GUIDANCE FOR SITE SELECTION, SAFETY EFFECTIVENESS EVALUATION, AND CRASH MODIFICATION FACTORS OF MEDIAN CABLE BARRIERS IN TENNESSEE

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16. Abstract

This project evaluated the median cable barrier safety effectiveness as experienced on Tennessee highways. Apart from descriptive statistics and questionnaire survey, before and after statistical evaluation was used to estimate the cable barriers Safety Effectiveness. The study revealed that installation of Cable Barriers in Tennessee considered the following criteria: whether the posted speed limit is equal to or greater than 45 mph, clear zone, median width, crash volume and information gathered from interviews with local officials. Questionnaire survey from other states showed that the effectiveness of the cable barriers matches those experienced in Tennessee whereby the number of fatal and severe injury crashes was highly reduced while the PDO crashes increased after median cable barriers installation. The study found that the statewide cable barriers Safety Effectiveness (statistical percentage change in crash frequency statewide) for fatal crashes is 94%, incapacitating injury crashes is 92% and fatal and incapacitating injury crashes combined is also 92%. The safety effectiveness for fatal and all injury crashes combined was found to be 85%. Overall, 98% of the evaluated median cable barrier segments (561 out of 571) had 100% safety effectiveness for fatal crashes while 94% of the cable barrier segments had 100% safety effectiveness based on fatal and incapacitating crashes combined. In a direct comparison through descriptive statistics, statewide fatal crashes were reduced by 82% after the cable barriers installation while the incapacitating injury crashes were reduced by 76%. In addition, head-on crashes went down by 96% and crashes involving two or more vehicles went down by 92%. Fatalities due to median crossover crashes were reduced by 83% while number of people injured went down by 71% as a result of cable barriers. The study further developed Crash Modification Factors (CMF) for median cable barriers in Tennessee. Using comparison group approach that considers the number of crashes before and after the installation of cable barriers, CMF for fatal crashes was found to be 0.04, fatal and incapacitating injury 0.07, and 0.14 for fatal and all injury crashes. The developed CMFs translate into crash reduction percentages of 96% and 86% for fatal only and fatal and all injuries combined respectively. Wider cable offsets from the travel lane and wider inside shoulders were found to help reduce the number of severe median crossover crashes while segments with high differential elevations and high speed limit had higher number of crashes compared to the opposite measures.

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EXECUTIVE SUMMARY

Tennessee Department of Transportation (TDOT) has been installing Median Cable Barrier along some highway segments across the state. Among the intended benefits of the cable barriers was the prevention of cross-median crashes which occurs when a vehicle leaves its travel way enters or crosses the median dividing the highway directional lanes and collides with vehicles in the opposite direction. After more than three years since the installation of most cables throughout the state; TDOT approved Safety Effectiveness Evaluation study to determine whether the cables have been effective in reducing number of collisions and injury severities as intended.

Findings from safety effectiveness study are expected to reinforce future expansion of the program as well as respond to the public perception on the program. The study therefore evaluated safety effectiveness with respect to the reduction in the number of crashes, injury severities and fatalities. The study also evaluated the impact of different geometric features as well as traffic characteristics to the safety performance of the cable barriers. In addition, the study developed crash modification factors (CMF) for segments with median cable barriers relative to no cable barrier segments. The project evaluated all cable segments installed in Tennessee from 2005 to 2010 which included 27 pilot cable segments installed in 2006. The report presents the literature review, descriptive statistics and Safety Effectiveness evaluation and Crash Modification Factors (CMF) results from 577 median cable barrier segments along 32 different highways covering 48 counties. The average length of these 577 cable segments is 0.524 miles with a total of 302 miles in length. Furthermore, the study present Survey Questionnaire findings from other states which showed that the effectiveness of the cable barrier in other states matches those experienced in Tennessee whereby fatal and severe injury crashes were highly reduced while the PDO crashes went up after median cable barrier installation.

The comprehensive literature review covered the criteria and warrants for selecting locations to install median cable barriers. Literature showed that median width, crash history, vehicles median crossover frequency, traffic volume, clear zone, slopes and alignment, roadside objects, posted speed, and benefit cost ratio are the main factors considered when selecting locations for installing median cable barriers. In Tennessee, the following criteria were used in selecting location to install median cable barriers; clear zone, median width, crash volume and information gathered from interviews with local officials. Of the median cable barriers let to contract by TDOT in 2009 and 2010, 60% of the length met the median width criteria, 37% of the length met the crash criteria and three percent (3%) met the clear zone criteria.

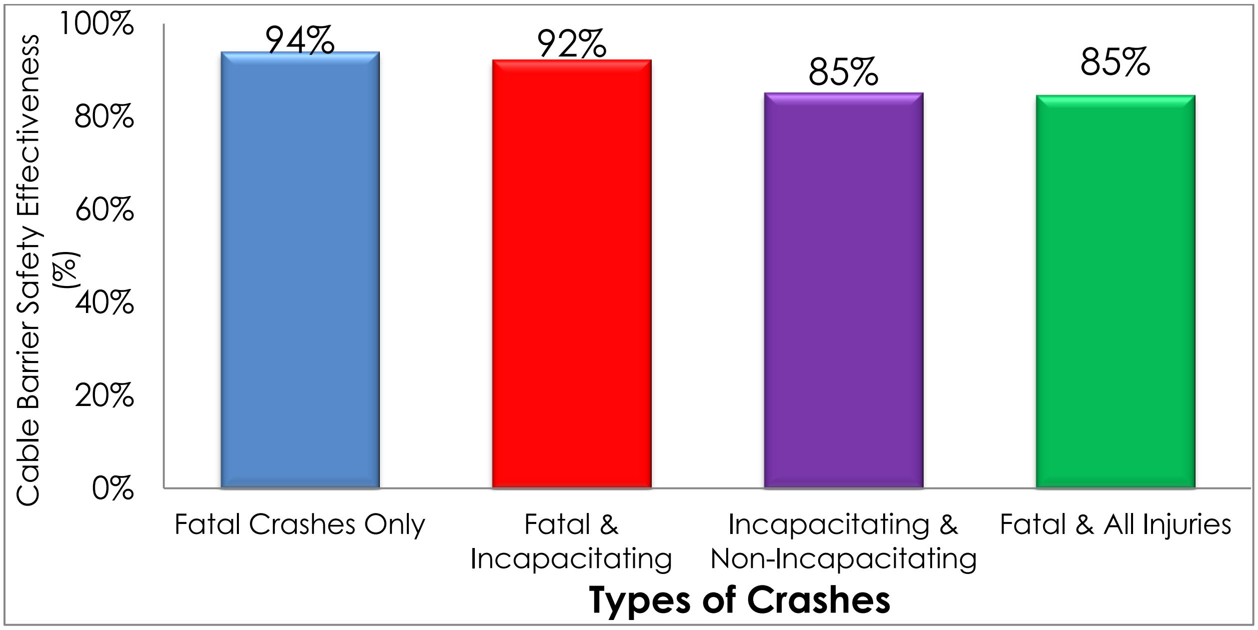
Three years of crash data before and after the cable barriers were installed along 577 segments were evaluated in terms of descriptive statistics of the critical factors associated with median related crashes whose occurrences could have been prevented or was impacted by the presence or absence of the median cable barriers. Safety effectiveness evaluation was performed following the procedures outlined in the Highway Safety Manual (2010 HSM). The HSM procedures apply crash modeling in the form of Safety Performance Functions (SPF), and Empirical Bayes (EB) before and after observational studies. The following are the findings from statewide safety effectiveness, effectiveness per individual cable segments and the averaged effectiveness per TDOT regions, counties and individual highways and the comparative descriptive statistics:

(1) Findings from the Statistical Safety Effectiveness Evaluation

Statistical before and after approach utilizing Empirical Bayes (EB) described in Highway Safety Manual (2010 HSM) was used to calculate the cable barriers Safety Effectiveness. The approach properly account for regression to the mean while normalizing for differences in traffic volume and cable segment length in relation to crash and injury severity history prior to and after the installation of the cable barriers. The individual segments safety effectivenesses were also averaged per corresponding TDOT regions, counties and individual routes. The following are some of the key Safety Effectiveness findings:

- Statewide cable barriers Safety Effectiveness for fatal crashes stands at 94%.
- Statewide Safety Effectiveness for incapacitating injury crashes stands at 92%.
- Statewide median cable barriers Safety Effectiveness for fatal and incapacitating injury crashes combined stands at 92%.
- Safety Effectiveness for fatal and all injury crashes combined is 85%.
- Statewide Safety Effectiveness for non-incapacitating injury crashes is 84%.
- Statewide Safety Effectiveness for incapacitating and non-incapacitating injury crashes combined stands at 85%.
- 98% of all evaluated median cable barrier segments (561 out of 571) have 100% safety effectiveness for fatal crashes.
- 94% of all evaluated cable segments (535 out of 571) have 100% safety effectiveness based on fatal and incapacitating crashes combined.

- 74% of all evaluated cable segments (422 out of 571) have above 80% safety effectiveness based on fatal and all injury crashes combined.
- Each of the TDOT regions have above 80% safety effectiveness for all fatal and injury crashes when cable barriers were averaged per TDOT regions.
- Plurality (98%) of the counties resulted with positive safety effectiveness.
- Majority of highways (31 out of 32) resulted with positive average safety effectiveness for all crash groups (SR-155 have negative for fatal crashes).

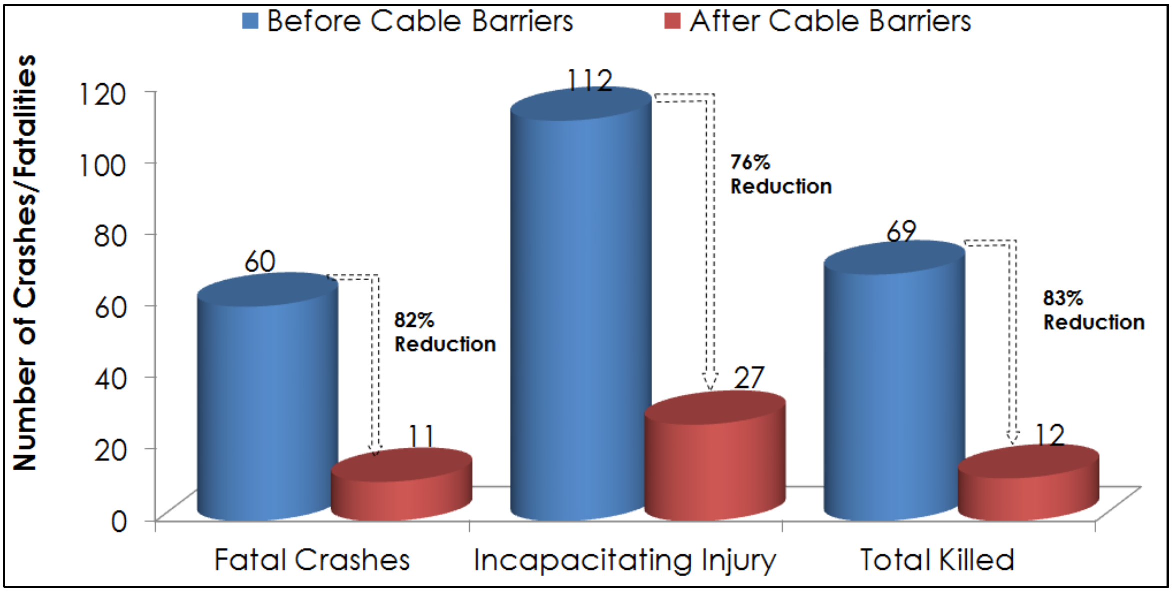


(2) Findings from Before and After Crash Reduction Statistics

Statistics comparing percentage reduction or increase in the number of crashes three years before and three years after the cable barriers were installed was performed. Analysis also compared direct percentage reduction or increase in injury severities whereas high percentage reduction is taken as a positive indicator to the effectiveness of the cables. The following are some of the findings three years before and after cable installation:

- Statewide fatal crashes were reduced by 82% after the cables installation.
- Statewide incapacitating injury crashes were reduced by 76%.
- Statewide non-incapacitating injury crashes were reduced by 60%.
- Statewide fatal and all injury crashes combined were reduced by 64%.
- Statewide total killed were reduced by 83% as a result of cable barriers.
- Statewide total injured went down by 71% as a result of cable barriers.
- Incapacitating injuries went down by 81% as a result of cable barriers.
- Statewide crashes involving two or more vehicles went down by 92%.

