displayed in Table 13.

Table 13. Comprehensive crash costs by severity

Crash Type	Iowa DOT Cost per Injury	Average Vehicle Occupancy	Iowa DOT Cost per Crash
Fatal	$ 4,500,000	1.196	$ 5,382,353
Incapacitating	$ 325,000	1.238	$ 402,510
Non-incapacitating	$ 65,000	1.325	$ 86,141
Possible injury	$ 35,000	1.242	$ 43,476
Property damage only	$ 7,400*	-	$ 7,400

*Assumed cost per crash per Iowa DOT

The per-injury costs from the Iowa DOT were used to estimate the per-crash costs on the basis of the average vehicle occupancy at each severity level, which was obtained from the dataset utilized for the safety analysis. The Iowa DOT costs were included in the analysis due to their state-specific nature.

Table 14 presents the rate of target crashes per HMVMT (the same data were previously presented in Table 7).

Table 14. Crashes prevented by cable barrier installations

Crash Type	Pre-barrier Crashes per HMVMT	Post-barrier Crashes per HMVMT	Crashes Prevented per HMVMT	Crashes Prevented Per Year
Fatal	0.321	0.105	0.216	6.634
Incapacitating	0.649	0.401	0.247	7.587
Non-incapacitating	1.693	1.366	0.326	10.013
Possible injury	2.028	2.274	-0.246	-7.556
Property damage only	8.813	19.606	-10.793	-331.506

By comparing the crash rates before and after median cable barrier installation, an estimate of the number of crashes prevented per HMVMT was determined. To forecast future crash cost savings, this rate was multiplied by the annual traffic volumes on the segments where existing barriers had been installed. Based on these projections, it was estimated that approximately 6.6 fatal crashes would be prevented per year by the existing cable barrier systems. Similar data are provided for the other injury severity levels. It should be noted that possible injury (C-level) crashes are projected to increase by 7.6 crashes per year after barrier installation, while property damage-only crashes are projected to increase by 331.5 crashes per year. These estimates were multiplied by the corresponding crash costs in Table 13 as part of the economic analysis.

Installation cost information for the median cable barrier systems was provided by the Iowa DOT. Based on 14 individual projects that were let between 2011 and 2015, the average cost per mile for median cable barrier construction was $80,803. At the conclusion of 2015, 251 miles of cable barrier had been installed along the Interstates of interest, which represents a $20,281,553 investment in this median countermeasure by the state of Iowa thus far. These system costs are comprehensive in nature and include construction of the median barrier system, removal of the barrier, necessary earthwork for installation, seeding near the construction area, and erosion control parameters. Note that these costs do not include traffic control or mobilization costs because these vary depending on the scope of the individual projects.

In order to estimate the annual maintenance costs, the maintenance/repair data from Table 11 and Table 12 were utilized in combination with the number of police-reported crashes that occurred in the districts where median cable barriers were present during the years for which maintenance cost data were available. The total maintenance costs based on the data provided by the Iowa DOT were $2,919,121, as displayed in Table 11. These repair costs corresponded to 2,096 police-reported crashes after median cable barrier was installed in districts one, five, and six during the years 2011 to 2015, resulting in an average maintenance and repair cost of approximately $1,393 per crash. Using the crash rates per HMVMT after median cable barrier installation for each of the five injury severity levels (presented in Table 7), in combination with the most recent VMT estimates for each cable barrier segment (total of 31.89 HMVMT for all segments), an annual average of 758 total target crashes was estimated. By multiplying the number of annual target crashes on the segments with median cable barrier by the average maintenance and repair cost per crash, total annual maintenance and repair costs of $1,055,894 are estimated, as shown in Table 15. One issue with this method is that not all crashes involving cable barrier strikes are reported, particularly nuisance strikes resulting in minimal property damage. However, if the underreporting rates are consistent across districts, this should provide a reasonable estimate when projecting future maintenance costs on a statewide basis.

Table 15 presents the results of the B/C analysis. The B/C ratio is the ratio of crash cost savings (i.e., monetary value of the reductions in K-, A-, and B-level injuries minus the monetary value of the increase in C-level injuries and O-level crashes) to the installation and maintenance/repair costs. Consistent with Iowa DOT policy, a discount rate of 4 percent and an annual traffic growth rate of 1 percent were applied. The design life of the median cable barrier system was estimated to be 20 years based on previous cable barrier installation research (Russo 2015 and Savolainen et al. 2014) and an Iowa DOT recommendation.

Table 15. Benefit-cost of current cable median barrier system installations in Iowa

Crash Type	Difference in Annual Target Crashes	Cost per Crash	Annual Target Crash Reduction Benefit
Fatal	7.377	$ 5,382,353	$ 39,706,755
Incapacitating	8.470	$ 402,510	$ 3,409,318
Non-incapacitating	11.168	$ 86,141	$ 962,050
Possible injury	-8.402	$ 43,476	-$ 365,277
Property damage only	-368.622	$ 7,400	-$ 2,727,800
Total	-350.009	-	$ 40,985,065

Economic Factors	Annual Value	Present Value
Installation		$ 20,281,553
Maintenance and repairs	$ 1,055,894	
Crash cost savings	$ 40,985,065	

Design Life	Annual Value Benefit	Annual Value Installation Costs	Annual Value Maintenance and Repair Costs	B/C Ratio
20 years	$ 40,985,065	$ 1,492,352	$ 1,055,894	16.08

Ultimately, each of the test scenarios generated a favorable investment. Because inflation and other annual economic parameters were not considered in this analysis, it was assumed that the before and after crash rates, as well as the difference between them, would remain the same during the life cycle of the median cable barrier. Based on the provided benefit-cost ratios, it is recommended that the Iowa DOT continue to invest in median cable barriers because they have proven to be effective safety treatments and provide a financially favorable investment over the course of their estimated design life.

4.4 Estimate of Unreported Crash Frequency

Given the fidelity and disaggregate nature of the acquired crash, maintenance, and repair data, an analysis was conducted to estimate the number of unreported crashes involving the median cable barrier systems currently installed. Both previous literature and the analyses in this study found that PDO crashes increased following barrier installation. Although the reported crashes exhibit this trend, there is a potential underreporting bias for PDO crashes. Because striking a roadside barrier may incur high costs and require an insurance claim to be filed, some motorists may choose not to self-report crashes, especially those involved in single-vehicle crashes with no witnesses.

To determine the rate of underreporting, all of the target crashes previously identified using the crash narrative methodology were geospatially matched to the analysis segments. Next, the locations of known maintenance and repair operations were matched to the analysis segments. To investigate the rate of underreporting, two buffers were created for the analysis. A spatial buffer of one mile from the crash location was created in two equivalent intervals (i.e., 0.5 miles before the crash location and 0.5 miles after the crash location), and a temporal interval between two and four weeks after a crash was used to match the maintenance and repair data to the relevant target crashes. In other words, crashes were paired with known maintenance and repair information based on spatial and temporal relevance. A one-mile buffer was utilized due to possible inaccuracies in crash reporting methods, while a temporal buffer between two and four weeks after a crash was used due to known repair contract deadlines (i.e., after a crash notification, the repairing organization must fix the cable barrier installation within a two-week period). Any maintenance and repair information that was not matched to a crash within these two buffers was considered to be the result of an unreported crash. Table 16 contains the results of the crash matching analysis.

Table 16. Matching crash, maintenance, and repair data

District	Repair Count	Matched within Two Weeks of Crash Date	Percentage of Total Repairs	Matched within Four Weeks of Crash Date	Percentage of Total Repairs
1	985	639	65%	732	74%
5	27	14	52%	14	52%
6	1,689	704	42%	959	57%

Note that the values in Table 16 are those maintenance and repair locations that matched geospatially with a known crash based on the restrictions and buffers previously mentioned. Therefore, any maintenance and repair information that did not match a target crash within the two previously defined buffers may have been the result of an unreported crash. Using a weighted average (of all crashes in all districts) and a two-week time period to match repair data, it is estimated that approximately 47% of crashes involving median cable barriers may go unreported. Similarly, a weighted average over a four-week time period suggests that 36% of crashes with the barrier system are unreported.

4.5 Vehicular Penetration and Effect of Post Spacing

In order to investigate the historical frequency of vehicular penetration of median cable barrier installations within Iowa, the relevant target crashes were reviewed. The review process involved the 6,718 target crashes that were determined to be median related based on the narrative review methodology. Using the police-reported crash narratives provided by the responding officers, an analysis was conducted to determine if any vehicle involved in a crash penetrated the cable barrier system. In order to further classify each penetration at a disaggregate level, crashes were classified into the following three categories:

- Category 1: A vehicle involved in the crash penetrated the median cable barrier but was still contained within the median by the system.
- Category 2: A vehicle involved in the crash penetrated the median cable barrier and entered the opposing lanes of travel but did not strike an opposing vehicle.
- Category 3: A vehicle involved in the crash penetrated the median cable barrier and entered the opposing lanes of travel, ultimately striking an opposing vehicle.

The results from this narrative analysis were disaggregated by vehicle type and are presented in Table 17. In the nine years of crash data, only 30 of the 6,718 target crashes (0.4 percent) resulted in a penetration of a barrier system. Of the penetration crashes, eight were prevented by the cable barrier from reaching the opposite direction of travel. Of the 22 remaining crashes, only 16 involved a collision with an opposing vehicle due to the failure of the median barrier treatment. Of all the vehicle types considered, passenger cars were the most likely to penetrate the barrier system; however, this was most likely due to their greater rate of exposure compared to other vehicle types. Larger and heavier vehicles, especially tractor trailers, were also subjected to penetration crashes. During the nine-year analysis period, vehicular penetrations from tractor trailer strikes occurred nine times. Note that these penetrations may not always be due to the barrier system alone, but rather other external factors that the barrier was not designed to handle, such as extreme vehicle sizes and weights or abnormally high speeds.

Table 17. Vehicular penetrations by vehicle type

Vehicle Type	Category 1	Category 2	Category 3	Total
Passenger car	4	3	5	12 (40%)
Sport utility vehicle (SUV)	0	0	1	1 (3%)
Van/minivan	1	1	0	2 (7%)
Pickup truck	1	1	2	4 (13%)
Single-unit truck	1	0	1	2 (7%)
Tractor trailer	1	1	7	9 (30%)
Total	8	6	16	30

The effects of weather also appear to influence the vehicular penetration rate of the median cable barrier systems. While a majority of penetrations occurred on dry roadway conditions due to inattention, drowsiness, distraction, or other factors, some countermeasure failures may have been due to wet or icy roadways. Adverse weather conditions decrease the ability of drivers to control their vehicle and increase the initial barrier impact force because the effects of motorist braking are reduced significantly. The results of the analysis of weather impacts on barrier penetrations for the three previously defined categories are displayed in Table 18.

Table 18. Vehicular penetrations by weather condition

Weather Condition	Category 1	Category 2	Category 3	Total
Dry	7	11	2	20 (67%)
Wet/icy	1	8	1	10 (33%)
Total	8	19	3	30

As shown in Table 18, 20 of the 30 vehicular penetrations (67 percent) occurred during dry weather conditions. Because this is the predominant weather condition in Iowa during most of the year, the rate of exposure for dry conditions is much greater than that of any other weather condition. However, 10 penetrations did occur under adverse weather conditions during the nine-year analysis period. Of these, most involved a vehicle entering the opposite lane of travel without striking another vehicle heading in the opposite direction (n = 8). One of the penetration crashes during wet/icy weather conditions involved a vehicle passing through the countermeasure but still remaining within the median, while another penetration crash involved a vehicle passing through the cables and striking another vehicle traveling in the opposite direction.

It is important to further analyze the penetration crashes for the severity of sustained injuries, if any. The worst degree of injury severity sustained in the 30 penetration crashes is shown in Table 19.

Table 19. Vehicular penetrations by crash severity

Crash Severity	Crash Frequency
Fatal (K)	1
Incapacitating (A)	1
Non-incapacitating (B)	2
Possible (C)	6
Property damage only (O)	20

Of the 30 experienced penetrations during the nine-year analysis period, 20 were of the lowest injury severity level (PDO). Furthermore, six additional crashes were classified as possible injury, potentially suggesting the severity reduction benefits of median cable barriers, even in cases of vehicular penetration. Of the crashes involving a barrier penetration, four resulted in confirmed occupant injuries (13 percent). Despite this, only one of the crashes was fatal, which again indicates the potential benefits of median cable barrier installations. The data for the nine-year analysis period indicate that even when an errant vehicle is able to penetrate through the barrier, the vehicle is often slowed enough to prevent a fatal injury.

After the vehicular penetration crashes were identified, an analysis of the effects of post spacing distance on vehicular penetrations was conducted. According to information provided by the Iowa DOT, median cable barrier installations traditionally had a post spacing of 20 ft. Beginning in 2015, this post spacing was reduced to 10 ft on curved installations due to a research-recommended practice. To determine the effects of this reduced spacing on the frequency of vehicular penetrations, each of the previously identified 30 penetration crashes was analyzed. Each crash location was identified and visually analyzed using Google Earth measurement tools. The effect of post spacing on vehicular penetration occurrence is shown in Table 20.