- Head-on crashes went down by 96% after median cable barriers installation.
- The number of segments which had at least one fatal crash before the cables were reduced by 82% after cable installation.
- Property Damage Only (PDO) crashes went up slightly after cable barriers.



(3) The Impact of Geometric Features to Cable Barrier Performances

The study evaluated the impact of roadway cross-sectional and geometric features, traffic characteristics and median cable barrier placement to the frequency of median related crashes through statistical modeling. Apart from number of lanes, inside shoulder width, median width, AADT, VMT and posted speed limit, the modeling included cable offset, horizontal curve data and differential elevation. Negative binomial (NB) model was used in linearizing and quantifying these factors with respect to crash frequency. The following are the overall impact of these variables to crash frequencies:

- **Impact of Cable Offset:** Cable barrier offsets were calculated as the distance from the end of the travel lanes to the location of the cable barriers. The study found that the wider the cable offset the lower the number of fatal and injury crashes involving vehicles hitting cable barriers. However, the impact of offset is not a significant factor.
- **Impact of Inside Shoulder Width:** Segments with wider shoulder widths were found to experience less number of crashes compared to narrow shoulder width segments.
- **Impact of Differential Elevation:** Differential elevation was calculated by taking the difference between the elevation of the centerline of the

opposite travel directions (data was provided by TDOT). The findings show high differential elevations increases the likelihood of median related crashes. However, the impact of differential elevation to crash occurrence is only significant and much consequential after the cables were installed compared to before cable conditions.

- **Impact of the Degree of the Curve:** Curved segments appear to have higher probability of fatal and injury crashes compared to straight segments. As the sharpness of the curve increases, the likelihood of crashes also increases.
- **Impact of Traffic Volume per Lane to Safety Performances:** Number of crashes was found to increase with increase in traffic volume (AADT). However the contributing effect of traffic volume to crash occurrence along these segments was significant before the cables compared to after cable conditions.

(4) Crash Modification Factors for Median Cable Barriers

The study developed CMFs for median cable barriers in Tennessee. Using screened median cross-over related crashes;

- The CMF for fatal crashes was found to be 0.04 translating that the fatal crashes are reduced by 96% with cable barrier installation.
- The CMF for fatal and incapacitating crashes combined was found to be 0.07.
- The CMF for fatal and all injuries combined was found to be 0.14.

These CMFs are in line with some of the findings from other states which found relatively similar numbers for median cable barriers. The crash reduction factors extracted from these CMFs are within the range of the percentage found in the safety performance effectiveness reported in this study. The CMFs found using all crashes within the cable segments however resulted with high numbers (low reduction of crashes); this may be due to the fact that some crashes counted were not necessarily cable barriers related.

DEFINITION OF ABBREVIATIONS

MRC:	Median Related Crashes
PDO:	Property Damage Only Crashes
SPF:	Safety Performance Functions
RTM:	Regression to the Mean
HSM:	Highway Safety Manual
CMF:	Crash Modification Factor
AADT:	Average Annual Daily Traffic
TRIMS:	Tennessee Roadway Information Management System
NB:	Negative Binomial
EB:	Empirical Bayes
KABCO:	Scale measure of injury level of the victim at the crash scene
$N_{expected}$	Expected crash frequency for the entire period
$N_{predicted}$ (N_{spf})	Predicted crash frequency for the entire period
$N_{Observed,B}$	Observed crash frequency at segment for the before period
$N_{Observed,A}$	Observed crash frequency at segment for the after period
FHWA:	Federal Highway Administration
TDOT:	Tennessee Department of Transportation

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1. Overview

The Tennessee Department of Transportation (TDOT) has been installing Median Cable Barrier Systems along some sections of the state interstate highways and freeways since 2005. Among the intended benefits of the cable barrier systems was the prevention of cross-median crashes which occur when a vehicle leaves its travel way enters or crosses the median dividing the highway directional lanes and collides with a vehicle in the opposite direction. Apart from cross-median crash reductions, lowering injury severities, e.g. reduction of fatal or incapacitating and certain types of crashes were also some of the expected benefits of the median cable barriers. The study utilized data from the first 27 pilot cable barrier segments installed in 2005 and 2006 and over 550 segments installed in 2009 and 2010. According to the TELA report [1], three different proprietary high tension cable barrier systems were used in Tennessee, Figure 1.1. These include; Nucor Marion Steel U.S. High Tension 3 Cable Longitudinal Barrier System, Brifen Wire Rope Safety Fence (WRSF), and Trinity Industries Cable Safety System (CASS). Sufficient time passed since installations of these cable barriers that ignited the need for safety effectiveness evaluation. The need for evaluation was to determine whether the cables are effective in reducing significant number of collisions and injury severities as initially intended. Findings from safety effectiveness analysis are expected to reinforce expansion of the program, also serve as a response to the public perception about this program.

U.S. High Tension Cable System

Brifen Wire Rope Safety Fence System

CASS System

Figure 1.1: Cable Barrier Types Used in Tennessee [1]

To evaluate the effectiveness of these cable barrier systems, statistical methodologies including descriptive statistics, crash modeling in the form of safety performance models and Empirical Bayes (EB) observational safety effectiveness evaluation were applied. Empirical Bayes and Safety Performance Functions (SPFs) have been used widely for estimating safety impacts of different engineering improvements as detailed in Highway Safety Manual (HSM) [2].

1.2. Study Scopes

To achieve the study objectives, the research involved three primary tasks:

1.2.1. Median Cable Barrier Performance Survey from other States

A survey was synthesized to selected states and jurisdictions to solicit information related to this subject. Information of interest in the survey included questions such as if the median cable system resulted in significant safety effectiveness, which cable barrier manufacturer are preferred in that state, the safety impact of cable designs, installation procedures, cable material types, and other technical specifications related to the overall safety effectiveness of cable barrier systems. The findings are presented in Chapter 4.

1.2.2. Safety Evaluation through Descriptive Statistics

Descriptive statistics of critical factors associated with median-crossover related crashes was performed. This covered comparison on what was the percentage reduction or increase of certain type of crashes, crash attributes and other elements to the total crashes before and after cable barriers were installed. The findings are presented in Chapter 6.

1.2.3. Development of Safety Performance Functions (SPF)

Safety Performance Functions (SPF) are developed through models as “crash frequency model”. The main feature of SPF is the "crash prediction algorithm" developed through regression analysis. The developed crash prediction algorithm is able to make quantitative estimates of crash frequency given various independent geometric and traffic variables. Safety Performance Functions (SPF) are used for before and after Safety Effectiveness analysis. The developed models are presented in Chapter 7.

1.2.4. Before and After Safety Effectiveness Evaluation

To evaluate the effectiveness of the cable barrier systems, the research applied crash modeling in the form of safety performance models, and Empirical Bayes (EB). Empirical Bayes and Safety Performance Functions (SPFs) have been used widely for estimating safety impacts of different engineering improvements. The EB safety evaluation procedures are well documented in Highway Safety Manual, the steps which were applied in this study [2]. The results are presented in Chapter 8.

1.2.5. The Impact of Geometric Features

The study evaluated the impact of roadway features and traffic characteristics to the safety performance of the median cable barriers. The focus was on quantifying crash frequency with respect to geometric and operational factors that contribute to crash trends, and identifying other factors that influence the effectiveness of the cable barrier systems. The findings are detailed in Chapter 9.

1.2.6. Development of Crash Modification Factors (CMF)

Crash Modification Factors (CMFs) as a result of installing median cable barrier systems is developed. The CMFs will be able to estimate the change in crashes and injury severity as a result of the cable barrier installations. The developed CMFs are detailed in Chapter 10.

CHAPTER 2: LITERATURE REVIEW

2.1. Overview

Over the past decade, Federal Highway Administration (FHWA) and State Transportation Departments (DOTs) have greatly stepped up their efforts to reduce fatalities along highways especially freeways. As severe crashes mostly occur at locations with high speeds and a lot of traffic ensues, freeways have been the major focus. The most common road safety trend that continually results in severe injury or fatality has been the occurrence of median crossover crashes. One of the approaches that are being used to counter and prevent median crossover crashes is through median cable barrier systems.

2.2. Brief Review from other States

The first step leading to installation of the cable barrier system is to identify crash patterns for the subject highway location. In a study conducted in Washington State [3], the analysis used median related crashes, such as: collision with median fixed objects, collision with median cable barriers, median roll-over crashes, and median crossover crashes as a basis for installing cable barriers. Median related crashes are important to identify due to their uniqueness compared to other crash types. The Washington study highlights the importance of developing lists of relevant crashes when conducting the analysis of the cable barrier systems. Another important point which should be noted with respect to median cable barrier systems from other states is that the overall number of crashes in the cable areas has gone up (mainly due to property damage crashes) after the installation, but the severity of the crashes decreased. Another study [4] theorized that this increase could be due to more property damage crashes having to be reported once contact occurs with the cable barrier. In other words, after the installation of the cables, any contact between the vehicle and the cable barriers were reported as property damage which create new category of crashes not previously reported before the cables were mounted.

2.3. Median Cable Barriers Testing

Some of the installation elements that have been considered include slope (front side and backside), post spacing, high or low tension cables, and median width. In the standard crash test, which is at 60 mph and at an impact angle of 25 degrees, the cable tends to flex up to 12 feet for a low tension system [3]. Additional tests show that the low tension systems have a designed deflection of 11 feet 6 inches. The AASHTO guidelines recommends that a cable barrier should only be installed if adequate deflection distance exists, thus the median width at a minimum should be 24 feet if the system is located in the center [5]. The deflection of the cable barrier system can be controlled to some degree by adding or reducing the number of posts within the cable barrier system. When this is done (due to cost, materials, or approved design) a deflection of 7 - 16 feet was seen due to post spacing [5]. Noting that the deflection can be greater than 12 feet depending on the post spacing, and since the test is conducted at 60 mph and most posted speed limits range from 55 to 70 mph, this leads to observe deflection potentially being greater than test results. Thus some states have generated guidelines where the cable barrier is not recommended for use on 36 feet median width or less. The placement of the cable barrier within the median is also an important characteristic due to how the angle of impact will affect the system's effectiveness. The standard test is conducted for impact at 25 degrees, but if the cable barrier is placed at the middle of the median there is a greater chance that a collision with the system will occur at a greater impact angle. The system may deflect more or if the collision exceeds the overall test level specification the system could fail [6]. Ensuring the system was correctly placed within the median is important to understand how effective the cable barrier is at reducing the severity of the crashes that enter the median. If a system that was installed incorrectly is being included into an analysis then it has the potential to provide error and misleading results regarding the overall effectiveness of the statewide cable barrier system being studied.

2.4. Evaluation Methodologies

Empirical Bayes is one of the relevant methodologies in examining the cable barrier efficiency once it has been installed. This approach is now widely accepted among researchers and is greatly preferred over simple before and after analysis. The empirical Bayes method utilizes a before period crash on the treated site compared to possible crash trend if the facility or the site could have been left untreated (no cable barrier). These results are then compared to the actual crash count seen after the site has been treated to determine the system's effectiveness [7]. The approach can either be abridged or full, the difference is that the abridged technique utilizes only the last 2 -3 years of traffic data, while the full version can make use of more data. Although common thought is that the last 2 - 3 years best represent the current traffic trends, the empirical Bayes removes much of this error in its analysis. More data yields more accurate results [8]. When using the EB approach, it is important to develop the dispersion parameter, k, for each type of crash within the model. This dispersion parameter, k, is used to reflect the distribution of each type of crash within the prediction part of the model [2].

2.5. Important Safety Evaluation Literature from 2010 HSM

Highway Safety Manual (HSM) describes in detail different highway safety evaluation procedures. Equally, this study utilized some of these procedures. The following important components of highway safety effectiveness evaluation procedures are cited from the manual [2] which include importance of prediction models, regression to the mean, weighted factor, crash modification factors and the use of empirical bayes (EB).

2.5.1 Regression to the Mean (RTM)

According to the HSM [2], the use of the predictive model method in crash analysis has several advantages; 1) prediction models use the concept of the regression-to-the-mean bias which addresses long-term expected average crash frequency rather than short-term observed crash frequency, 2) reliance on availability of limited crash data is reduced by incorporating predictive relationships based on data from many similar sites, and 3) the method accounts for the fundamentally nonlinear relationship between crash frequency and traffic volume. Regression to the mean is important in crash analysis and modeling because crash frequencies naturally fluctuate up and down over time at any given site. A short-term average crash frequency may vary significantly from the long-term average crash frequency. When a period with a comparatively high crash frequency is observed, it is statistically probable that a lower crash frequency will be observed in the following period [2].

2.5.2 Overdispersion Parameter

In EB analysis, the SPFs are regression equations as a function of annual average daily traffic (AADT) and, in the case of roadway segments as for this study, the segment length (L). The regression parameters of the SPFs are determined assuming that crash frequencies follow a negative binomial distribution. Data for which the variance exceeds the mean are said to be overdispersed, and the negative binomial distribution is very well suited to modeling overdispersed data. The degree of overdispersion in a negative binomial model is represented by a statistical parameter, known as the overdispersion parameter that is estimated along with the coefficients of the regression equation. The larger the value of the overdispersion parameter, the more the crash data varies. The overdispersion parameter is used to determine the value of a weight factor for use in the EB analysis [2].

2.5.3 Weighted Factor

The EB Method uses a weight factor, which is a function of the SPF overdispersion parameter, to combine the two estimates into a weighted average. The weighted adjustment is dependent on the variance of the SPF and is not dependent on the validity of the observed crash data. The weighted adjustment factor, *w*, is a function of the SPF's overdispersion parameter, *k* [2].

$$w=\frac{1}{1+k\sum_{\text{All years}} N_{\text{predicted}}} \tag{2.1}$$

As the value of the overdispersion parameter increases, the value of the weighted adjustment factor decreases. Thus, more emphasis is placed on the observed rather than the predicted crash frequency. When the data used to develop a model are greatly dispersed, the reliability of the resulting predicted crash frequency is likely to be lower. In this case, it is reasonable to place less weight on the predicted crash frequency and more weight on the observed crash frequency. On the other hand, when the data used to develop a model have little overdispersion, the reliability of the resulting SPF is likely to be higher. The weighted factor is then used as follows [2]:

$$N_{\text{expected}}=w*N_{\text{predicted}}+(1-w)*N_{\text{observed}} \tag{2.2}$$

2.5.4 The EB Observational Before-After Evaluation Method

The EB method combines a site's observed crash frequency and SPF-based predicted average crash frequency to estimate the expected average crash frequency for the after period had the cable barrier not been implemented. The EB method addresses the regression-to-the-mean issue by incorporating crash information from similar sites into the evaluation. This is done by using SPF and weighting the observed crash frequency with the SPF-predicted average crash frequency to obtain expected average crash frequency [2].

2.5.5 Safety Effectiveness

Effectiveness evaluation is the process of developing quantitative estimates of the effect a treatment, project, or a group of projects has on expected average crash frequency [2]. Effectiveness evaluation may include; 1) evaluating a single project at a specific site to document the effectiveness of that specific project, 2) evaluating a group of similar projects to document the effectiveness of those projects, and 3) assessing the overall effectiveness of specific types of projects or countermeasures in comparison to their costs. There are three basic study designs that can be used for effectiveness evaluations; 1) Observational before-after studies, 2) Observational cross-sectional studies and 3) Experimental before-after studies. This study uses observational before-after studies.

2.5.6 Crash Modification Factors

Crash Modification Factors (CMFs) represent the relative change in crash frequency due to a change in one specific condition. CMFs are the ratio of the crash frequency of a site under two different conditions. Application of a CMF provides an estimate of the change in crashes due to a treatment. The CMFs can be multiplied together to estimate the combined effects of the respective elements or treatments [2].

CHAPTER 3: MEDIAN CABLE BARRIERS INSTALLATION GUIDELINES

3.1. Cable Installation Guidelines from other States

Literature shows that median width, crash history, vehicles median crossover frequency, traffic volume, clear zone, slopes and alignment, roadside objects, posted speed, and benefit cost ratio are the main factors considered when selecting locations for installing median cable barriers. Placement of the cable barrier within the median is an important factor in selecting installation locations due to how the angle of impact will affect the barrier's effectiveness.

3.2. California Installation Criteria

In California, collision and freeway volume/median width relationship and collision study warrants are used to select locations to install cable barriers [9]. A collision study warrant for any severity is met if a location has three or more cross-median collisions and a total cross-median collision rate of at least 0.5 collisions per mile per year in a five year period. Fatal collision study warrant is met if a location has three fatal collisions or more and a fatal cross-median collision rate of at least 0.12 collisions per mile per year in a five year period. Highway locations with four or more lanes satisfying either of the above collision warrants are studied. The collision warrant for two or three-lane highways is based on fatal study warrant criteria only. As shown Figure 3.1, cable barriers are warranted along segments with 46ft to 75ft wide median and at least 40,000 vpd traffic volume.

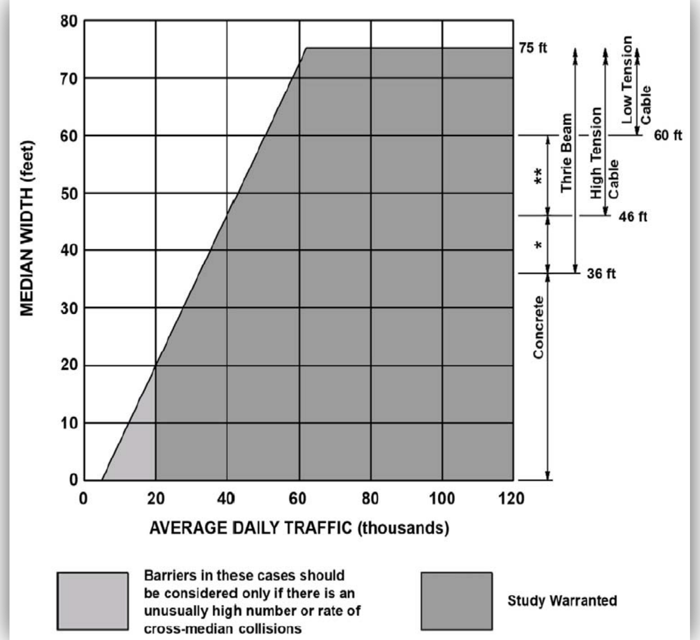


Figure 3.1: Barrier Selection Criterial in California

3.3. Tennessee Cable Barriers Installation Guidelines

Tennessee Executive Leadership Academy (TELA) report published in February 2011 [1] described criteria used for selecting median cable barrier pilot segments. In support of the TELA report, the criteria used for selecting location to install median cable barriers in Tennessee are documented in a report titled "Cable Median Barrier Summary Report" to Tennessee Department of Transportation prepared by Florence & Hutcheson in 2010 [10]. As detailed in the cited report, determination of Cable Barrier segments in Tennessee considered the following criteria:

- Posted speed limit equal to or greater than 45 mph.
- The geometric data.
- Clear zone.
- Median width.
- Crash volume.
- Information gathered from interviews with local officials.

Of all the cable median barrier segments let to contract by TDOT in 2009 (percentages are based upon the length of cable barrier, not the number of locations):

- Sixty percent (60%) met the median width criteria.
- Thirty-seven percent (37%) met the crash criteria.
- Three percent (3%) met the clear zone criteria.

Local TDOT maintenance personnel as well as district Tennessee State Patrol officers were interviewed to gain their input on sites known to have high volume of median crossover crashes. They were also asked to comment on locations where a cable median barrier installation would provide protection to obstacles in the median, such as bridge piers, that are not currently protected by any other means. Any locations identified through these conversations were added to the list of candidate sites.

3.3.1. Median Width Criteria

The cited report [10] defined median width as the distance between travel lanes in opposing directions of traffic including the inside paved shoulders, Figure 3.2. Of the sixty percent (60%) of the cable barrier installed due to the median criteria:

- 23% were placed in medians of less than forty (40) feet.
- 43% were placed in medians between forty (40) and fifty (50) feet.
- 34% were placed in medians between 51 and 59 feet.
- Cable barriers were not installed in medians over 60 feet wide unless other criteria determined their installation.