Table 20. Vehicular penetrations by post spacing

Year	10-ft Post Spacing	20-ft Post Spacing
2007	-	0
2008	-	0
2009	-	0
2010	-	0
2011	-	0
2012	-	1
2013	-	1
2014	-	5
2015	1	22

Note that the 10-ft post spacing was only implemented on curves beginning in 2015 and curves make up a small percentage of the overall mileage. Because of this, almost all vehicular penetrations occurred through barrier systems where the post spacing was 20 ft. Interestingly, the review of police officer crash narratives indicated that 77 percent of vehicular penetrations (n = 23) occurred in 2015, with only seven other penetrations occurring during the previous eight years. The reason for this may be that in 2015 an option was added to the Iowa DOT Crash Report Form that allowed officers to indicate that a median cable barrier was struck. Before 2015, the police crash report form did not include an option for specifically indicating that a median cable barrier was struck. Because of this new option, responding police officers may have been much more likely to mention the role of median cable barriers in their narratives, which allowed a more accurate identification of vehicular penetrations through the crash narrative methodology.

4.6 Detailed Investigation of Fatalities and Serious Injury Penetrations

An in-depth investigation was conducted of those crashes that involved an existing median cable barrier installation and that involved at least one occupant who suffered a fatal injury. Based on the crash coding provided by the Iowa Accident Report Form, six target crashes had at least one occupant suffer a fatal injury along a segment with median cable barrier installed. Note that segment-year combinations during which cable barrier installation occurred were removed from the analysis because it was assumed that construction changes may increase the number of crashes.

One fatal median cable barrier crash occurred in 2012 and involved a vehicle fire. As noted in the crash narrative, the emergency responders located the vehicle after the crash had occurred and the vehicle was already on fire. Because the sole occupant had passed before the responders were present and there were no witnesses to the crash, it was not possible to tell whether the vehicle striking the barrier started the fire or whether the vehicle was on fire before striking the barrier system. Another fatal median crash occurred in 2013 that involved three separate vehicles. The occupant fatally injured in this crash rear-ended the other two vehicles at a high speed before entering the median. The sole driver had passed from his or her injuries before entering the median at this location.

Three fatal median crashes occurred in 2014. The first was a single-vehicle crash in which the driver left the roadway to the left and collided with the cable barrier. Following this, the vehicle rolled a number of times along the median. Ultimately, the driver was declared deceased from his or her injuries at the scene of the crash. The second fatal crash of 2014 involved a vehicle entering the median for an unknown reason and becoming trapped between two median cable barriers on either side of the roadway. While between the barriers, the vehicle continued speeding within the grassy median and struck a large cement bridge pillar. The driver sustained fatal injuries from this collision and was pronounced dead at the scene. The last fatal median crash in 2014 involved a vehicle entering the median sideways. From this position, the vehicle rolled over the cable system and struck a vehicle travelling in the opposite direction. The driver of this vehicle passed away later in the hospital due to his or her injuries.

The last fatal median crash during the analysis period occurred in 2015. Based on the reported crash narrative, a vehicle travelling along a segment with a median cable barrier lost control and entered the median at a high rate of speed. Immediately upon entering the median, the vehicle struck a median turn-around and ramped over the cable barrier. The vehicle rolled a few times and ejected two of its passengers. Of the three occupants in the vehicle, two were pronounced dead at the scene of the crash.

Those crashes that resulted in reported injuries from median cable barrier penetrations were analyzed in detail. The only fatality reported occurred in 2014. Based on the coded information from the crash report form, the crash involved a pickup truck driving under clear weather conditions. From the events explained in the police-reported crash narrative, the driver abruptly left the roadway to the left and entered the median skidding sideways. After entering the median, the vehicle struck the barrier system and rolled over it entirely, ending in the inside lane of the opposite direction of travel. While there, the flipped vehicle was struck by another motorist. At the conclusion of these events, the operator passed away from his or her injuries.

Two separate crashes that involved median cable barrier penetrations resulted in serious injuries. Both of these crashes occurred during daylight hours. In one serious injury crash, the vehicle left a wet roadway surface and penetrated the barrier. After this event, the vehicle was struck by a motorist traveling in the opposite direction. The second serious injury crash was the result of an operator swerving away from the rear tires of a tractor trailer and losing control of the vehicle. After this, the vehicle penetrated the barrier and came to rest on the opposite side of the roadway.

The final median cable barrier penetration crash resulted in minor injuries. This was a single-vehicle crash that occurred during daylight hours and involved an intoxicated driver. In this scenario, the driver lost control of the vehicle, passed through the median cable barrier system, and entered the oncoming lanes of traffic.

4.7 Installation of Median Cable Barriers on Expressways

Based on the analysis of the Interstate segments, a parallel investigation of expressway segments within the state was conducted for potential application of median cable barriers. An expressway is a divided, access-controlled highway that has limited at-grade intersections. The expressway segments were collected from the Iowa DOT GIMS database. Quality assurance procedures were employed to ensure that all analysis segments were expressways (i.e., consistent with the GIMS categorization of the individual segments). To establish further accuracy, the Iowa DOT maintenance data, which contains geospatial information on all statewide median barriers, were consulted to determine where median barriers (concrete, steel-beam, and cable) existed on the expressways during the analysis period. Segments with extensive lengths of existing barriers of any type were removed from the analysis dataset because these segments were not eligible candidates for future median cable barrier installation. Furthermore, segments less than 0.06 miles in length were joined to nearby segments to mitigate concerns related to the spatial accuracy of short segments. Ultimately, 1,140 miles of expressway were utilized for the analysis. Figure 12 details the geospatial locations of the expressway analysis segments.

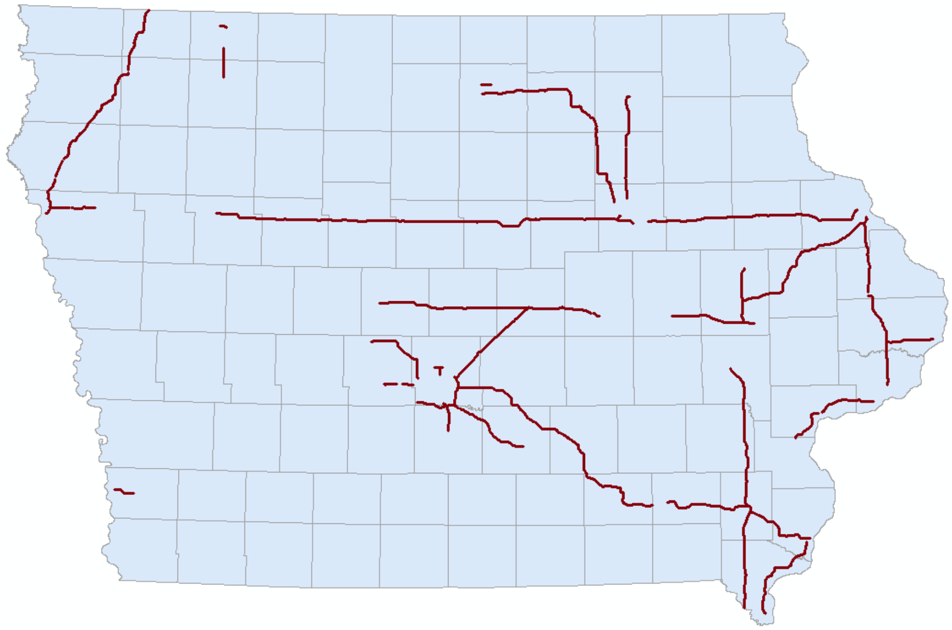

Figure 12. Expressway analysis segments

The most recent five years of complete data (2011–2015) were utilized for this analysis. A 100-ft buffer was applied to the expressway analysis segments to obtain the relevant crashes. In total, information from 16,084 crashes was collected. The previously mentioned keyword methodology was applied to the total crashes on the expressway network to determine the target crashes for the analysis. A review of the crash narratives showed that 1,715 target crashes occurred during the five-year period. This was 10.6 percent of the total expressway crashes included within the buffer areas. Recall that a target crash is any crash in which the vehicle departs the roadway towards the left (towards the median). Table 21 displays the numbers and percentages of target crashes at each crash severity level, while Table 22 contains the descriptive statistics of the analysis segments.

Table 21. Expressway target crashes by severity

Severity	Number of Target Crashes	Percent of Target Crashes
K – Fatal	36	2.10%
A – Incapacitating	103	6.01%
B – Non-incapacitating	310	18.08%
C – Possible injury	336	19.59%
O – No injury	930	54.23%
Total	1715	100.00%

Table 22. Expressway analysis segments descriptive statistics

Variable	Min	Max	Mean	Std Dev
Average AADT	1832	37,580	10,232	5463
Segment length (mile)	0.06	2.24	0.31	0.24
Posted speed limit (1 if 65 mph; 0 if less than 65 mph)	0	1	0.63	0.48
Median width (feet)	4	262	63.14	19.08
Total crashes	0	162	4.43	7.11
Target crashes	0	10	0.47	0.87
K – Fatal	0	2	0.01	0.10
A – Incapacitating	0	2	0.03	0.17
B – Non-incapacitating	0	3	0.09	0.31
C – Possible injury	0	3	0.09	0.33
O – No injury	0	6	0.26	0.60

In total, 3,629 segments from 1,140 miles of expressway were utilized for the analysis. As discussed previously, the minimum segment length was 0.06 miles, while the maximum segment length was 2.24 miles. The average AADT during the five-year analysis period ranged from 1,832 vehicles per day (vpd) to more than 37,000 vpd. Three speed limits were included within the analysis segments: 55 mph, 60 mph, and 65 mph. A majority (63%) of the analysis segments had a posted speed limit of 65 mph. The medians of the selected roadways had a minimum width of 4 ft and an average width of 63 ft. Lastly, from the presented crash frequency data, the maximum amount of K crashes on one segment was 2, while the largest frequency of PDO crashes was 6.

As in the Interstate analysis, a NB regression framework was used to estimate a crash prediction model for the identified target crashes. The NB framework is explained in further detail in Section 4.1. The resultant parameter estimates are displayed in Table 23. Note that the segment length was again considered as an offset variable, similar to the Interstate models.

Table 23. Negative binomial estimates of expressway target crashes

Parameter	Estimate	Std Error	z-value	Pr(>|z|)
Intercept	-6.021	0.740	-8.133	<0.001
Natural logarithm of AADT	0.782	0.064	12.285	<0.001
Natural logarithm of median width (ft)	-0.195	0.085	-2.282	0.023
Speed less than 65 mph (base)	-	-	-	-
Speed equal to 65 mph	0.118	0.067	1.761	0.078
Overdispersion	0.589	0.073	8.120	<0.001

Based on the statistical estimates, as the AADT increases on an expressway segment, the target crashes are also likely to increase. A one-percent increase in traffic volume is associated with an increase of 0.78 percent in target crashes. Conversely, target crashes are expected to decrease as median width increases. Based on the estimates in Table 23, a one-percent increase in median width is associated with a 0.20 percent decrease in target crashes. Lastly, segments with a posted speed limit of 65 mph experienced 12.52 percent more crashes on average than segments with lower speed limits.

Figure 13 graphically depicts the predicted number of crashes at different median width and traffic volume combinations using the statistical estimates from Table 23. Each line in Figure 13 represents a different median width, ranging from 50 ft to 250 ft in 50-ft increments. Regardless of median width, crashes are expected to increase logarithmically as traffic volume increases; however, the expected number of target crashes is likely to be fewer as the median width increases. Ultimately, these trends are similar in nature to what was observed for the Interstate system.

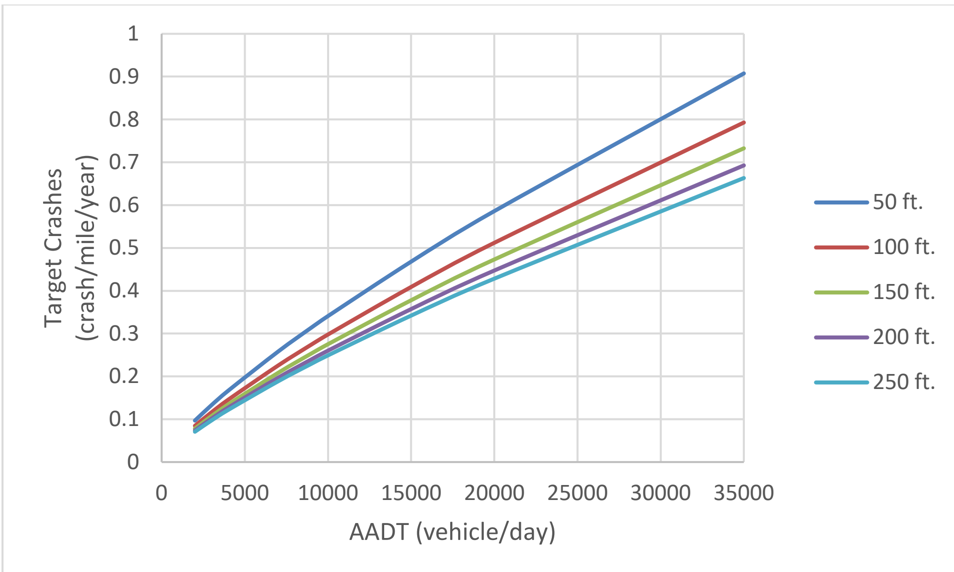

Figure 13. Estimated number of target crashes based on median width and AADT

5. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this analysis was to determine both the safety and cost-effectiveness of 251 miles of median cable barrier systems installed along Interstates within the state of Iowa by the end of 2015. Median barriers are typically installed on divided roadways to reduce the risk of cross-median crashes. These crashes are typically severe due to the high travel speeds of vehicles on divided roadways in combination with the presence of fixed roadside objects and the threat of striking a vehicle traveling at a high rate of speed in the opposite direction of travel. To mitigate this crash type, the Iowa DOT began installing median cable barrier systems in 2003. Anecdotal evidence and prior studies in other regions have shown favorable results for median cable barrier installations, especially when compared to other common median treatments such as concrete barriers and steel-beam guardrail barriers.