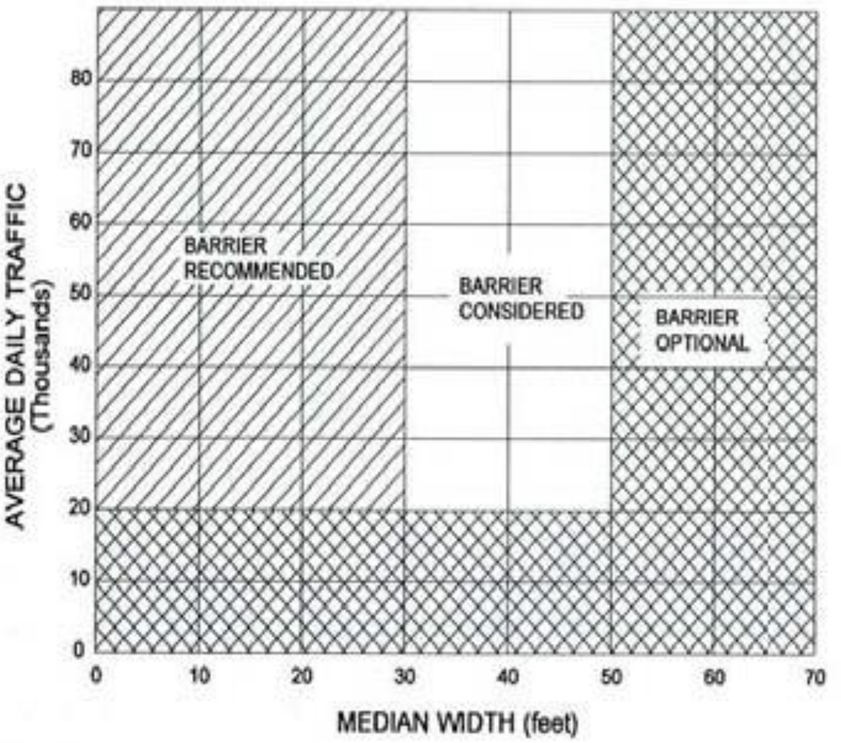


Figure 3.2: Median Width and Traffic Volume Criteria

3.3.2. Clear Zone Criteria

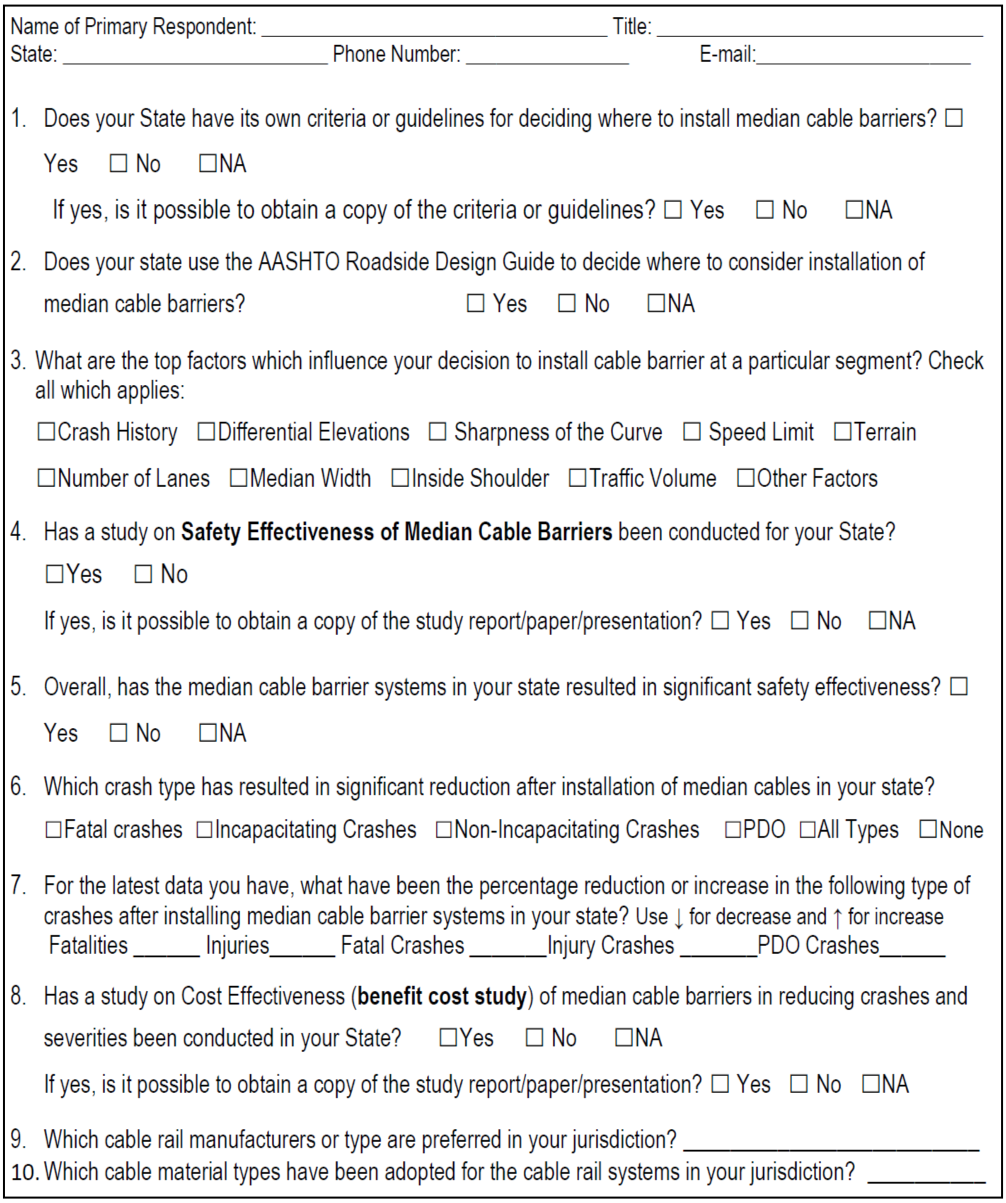
The Florence & Hutcheson report [10] defined a clear zone as a traversable and unobstructed roadside area beyond the edge of the traveled way, particularly on high-volume, high-speed roadways. For the purposes of determining candidate cable median barrier sites, a standard clear zone of thirty (30) feet in tangent (straight) roadway segments was used. This was in part because TRIMS data only provides the posted speed limit, and not the design speed and does not report the side slope of the adjacent terrain. The median width of each candidate segment was compared to its corresponding clear zone chart based on whether the segment is horizontal curve or tangent section of the roadway. If the median width of the roadway segment failed to meet the clear zone criteria, it was recommended as a location for safety improvements, including potentially cable median barrier installation.

3.3.3. Crash Volume Criteria

According to Florence & Hutcheson report [10], the crash data utilized was not exclusive to median crossover crashes because sites with significant median crossover crashes had previously been evaluated through a pilot program. Therefore, the criteria utilized all crash types in which a higher number of crashes indicated some level of unsafe condition along the roadway segment. Crash types from 2006 to 2008 from TRIMS provided a larger sample size of crash data which assisted in locating sites with the propensity for a median crossover crash. Locations that experienced the highest twenty percent (20%) of crashes along each route were determined to be candidate locations for cable median barrier. The twenty percent (20%) value was chosen to identify the locations with the highest potential for unsafe conditions. Crash volume (crashes per mile) was chosen as the criteria, instead of crash rate.

CHAPTER 4: SURVEY QUESTIONNAIRE

A survey questionnaire was synthesized to all states to solicit information related to safety effectiveness of the cable barrier. Information of interest in the survey included among other questions, if the median cable system resulted in significant safety effectiveness, which cable barrier manufacturer were preferred in that state, the safety impact of cable designs, installation procedures, cable material types, and other technical specifications to the overall safety effectiveness of cable barrier systems and the safety impacts of varying installation specifications and benefit cost outcomes. The targeted responders to the survey included state safety engineers, traffic engineers, maintenance engineers, and planners. The copy of the survey questionnaire is as shown below.



Name of Primary Respondent: ________________________________ Title: ______________________________
State: ________________________ Phone Number: _______________ E-mail:____________________

1. Does your State have its own criteria or guidelines for deciding where to install median cable barriers? ☐ Yes ☐ No ☐NA
   If yes, is it possible to obtain a copy of the criteria or guidelines? ☐ Yes ☐ No ☐NA
2. Does your state use the AASHTO Roadside Design Guide to decide where to consider installation of median cable barriers? ☐ Yes ☐ No ☐NA
3. What are the top factors which influence your decision to install cable barrier at a particular segment? Check all which applies:
   ☐Crash History ☐Differential Elevations ☐ Sharpness of the Curve ☐ Speed Limit ☐Terrain
   ☐Number of Lanes ☐Median Width ☐Inside Shoulder ☐Traffic Volume ☐Other Factors
4. Has a study on **Safety Effectiveness of Median Cable Barriers** been conducted for your State?
   ☐Yes ☐ No
   If yes, is it possible to obtain a copy of the study report/paper/presentation? ☐ Yes ☐ No ☐NA
5. Overall, has the median cable barrier systems in your state resulted in significant safety effectiveness? ☐ Yes ☐ No ☐NA
6. Which crash type has resulted in significant reduction after installation of median cables in your state?
   ☐Fatal crashes ☐Incapacitating Crashes ☐Non-Incapacitating Crashes ☐PDO ☐All Types ☐None
7. For the latest data you have, what have been the percentage reduction or increase in the following type of crashes after installing median cable barrier systems in your state? Use ↓ for decrease and ↑ for increase
   Fatalities ______ Injuries______ Fatal Crashes _______Injury Crashes _______PDO Crashes______
8. Has a study on Cost Effectiveness (**benefit cost study**) of median cable barriers in reducing crashes and severities been conducted in your State? ☐Yes ☐ No ☐NA
   If yes, is it possible to obtain a copy of the study report/paper/presentation? ☐ Yes ☐ No ☐NA
9. Which cable rail manufacturers or type are preferred in your jurisdiction? _________________________
10. Which cable material types have been adopted for the cable rail systems in your jurisdiction? __________

4.1. Response Results

The states which responded to the questionnaire included New York, New Hampshire, Montana, Louisiana, Pennsylvania, Arkansas, Maine, North Carolina, Iowa, Missouri, Delaware, Kentucky, California and Nevada. The following are some of the responses and corresponding statistics.

Question: *Overall, has the median cable barrier systems in your state resulted in significant safety effectiveness?*

Figure 4.1 shows that 64% responded in agreement that the median cable barriers do in-fact significantly improve the overall safety of median cross-over crashes. The 7% of the respondents didn't respond to that question and the 29% didn't have statistics on hand to make a conclusive determination of the impact of cable barriers.

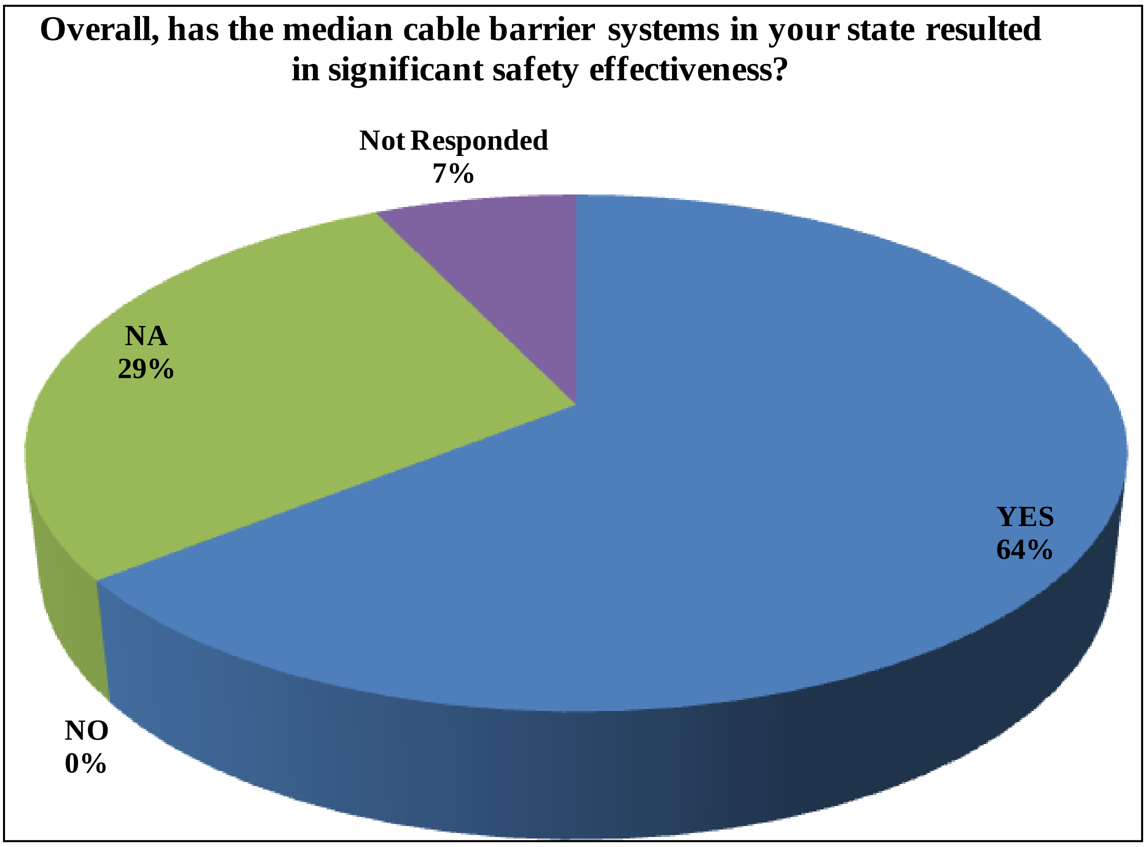


Figure 4.1: Effectiveness of Cable Barriers from Other States

Question: *Since installed, have the median barriers lowered the number of median crossover crashes?*

Figure 4.2 shows that almost 72% of the states which responded to the survey indicated the median cable barriers lowered median crossover crashes, 14% didn't respond to that question and in 24 states there was no change at all.

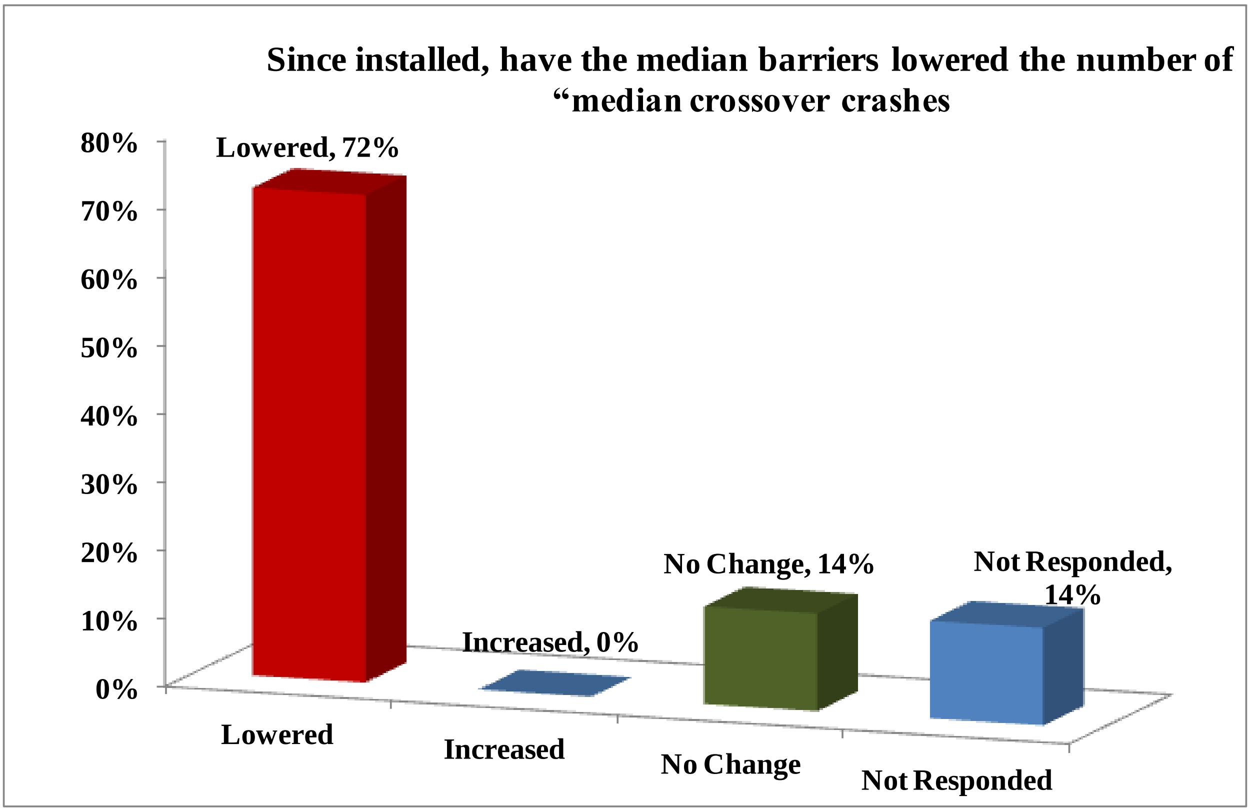


Figure 4.2: Lowering Median Cross Over Crashes from Other States

Question: *Which crash type has resulted in significant reduction after installation of median cables in your state?*

Figure 4.3 summarizes the responses for this question as follows:

- Fatal crashes—all states (100%) that responded saw fatal crashes reduced
- Incapacitating Injury crashes—91% of the states saw incapacitating crashes decreased but 9% saw an increase
- Non-Incapacitating Injury crashes—45% of the states saw decrease in these type of crashes while 55% saw increase
- Property Damage Only (PDO) crashes—Only 27% of the states experienced reduction in PDO crashes, while majority, 73% saw increase in PDO crashes (the same as Tennessee).

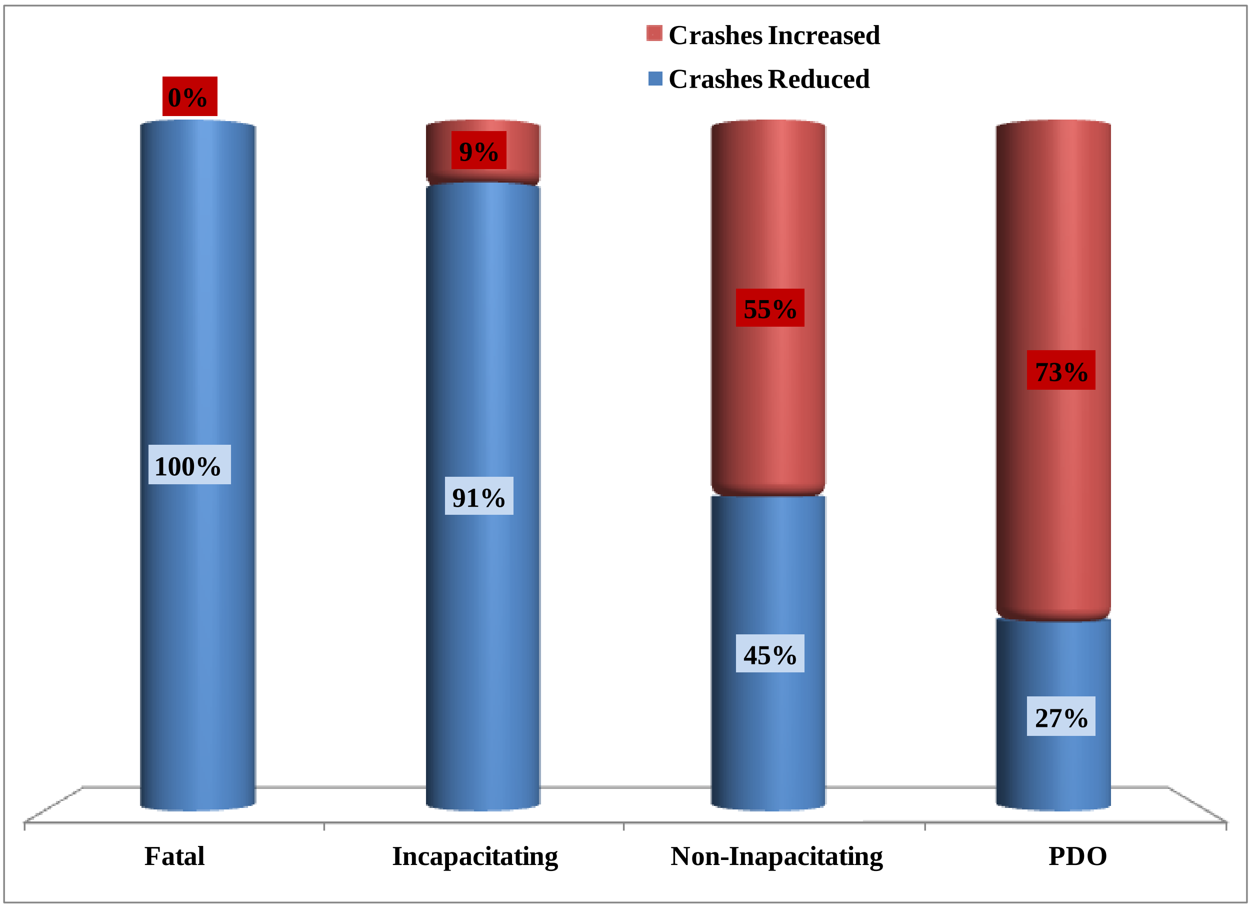


Figure 4.3: Reduction of Crashes by Injury Type from Other States

Question: *Has a study on Safety Effectiveness of Median Cable Barriers or any related subject been conducted for your state?*

Many states haven't conducted studies related to safety effectiveness of cable barriers, Figure 4.4.