In this study, an in-depth analysis of the frequency and severity of crashes was performed on divided roadway segments both with and without cable barrier systems. The study considered 6,718 median-related crashes over a nine-year (2007 to 2015) analysis period that were identified based on a manual review of relevant crash narratives. A collection of financial information, including installation, maintenance, and repair costs, was utilized to determine the financial effectiveness of the median treatments to date.

5.1 Safety Benefits of Median Cable Barrier Installations

In order to examine the safety effectiveness of the median cable barrier installations in Iowa, statistical analyses were conducted to discern the influence of the cable barrier systems on traffic crashes, injuries, and fatalities. A naive before-after comparison showed that median cable barrier installations have reduced K-, A-, and B-level crashes by 68.7, 36.8, and 23.9 percent, respectively. Conversely, C- and O-level crashes increased by 5.7 and 95.4 percent, respectively. These increases are reflective of the efficacy of the barrier system in reducing the severity of crashes that may have resulted in fatal or severe injury prior to the barrier being installed. In addition, some of this increase is also attributable to nuisance strikes given the proximity of the barrier to the traveled way. To address potential concerns related to regression-to-the-mean, a cross-sectional analysis was also conducted, which showed similar results. K-, A-, and B-level crashes were reduced by 61.6, 30.8, and 25.8 percent, respectively. C- and O-level crashes increased 11.2 and 108.3 percent, respectively.

5.2 Benefit-Cost Analysis of Median Cable Barrier Installations

By comparing the observed changes in crashes by injury severity level between the periods before and after installation of the median cable barrier systems, an economic analysis was conducted to compare the crash cost savings to the installation and maintenance/repair costs. Crash costs were based on monetary values provided by the Iowa DOT. A service life of 20 years was considered based on existing literature and an Iowa DOT recommendation. Ultimately, the financial calculations estimated a positive B/C ratio, representing a favorable investment. An estimated design life of 20 years resulted in a B/C ratio of 16.08 when Iowa DOT crash costs were used on a per crash basis. According to these results, the median cable barrier installation program has provided an effective median treatment that reduces injury severity and represents a very favorable investment of financial resources.

5.3 Future Installation Guidelines for Median Cable Barriers

Based on the historical target crashes that were manually identified through the crash narrative review process, a design chart was developed to provide installation guidance for future installations of median cable barriers in Iowa. These guidelines are similar to those found in the *Roadside Design Guide* (AASHTO 2011) in that they are based on AADT and median width. Figure 14 shows how the B/C ratio changes based upon various combinations of AADT and median width. The prioritization scheme has been established such that there are comparable miles of Interstate that fall under the various B/C thresholds defined in Figure 14, except for those combinations that have a B/C < 1.00. All combinations with a B/C < 1.00 are identified independently since they have a negative rate of return. Sample calculations outlining the benefit/cost analysis that was conducted in preparation of Figure 14 are contained in the Appendix of the report.

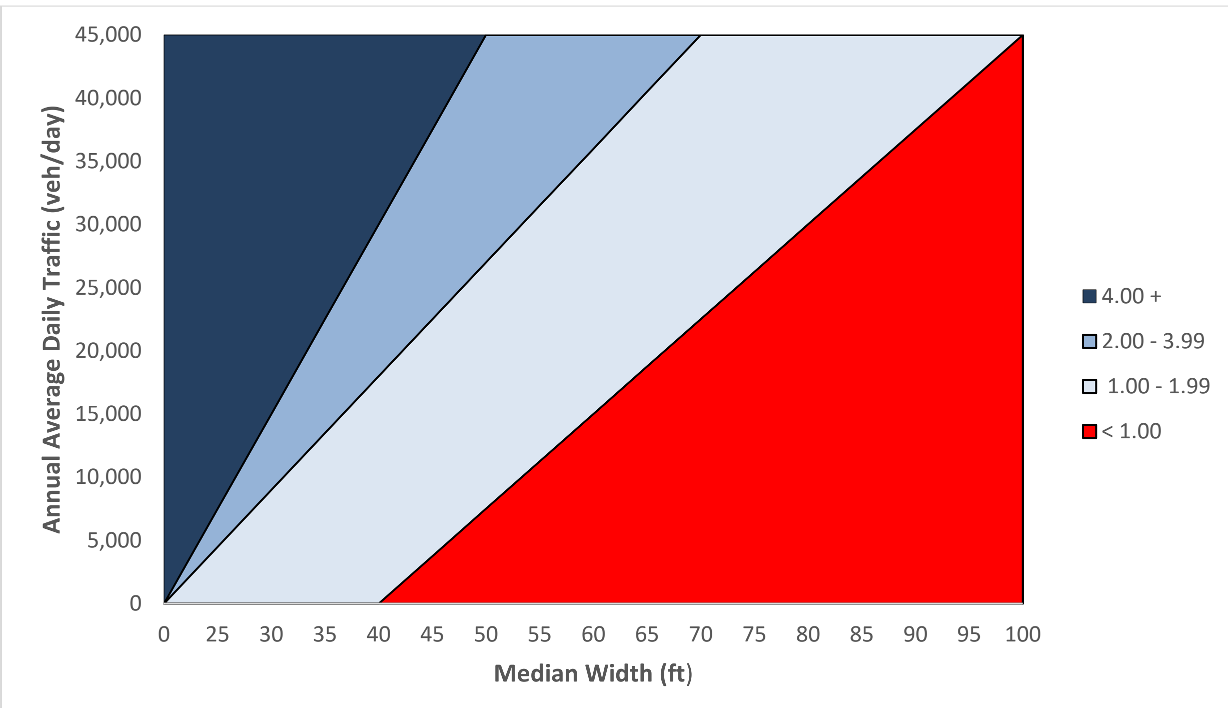

Figure 14. Benefit-cost ratio for median cable barrier installation based on AADT and median width

These guidelines were ultimately applied to the remaining candidate segments on the Interstate system where median cable barriers are not currently installed. Using AADT and median width as input values for each candidate section, the expected annual number of crashes by severity level was calculated. For these same segments, the expected annual number of crashes after barrier installation was also estimated. The differences between these estimates were then used to estimate the crash cost savings (or increases) that could be realized by installing barriers on each segment using the Iowa DOT economic data from Table 13. These crash costs were used in combination with cost data for barrier installation and maintenance to calculate the B/C ratio for each individual segment. The results of this economic analysis were then used to develop the map in Figure 15, which assigns each candidate segment a priority level (high, medium, low, or not economically viable).