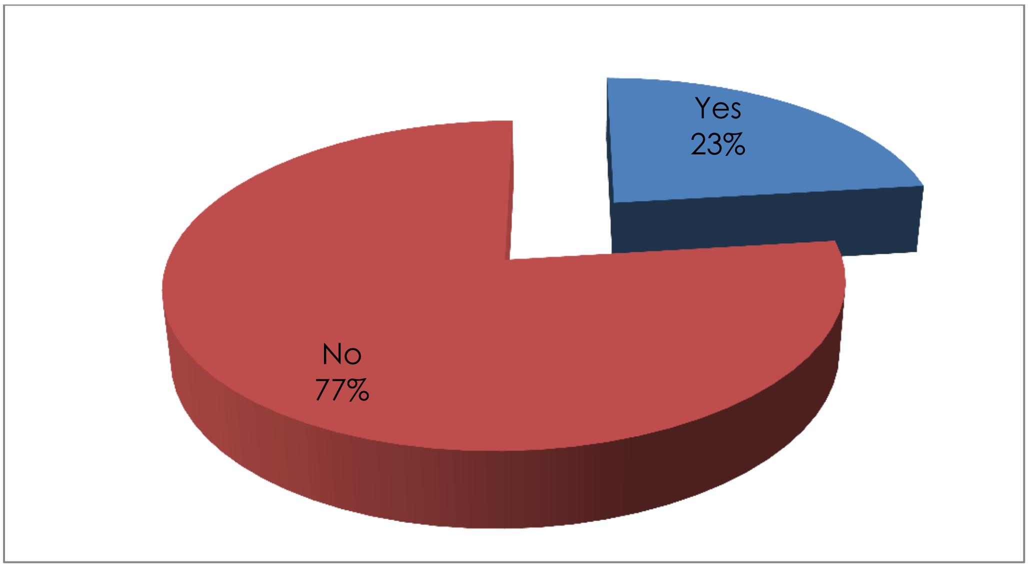


Figure 4.4: Study on Cable Barriers from Other States

Question: *What are the top factors which influence your decision to install cable barrier at a particular segment?*

Figure 4.5 shows that traffic volume, median width, and crash history are the main factors that influence the decision to install cable barriers in a many states.

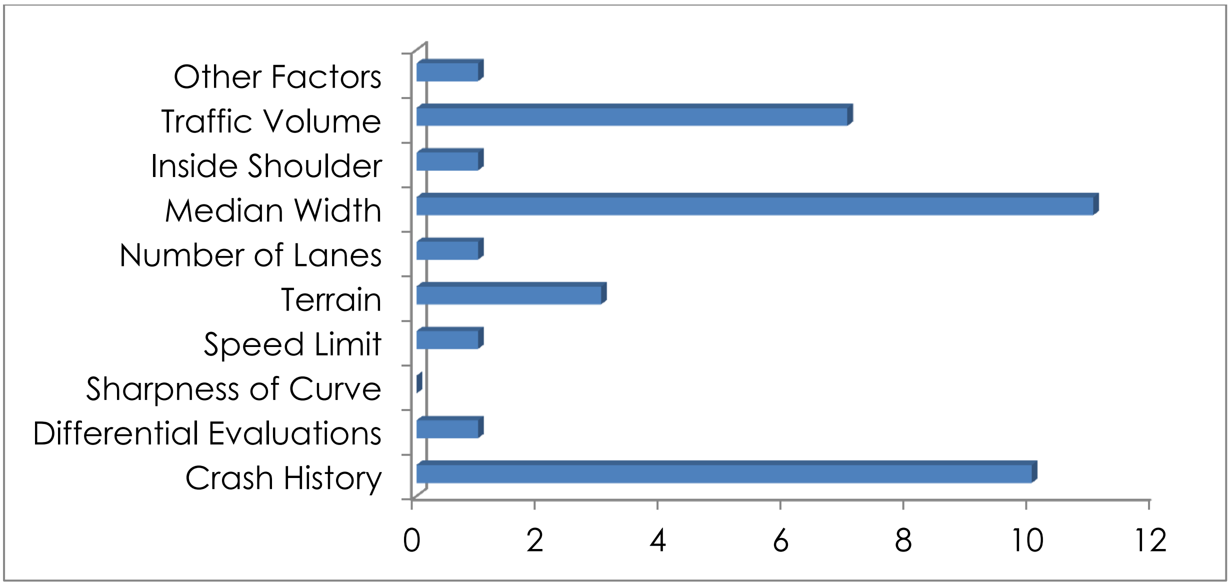


Figure 4.5: Factors Influencing Installation of Cable Barriers from Other States

Question: *Does your state have its own criteria or guidelines for deciding where to install median cable barriers?*

62% of the states have some kind of guidelines for deciding where to install median cable barriers, Figure 4.6

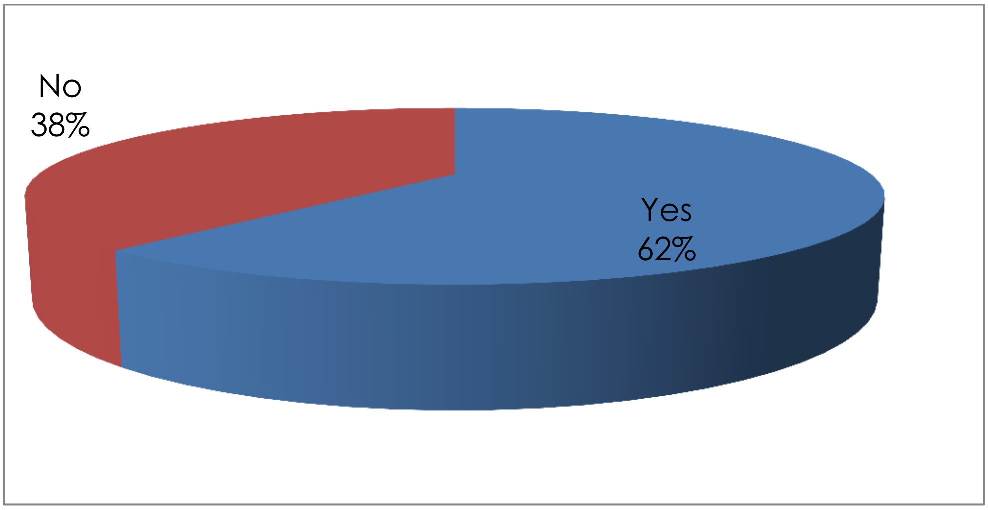


Figure 4.6: Does Other States have their own Guidelines for Cable Barriers

Question: *Does your State use the AASHTO Roadside Design Guide to decide where to consider installation of median cable barriers?*

Majority of states still use AASHTO Roadside Design Guide, Figure 4.7.

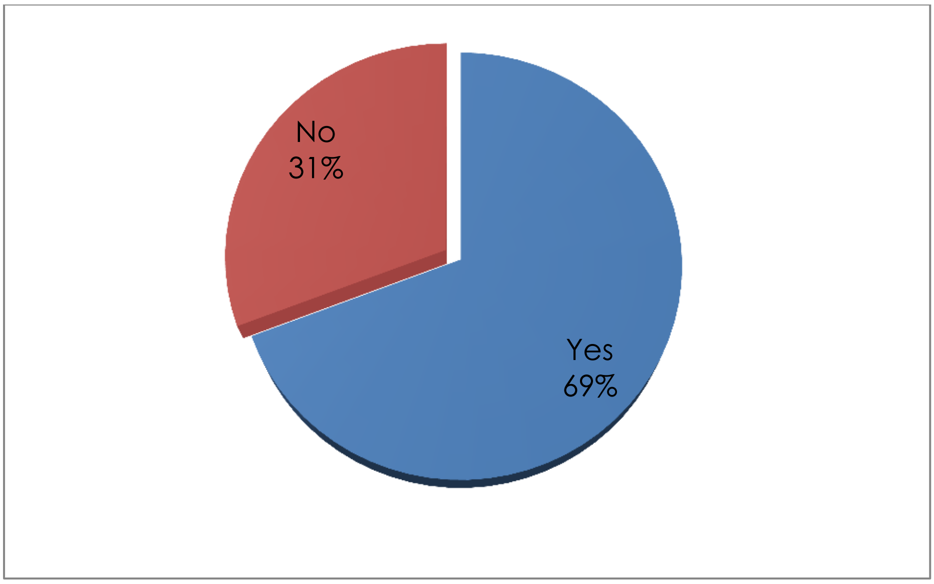


Figure 4.7: Use the AASHTO Roadside Design Guide for Cable Barriers

Question: *Which cable barrier manufacturers or type are preferred in your jurisdiction?*

Brifen was shown to be the most popular choice for Cable Barrier Manufactures followed by Gibraltar and Trinity, Figure 4.8.

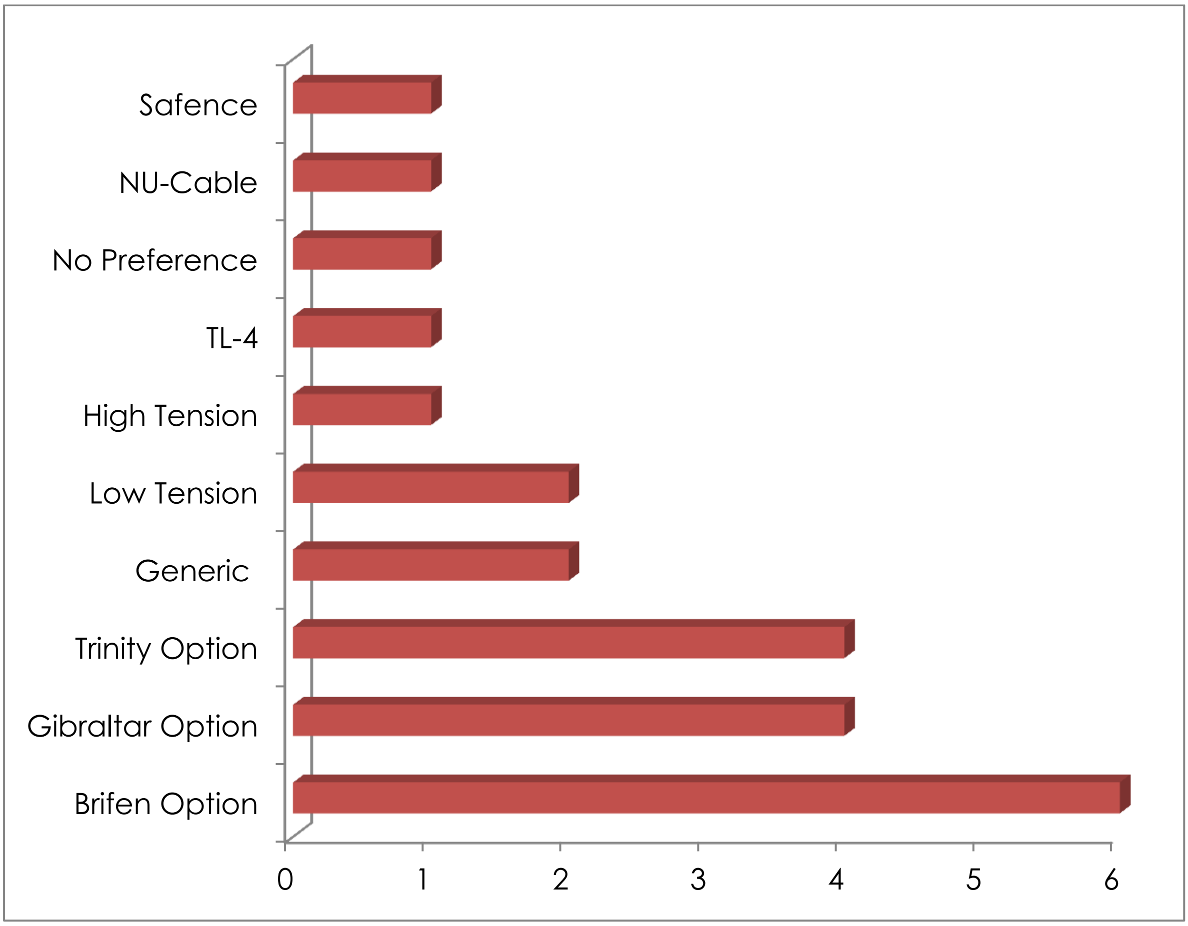


Figure 4.8: Preferred Cable Barrier Manufacturers

CHAPTER 5: STUDY DATA

5.1. Data Overview

Crash data along the study segments was downloaded from Tennessee Roadway Information Management System [E-TRIMS] database. The E-TRIMS database has crash data embedded with attributes such as location, crash date, mile maker, crash type, total injured, total killed, number of vehicles involved in a crash, first harmful event, contributing causes, injury severities, traffic characteristics, and geometric characteristics among others. The data also have the exact mile maker where the crash occurred. The Average Annual Daily Traffic (AADT) was downloaded from TDOT traffic history website [11] which is available to the public. To fully assess safety effectiveness of the median cable barriers, segments with at least three years of complete crash data before and after the median cable barrier installations was used. In coordination with TDOT officials involved with the cable barrier systems, project planning, safety office, and crash data management section, it was revealed that many cable barrier segments did meet this criterion as some were installed in 2006, some 2009 and some 2010. As of December, 31st 2013, all of the median cable barriers installed in 2006, 2009 and 2010 had passed 3 years after cable installation, making them adequate for before and after safety effectiveness evaluation.

5.2. Study Segments and Cable Installation Dates

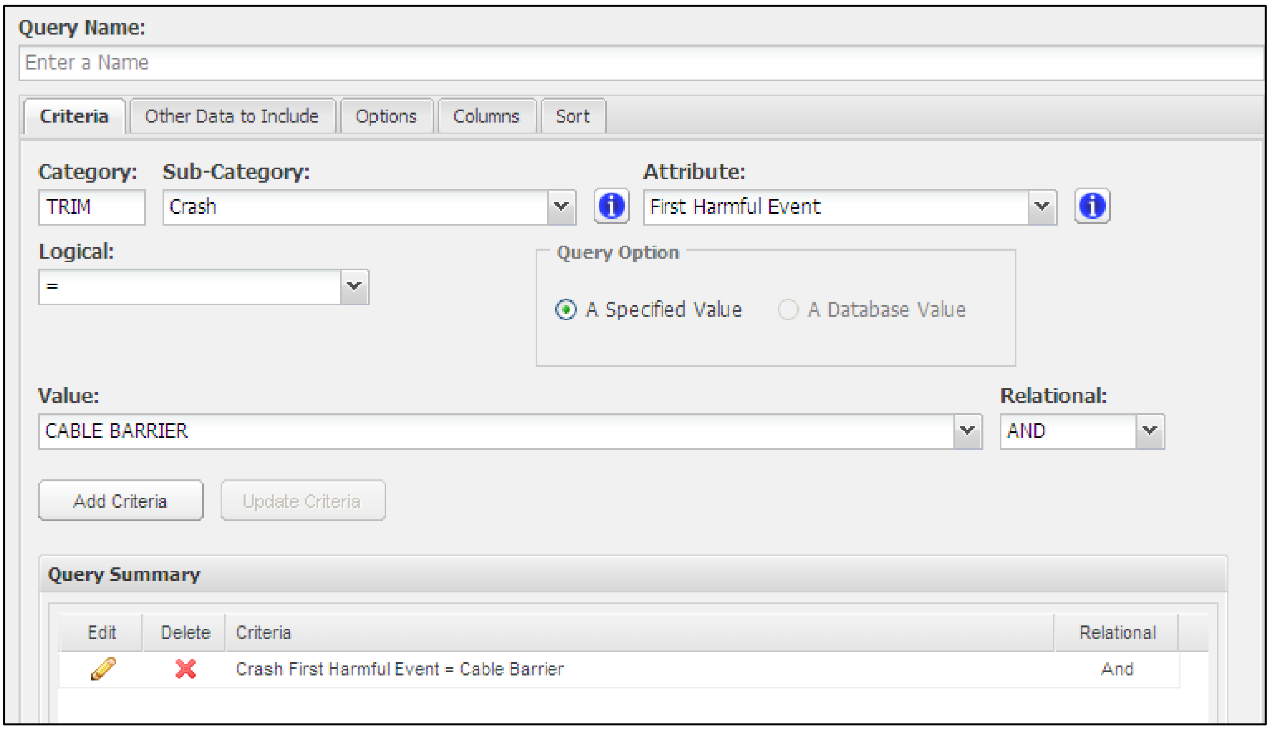
The study identified five hundred and seventy seven (577) median cable barrier segments for evaluation with a total of 302 miles covering forty eight different counties and thirty two different highways including interstates (Table 5.1). The average cable barrier segment length was found to be 0.524 miles with the longest segments found in Williamson County along I-65 from milepost 5.935 to 8.754 (2.819 miles). All segments had three years of complete crash data before and after the cables.

Table 5.1: Summary of the Study Cable Barrier Segments

Study number of Cable Segments	577
Total length (miles)	301.974
Mean segment length (miles)	0.524
Number of Counties covered	48
Number of Different Highways covered	32
Earliest Cable Segment date	3/15/2006
Latest Cable Segment date	12/31/2010

5.3. Reviewing Crash Hard Copies

Before and after cable crashes are defined using cable barrier installation completion dates as a threshold. Taking installation completion dates as a reference, there were 6084 crashes along these segments within three years before the cable barriers were installed and 6223 crashes within three years after the installation of the cable barriers (12,307 crashes in total). These are total crashes without segregating as median related or not. The hard copies of these crashes were downloaded from Titans database for review to determine whether they were median related or not. Crash collision diagrams, officer and crash witness narratives were the basis of hard copy reviews as collision diagrams proved to be useful in understanding the location and progression of events in a crash. Along with the police narrative, a sequence of events was used to help determine the contributing factors and where the injury occurred. This was useful in developing conclusion of whether presence or absence of the cable barriers influenced the course of events that led to the crash injury or location. Statements from the drivers, passengers, or witnesses as recorded in the crash hard copy also provided additional perspectives about the crash. For the after cable crashes, recorded first harmful and most harmful events was used as the criteria to determine if the crash was a median related or not. Through E-trims, first harmful event attribute was set as "Cable Barrier" and all related crashes downloaded, Figure 5.1.



Query Name: Enter a Name

Category: TRIM
Sub-Category: Crash
Attribute: First Harmful Event
Logical: =

Query Option
● A Specified Value ○ A Database Value

Value: CABLE BARRIER
Relational: AND

Query Summary

Edit	Delete	Criteria	Relational
✎	✗	Crash First Harmful Event = Cable Barrier	And

Figure 5.1: Cable Barriers as First Harmful Event Crash Attribute in E-Trims

5.4. Median Related Crashes (MRC)

The study screened 12,307 fatal and injury crashes that occurred three years before and after the cable barriers were completed to determine if they were median related relevant for the intended analysis. A crash was considered median related if it met the following criteria:

i. If the vehicle's first action ("first harmful event" or the initial action of the crash) was that it entered the median.
ii. If the "most harmful event" was located in the median or opposite travel lanes.
iii. If the vehicle sustained significant damage once it entered the median although this act may not have been the "first harmful event." This criterion was used to determine whether the presence/absence (after/before installation) of the cable barrier had an impact on the crash severity.

Based on the crash hard copies review and "cable barrier" as the first harmful event for the after cable period, 1010 crashes encompassing 71 fatal, 139 incapacitating, and 800 non-incapacitating injury crashes were found to be Median Related Crashes (MRC) relevant for cable effectiveness evaluation as detailed in Table 5.2. The PDO crashes analysis is not included in this report.

TABLE 5.2 Fatal and Injury Median Related Crashes (MRC)

Type of crash	Before Median Cable Barriers	After Median Cable Barriers	% Reduction
Fatal Crashes	60	11	82%
Incapacitating Injury Crashes	112	27	76%
Non- Incapacitating Injury Crashes	570	230	60%
Fatal and Injury Crashes Combined	742	268	64%

5.5. Fatal Crashes After Cable Barriers Installation

The first harmful event criteria returned 11 fatal crashes, 27 incapacitating injury crashes and 230 non-incapacitating injury crashes involving hitting cable barriers within three years after the cables were installed, Table 5.2. Shown in Table 5.3 are the details of these 11 fatal crashes considered to be median related occurring after the cables were installed.

TABLE 5.3 Details of Fatal Crashes After Cable Barriers Installation

Crash Case Number	Brief Narrative	1st Harmful Event	Most Harmful Event	Fatality occurred after hitting the Cable?	Final Decision
100035973 (Cumberland)	Vehicle hit cable barrier and rotated 90 degrees. It was then hit by another vehicle since the driver of the other vehicle being obstructed by the curvature of the road didn't see it.	Cable Barrier	Vehicle in transport	YES-Vehicle was hit after being re-directed to traffic	Cable Barrier Related
100038648 (Cheatham)	Driver of motorcycle attempted to pass a commercial vehicle when he lost control. He went off-road to the left while his motorcycle went to the right. He hit the barrier and died	Overturn	Cable Barrier	YES-The driver fell on the cables	Cable Barrier Related
100112597 (Obion)	The vehicle went off-road at a construction zone with lane closure. It hit the cable barrier and was redirected back to traffic where it ran across lanes into the ditch on right side.	Cable Barrier	Ditch	Yes- But on the other side of roadway	Cable Barrier Related
100193758 (Cocke)	The vehicle went off-road to the left then corrected into the roadway. It then overcorrected again to the left of the roadway where it hit the cable barrier and overturned	Cable Barrier	Rollover	Yes	Cable Barrier Related
100246586 (Davidson)	Motorcycle went off roadway into the median where it struck the cable barriers. The driver died	Guardrail Face (Cable)	Guardrail Face	Yes	Cable Barrier Related
300025881 (Sullivan)	A vehicle (veh 1) went off-road to the left of the roadway into the median and struck the cable barrier. It then crossed the median into the other direction of the roadway where it struck other vehicle. The driver was ejected and came to rest into the median. Other vehicle (veh 2) also struck the cable barrier and travelled through the median to the opposite side where veh 1 travelled before going off-road.	Cable Barrier	Vehicle in transport	Yes	Cable Barrier Related
900064887 (Anderson)	A vehicle went off road into the median and struck the cable barrier. It also struck two pedestrians who were working on the cable barrier	Pedestrian	Pedestrian	Yes	Cable Barrier Related
900123955 (Hamilton)	Motorcycle was negotiating a curve where it went off-road. It then struck a cable barrier and the driver came to rest on the roadway while the driver came to rest in the median	Cable Barrier	Cable Barrier	Yes	Cable Barrier Related
900030891 (Marion)	Neither diagram nor police narrative	Cable Barrier	Cable Barrier	No info.	---
300075386 (Sullivan)	The vehicle went off road to the right, struck the guardrail face and was re-directed back to the right where it entered the median and hit the concrete ditch line. The vehicle then went airborne and struck the cable barrier but crossed to other direction	Cable Barrier	Guardrail-face	Hard copy shows Guardrail face as the first and most harmful event. Cable barrier is the third event	Cable barrier related
300002009 (Washington)	The vehicle crossed over through the cable barrier to other direction lanes and collided with the oncoming vehicle. The driver died from injuries	Cable Barrier	Vehicle in transport	Yes	Cable barrier related