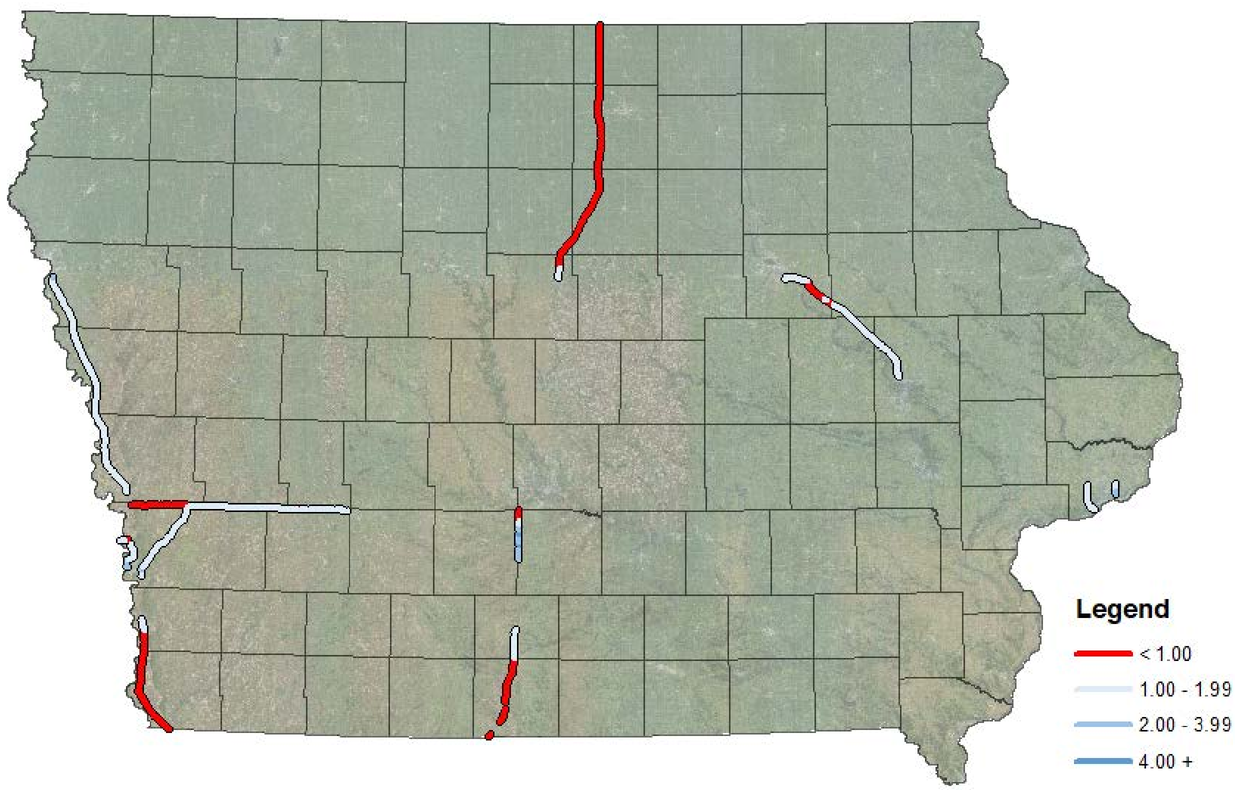

Figure 15. Candidate locations for median cable barrier installation on Interstates

The same prioritization scheme, using AADT and median width as input values, was developed for the expressway system. Figure 16 provides a map of the expressway segments that fall under the same priority levels as comparable Interstate segments. Ultimately, Figure 15 and Figure 16 can be used to aid in subsequent investment decisions related to the installation of median cable barriers.

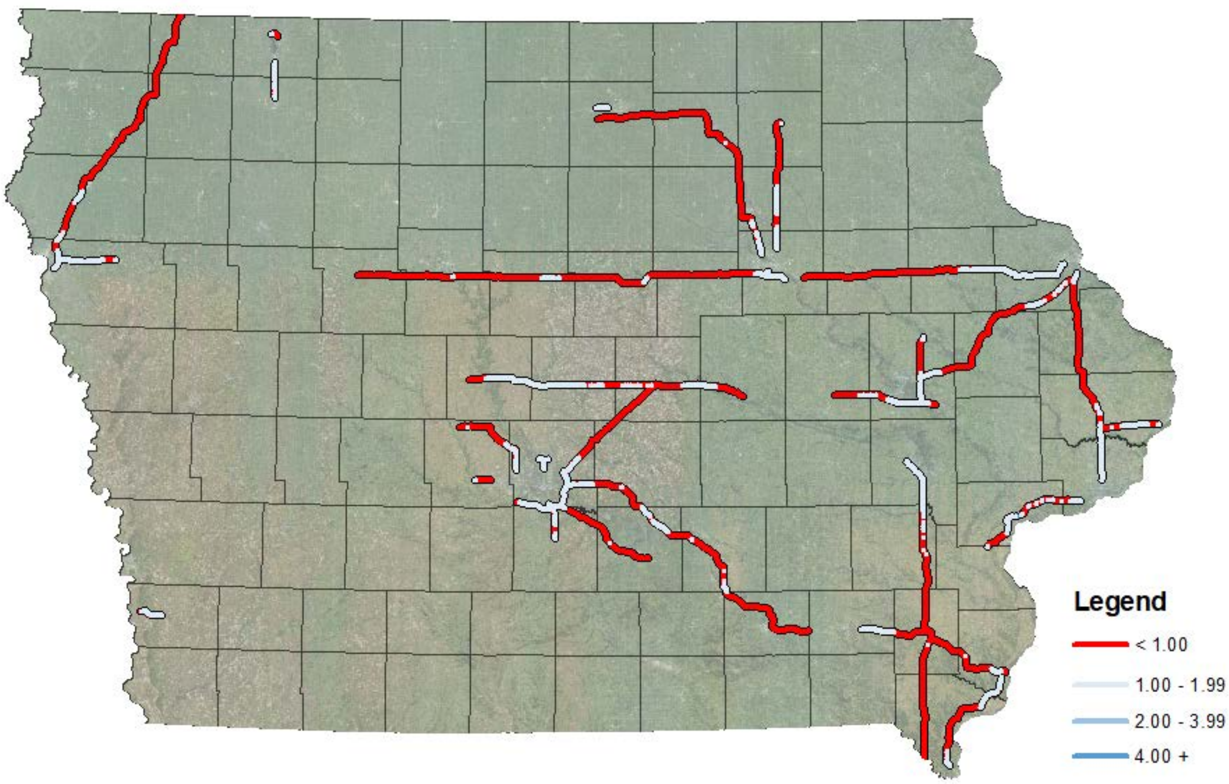

Figure 16. Candidate locations for median cable barrier installation on expressways

REFERENCES

Agent, K. R., and J. G. Pigman. 2008. *Evaluation of Median Barrier Safety Issues.* KTC-08-14/SPR329-07-1F. Kentucky Transportation Center, Lexington, KY.

Alluri, P., K. Haleem, and A. Gan. 2012. *In-Service Performance Evaluation (ISPE) for G4 (1S) Type of Strong-Post W-Beam Guardrail System and Cable Median Barrier: Volume II.* BDK80 977-19. Lehman Center for Transportation Research, Miami, FL.

AASHTO. 2010. *Highway Safety Manual*. American Association of State Highway and Transportation Officials, Washington, DC.

AASHTO. 2011. *Roadside Design Guide*. 4th ed. American Association of State Highway and Transportation Officials, Washington, DC.

Bligh, R. P., S.-P. Miaou, D. Lord, and S. Cooner. 2006. *Median Barrier Guidelines for Texas.* FHWA/TX-06/0-4254-1. Texas Transportation Institute, College Station, TX.

Blincoe, L. J., T. R. Miller, E. Zaloshnja, and B. A. Lawrence. 2014. *The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised)*. Report No. DOT HS 812 013. National Highway Traffic Safety Administration, Washington, DC.

Chandler, B. 2007. Research Pays Off: Eliminating Cross-Median Fatalities: Statewide Installation of Median Cable Barrier in Missouri. *TR News*, No. 248.

Chimba, D., D. Emaasit, S. Allen, B. Hurst, and M. Nelson. Safety Effectiveness Evaluation of the Cable Rail Systems in Tennessee. 92nd Annual Meeting of the Transportation Research Board, Washington, DC, January 13–17, 2013.

Cooner, S. A., Y. K. Rathod, D. C. Alberson, R. P. Bligh, S. E. Ranft, and D. Sun. 2009. *Performance Evaluation of Cable Median Barrier Systems in Texas.* FHWA/TX-09/0-5609-1. Texas Transportation Institute, College Station, TX.

Daniello, A., and H. C. Gabler. 2011. Effect of Barrier Type on Injury Severity in Motorcycle-to-Barrier Collisions in North Carolina, Texas, and New Jersey. *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 2262, No. 1, pp. 144-151.

Donnell, E. T., D. W. Harwood, K. M. Bauer, J. M. Mason, and M. T. Pietrucha. 2002. Cross-median Collisions on Pennsylvania Interstates and Expressways. *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 1784, No. 1, pp. 91-99.

Graham, J. L., D. W. Harwood, K. R. Richard, M. K. O'Laughlin, E. T. Donnell, and S. N. Brennan. 2014. *NCHRP Report 794: Median Cross-Section Design for Rural Divided Highways*. National Cooperative Highway Research Program, Washington, DC.

Marzougui, D., U. Mahadevaiah, F. Tahan, C. D. Kan, R. McGinnis, and R. Powers. 2012. *NCHRP Report 711: Guidance for the Selection, Use, and Maintenance of Cable Barrier Systems.* National Cooperative Highway Research Program, Washington, DC.

McClanahan, D., R. B. Albin, and J. C. Milton. 2003. Washington State Cable Median Barrier In-service Study. 83rd Annual Meeting of the Transportation Research Board, Washington, DC, January 11–15, 2003.

Miaou, S.-P., R. P. Bligh, and D. Lord. 2005. Developing Guidelines for Median Barrier Installation: Benefit-cost Analysis with Texas Data. *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 1904, pp. 3-19.

Noyce, D. A. 2006. Reducing Median Crossover Crashes in Wisconsin. 2006. *2006 Institute of Transportation Engineers (ITE) Annual Meeting and Exhibit Compendium of Technical Papers: August 6–9, 2006*. Institute of Traffic Engineers, Washington, DC.

Olson, D., M. Sujka, and B. Manchas. 2013. *Cable Median Barrier Program in Washington State.* WA-RD 812.1, Washington State Department of Transportation, Olympia, WA.

Qin, X., and M. Wang. 2010. High-Tension Median Cable In-Service Performance Evaluation and Cost-Effectiveness Analysis. 89th Annual Meeting of the Transportation Research Board, Washington, DC, January 10–14, 2010.

Ray, M. 2007. *A Report Requested by the Governor of the State of Washington: Cable Median Barrier, Reassessment and Recommendations*. Washington State Department of Transportation, Olympia, WA.

Ray, M., C. Silvestri, C. Conron, and M. Mongiardini. 2009. Experience with Cable Median Barriers in the United States: Design Standards, Policies, and Performance. *Journal of Transportation Engineering,* Vol. 135, No. 10, pp. 711-720.

Russo, B. J. 2015. Guidance on the Application of Cable Median Barrier: Tradeoffs between Crash Frequency, Crash Severity, and Agency Costs. MS thesis. Iowa State University, Ames, IA.

Savolainen, P. T., T. J. Gates, B. J. Russo, and J. J. Kay. 2014. *Study of High-Tension Cable Barrier on Michigan Roadways on Michigan Roadways*. RC-1612. Wayne State University, Detroit, MI.

Stasburg, G., and L. C. Crawley. 2005. Keeping Traffic on the Right Side of the Road. *Public Roads,* Vol. 68, No. 4, pp. 34-37.

Stolle, C. S., and D. L. Sicking. 2012. *Cable Median Barrier Failure Analysis and Prevention.* TRP-03-275-12. Mid-America Transportation Center, Lincoln, NE.

Zeitz, R. 2003. Low-cost Solutions Yield Big Savings. *Public Roads,* Vol. 67, No. 3, pp. 48-50.

Zou, Y., A. P. Tarko, E. Chen, and M. A. Romero. 2014. Effectiveness of Cable Barriers, Guardrails, and Concrete Barrier Walls in Reducing the Risk of Injury. *Accident Analysis & Prevention,* Vol. 72, pp. 55-65.

APPENDIX

This appendix provides sample calculations that detail how the benefit/cost (B/C) analysis procedures can be used to estimate the economic viability of median cable barrier installation based upon unique median width and AADT combinations. The following is a brief summary of the procedures involved in estimating the B/C ratio for a segment with specific median width and AADT:

- The predicted number of crashes, both without and with median cable barrier present, were determined for each combination of AADT and median width using the results of the negative binomial models from the cross-sectional analysis (as presented in Table 9). Separate estimates are calculated for each of the five injury severity levels.
- The expected change in crashes associated with median cable barrier installation was determined at each severity level by taking the difference between the predicted number of crashes if barrier was installed or not. For K-, A-, and B-level injury crashes, reductions are expected following barrier installation. Conversely, increases are expected for C- and O-level crashes.
- The crash cost savings at each severity level were determined by applying the Iowa DOT costs per crash as detailed in Table 13. This results in savings associated with the reductions in K-, A-, and B-level injury crashes and costs (i.e., negative savings) due to the increases in C- and O-level crashes.
- For agency costs, annual installation costs were estimated at an average of $5,946 per mile. (This value is based on the $80,803 per-mile installation costs, which were converted to an annual basis over the 20-year design life.)
- The annual maintenance and repair costs were estimated by multiplying the predicted number of total crashes (summing across all severity levels) with barrier installed by the per-crash repair costs of $1,393.
- Lastly, the analysis assumed the aforementioned 20-year design life, as well as an annual traffic growth rate of one percent, the latter of which impacts both the crash cost savings, as well as the maintenance and repair costs.

The steps to calculate the expected B/C ratio for a segment with a median width of 25 ft and an AADT of 45,000 vpd are as follows:

1. Use the negative binomial models from the cross-sectional analysis to calculate the expected number of crashes that would occur without the presence of median cable barrier for each crash severity level. The estimates for the initial year (with AADT=45,000) for each crash severity level are obtained as shown here:
   - $K = e^{-5.163+0.763*\ln(45{,}000*1.000)-0.958(0)-1.887*ln(25)} = 0.0468$
   - $A = e^{-12.335+0.886*\ln(45{,}000*1.000)-0.369(0)-0.186*ln(25)} = 0.0320$
   - $B = e^{-11.446+1.015*\ln(45{,}000*1.000)-0.299(0)-0.463*ln(25)} = 0.1273$
   - $C = e^{-12.412+1.081*\ln(45{,}000*1.000)+0.106(0)-0.359*ln(25)} = 0.1373$
   - $O = e^{-12.376+1.203*\ln(45{,}000*1.000)+0.734(0)-0.299*ln(25)} = 0.6383$

These estimates are then averaged over the 20-year design life assuming a one-percent annual increase in AADT.

2. Use the negative binomial models from the cross-sectional analysis to calculate the expected number of crashes that would occur with the presence of median cable barrier for each crash severity level. The estimates for the initial year (with AADT=45,000) for each crash severity level are obtained as shown here:
   - $K = e^{-5.163+0.763*\ln(45{,}000*1.000)-0.958(1)-1.887*ln(25)} = 0.0180$
   - $A = e^{-12.335+0.886*\ln(45{,}000*1.000)-0.369(1)-0.186*ln(25)} = 0.0222$
   - $B = e^{-11.446+1.015*\ln(45{,}000*1.000)-0.299(1)-0.463*ln(25)} = 0.0944$
   - $C = e^{-12.412+1.081*\ln(45{,}000*1.000)+0.106(1)-0.359*ln(25)} = 0.1527$
   - $O = e^{-12.376+1.203*\ln(45{,}000*1.000)+0.734(1)-0.299*\ln(25)} = 1.3298$

   These estimates are also averaged over the 20-year design life assuming a one percent annual increase in AADT.

3. Accounting for the 20-year analysis period and one percent traffic growth, the annual average expected number of crashes, both without and with median cable barrier, are as shown below, immediately followed by the change in crashes that is expected due to median cable barrier installation.

Without barrier:	With barrier:	Change in crashes due to barrier:
• $K = 0.0505$	• $K = 0.0194$	• $K = 0.0312$
• $A = 0.0350$	• $A = 0.0242$	• $A = 0.0108$
• $B = 0.1411$	• $B = 0.1046$	• $B = 0.0365$
• $C = 0.1533$	• $C = 0.1704$	• $C = -0.0171$
• $O = 0.7213$	• $O = 1.5028$	• $O = -0.7815$

4. Multiply each difference in the expected number of crashes at each severity level by the Iowa DOT cost per crash. Sum these crash costs to determine the annual crash cost savings due to barrier installation.
   - $K = 0.0312 * \$5{,}382{,}353 = \$167{,}668$
   - $A = 0.0108 * \$402{,}510 = \$4{,}353$
   - $B = 0.0365 * \$86{,}141 = \$3{,}141$
   - $C = -0.0171 * \$43{,}476 = -\$745$
   - $O = -0.7815 * \$7{,}400 = -\$5{,}783$
   - $Total = \$168{,}633$

5. Multiply the average maintenance and repair costs per crash ($1,393) by the expected annual number of crashes (with median cable barrier) at each severity level. Add the average annual installation cost for the barrier per mile ($5,946) to determine the average annual agency cost for this segment over the 20-year design life.
    - $K = \$5{,}946 + (0.0194 * \$1{,}393) = \$5{,}973$
    - $A = \$5{,}946 + (0.0242 * \$1{,}393) = \$5{,}979$
    - $B = \$5{,}946 + (0.1046 * \$1{,}393) = \$6{,}091$
    - $C = \$5{,}946 + (0.1704 * \$1{,}393) = \$6{,}183$
    - $O = \$5{,}946 + (1.5028 * \$1{,}393) = \$8{,}039$
    - $Total = \$32{,}265$

6. Divide the total benefit/crash costs savings (Step 4) by the total agency costs (Step 6) to determine the expected B/C value for the desired median width and AADT combination.
    - $B/C = \frac{\$168{,}633}{\$32{,}265} = 5.23$

THE INSTITUTE FOR TRANSPORTATION IS THE FOCAL POINT FOR TRANSPORTATION AT IOWA STATE UNIVERSITY.

InTrans centers and programs perform transportation research and provide technology transfer services for government agencies and private companies;

InTrans manages its own education program for transportation students and provides K-12 resources; and

InTrans conducts local, regional, and national transportation services and continuing education programs.

INSTITUTE FOR TRANSPORTATION IOWA STATE UNIVERSITY

Visit www.InTrans.iastate.edu for color pdfs of this and other research reports.