5.6. Ranking the Cable Barrier Segments based on Crash Frequency

The segments were ranked based on the number of cable barrier related crashes (for after period). The top 50 segments are as shown in Table 5.4 (the ranking for all segments are included in the Appendix). The ranking presents the frequency of vehicle-cable barrier collisions. Included in the last column are the corresponding crash rates calculated per million vehicle miles of travel (MVMT). The ranking position changes if crash rate is the criteria compared to crash frequency. The crash rates are calculated as:

Crash Rate= (Number of Crashes*1,000,000)/(365*AADT*Segment Length)

TABLE 5.4 Top 50 Ranked Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate /MVMT
1	SHE34	Shelby	SR385	10.49	12.377	1.887	38554	0	1	5	22	28	1.054
2	CAM07	Campbell	I0075	2.802	4.851	2.049	31993	0	0	6	16	22	0.919
3	SHE13	Shelby	I0040	23.905	25.831	1.926	51535	0	1	7	14	22	0.607
4	SHE30	Shelby	SR385	6.863	8.256	1.393	36626	0	0	2	19	21	1.128
5	CUM13	Cumberland	I0040	30.324	32.031	1.707	30576	1	0	1	18	20	1.050
6	PUT04	Putnam	I0040	8.781	9.573	0.792	37242	0	0	5	15	20	1.858
7	SUL09	Sullivan	I0026	6.347	7.064	0.717	38594	0	1	1	16	18	1.782
8	SUL11	Sullivan	I0026	7.133	7.665	0.532	38594	0	0	3	13	16	2.135
9	AND06	Anderson	I0075	3.148	3.87	0.722	39200	0	0	3	12	15	1.452
10	MAD07	Madison	I0040	6.572	7.516	0.944	39350	0	0	0	15	15	1.106
11	MAD26	Madison	I0040	19.783	21.146	1.363	40005	0	0	1	14	15	0.754
12	SUL39	Sullivan	I0026	5.64	6.18	0.54	41411	0	0	3	12	15	1.838
13	WAS03	Washington	I0026	1.459	2.304	0.845	41492	0	0	0	15	15	1.172
14	MAR16	Marion	I0024	30.365	31.061	0.696	43698	0	0	0	14	14	1.261
15	WILL04	Williamson	I0065	5.935	8.754	2.819	61896	0	0	5	9	14	0.220
16	CUM03	Cumberland	I0040	12.401	13.228	0.827	30298	0	0	3	10	13	1.421
17	HAY04	Haywood	I0040	6.119	7.131	1.012	35509	0	0	2	11	13	0.991
18	MAD04	Madison	I0040	2.946	4.783	1.837	39350	0	0	0	13	13	0.493
19	SHE11	Shelby	I0040	22.517	23.126	0.609	56640	0	1	3	9	13	1.033
20	SUL12	Sullivan	I0026	7.227	8.156	0.929	38594	0	0	1	12	13	0.993
21	SUM02	Sumner	I0065	1.061	2.451	1.39	58056	0	0	1	12	13	0.441
22	COC15	Cocke	I0040	4.336	5.5	1.164	24514	0	0	1	11	12	1.152
23	WAS01	Washington	I0026	0.135	1.028	0.893	44976	0	0	2	10	12	0.819
24	WAS08	Washington	I0026	4.234	4.742	0.508	54868	0	0	2	10	12	1.180
25	SHE04	Shelby	I0040	7.554	8.14	0.586	90534	0	0	2	9	11	0.568
26	SMI03	Smith	I0040	1.663	4.117	2.454	44290	0	0	2	9	11	0.277
27	CUM07	Cumberland	I0040	25.033	25.827	0.794	30576	0	0	1	9	10	1.129
28	HAY05	Haywood	I0040	7.163	8.854	1.691	35850	0	0	1	9	10	0.452
29	MAD08	Madison	I0040	7.548	8.305	0.757	39662	0	0	1	9	10	0.913
30	MAD14	Madison	I0040	12.06	13.262	1.202	50150	0	0	1	9	10	0.454
31	MAD16	Madison	I0040	13.316	14.688	1.372	50624	0	0	3	7	10	0.394
32	PUT22	Putnam	I0040	35.799	36.316	0.517	23783	0	0	0	10	10	2.228
33	SUL03	Sullivan	I0026	1.534	2.026	0.492	24366	2	0	1	7	10	2.285
34	SUL07	Sullivan	I0026	4.429	5.386	0.957	41411	0	1	2	7	10	0.691
35	WAS06	Washington	I0026	3.227	3.521	0.294	54868	1	0	1	8	10	1.698
36	WILL03	Williamson	I0065	4.87	5.83	0.96	61896	0	0	5	5	10	0.461
37	COC05	Cocke	I0040	3.072	4.336	1.264	27746	0	1	2	6	9	0.703
38	HAY08	Haywood	I0040	15.827	16.884	1.057	35415	0	0	0	9	9	0.659
39	MAD01	Madison	I0040	0.004	1.133	1.129	39396	0	0	0	9	9	0.554
40	MAD02	Madison	I0040	1.178	2.002	0.824	39396	0	0	1	8	9	0.760
41	MAD12	Madison	I0040	10.61	11.08	0.47	44920	0	0	1	8	9	1.168
42	MAD20	Madison	I0040	16.037	16.49	0.453	54527	0	0	1	8	9	0.998
43	SHE12	Shelby	I0040	23.215	23.861	0.646	56640	0	1	1	7	9	0.674
44	SMI02	Smith	I0040	1.088	1.729	0.641	44290	0	0	0	9	9	0.869
45	SMI05	Smith	I0040	5.09	6.015	0.925	35069	0	1	0	8	9	0.760
46	COC03	Cocke	I0040	0.784	1.685	0.901	26894	0	0	3	5	8	0.905
47	CUM02	Cumberland	I0040	2.938	3.912	0.974	23783	0	0	1	7	8	0.946
48	LOU03	Loudon	I0040	0.787	2.015	1.228	40882	0	0	0	8	8	0.437
49	MAD06	Madison	I0040	5.603	6.555	0.952	39350	0	1	1	6	8	0.585
50	MAD10	Madison	I0040	8.765	9.275	0.51	44943	0	0	0	8	8	0.956

CHAPTER 6: REDUCTION IN NUMBER OF CRASHES AND SEVERITY

6.1. Overview

The study compared number of crashes and injury severity levels before and after the cable barriers were installed. Percentage reduction in the number of crashes and injury severities after cable barrier installation is taken as an indicator of positive contribution of the cable barriers. Overall, fatal crashes were reduced by 82% and the combination of fatal and incapacitating injury crashes were reduced by 78% as a result of median cable barriers installation, Figure 6.1.

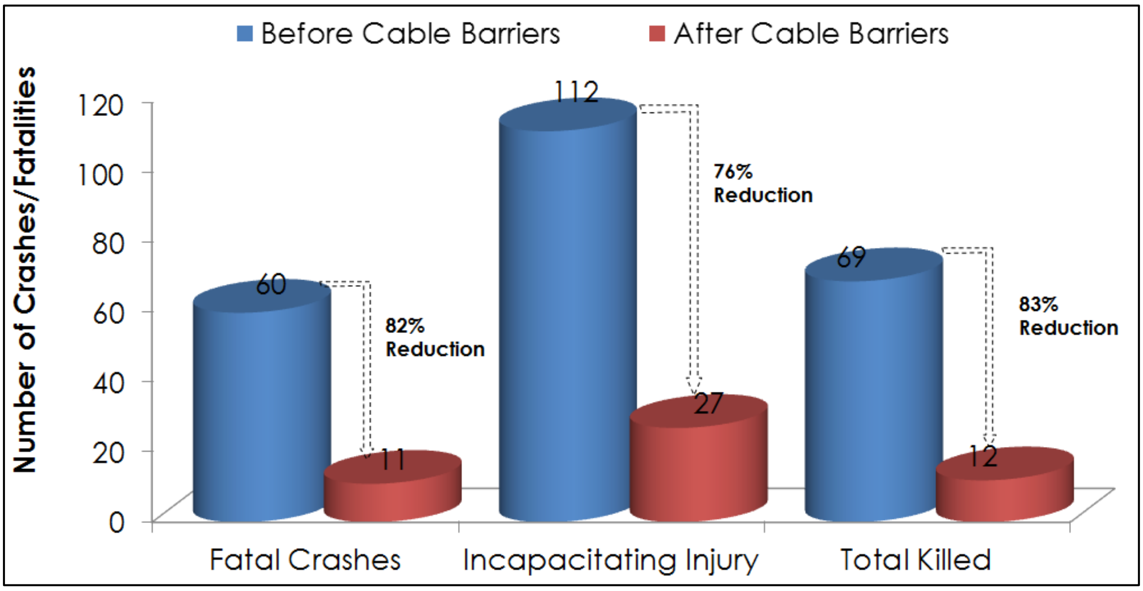


Figure 6.1: Reduction in Fatal and Incapacitating Crashes and Total Killed

6.2. Crash and Injury Reduction Percentages

Crash injury severities are categorized into four ranks by TDOT, named 1) fatal, 2) incapacitating, 3) non-incapacitating and 4) property damage only (PDO). Figure 6.1 exhibits that median related fatal crashes were reduced by 82% while number of persons killed was reduced by 83% after the median cable barriers were installed along these segments relative to before conditions. These fatal crashes are those listed in the first harmful event and verified through crash hard copy review. Figure 6.2 shows fatal and all injury crashes combined were reduced from 742 to 268 crashes (64% reduction). The total number of people killed or injured combined in these crashes was reduced from 1164 before the cable barriers to 333 after the cables installation (71% reduction). Reduction of fatal crashes and number of people killed in those crashes highlights the performance effectiveness of the median cable barriers in Tennessee.

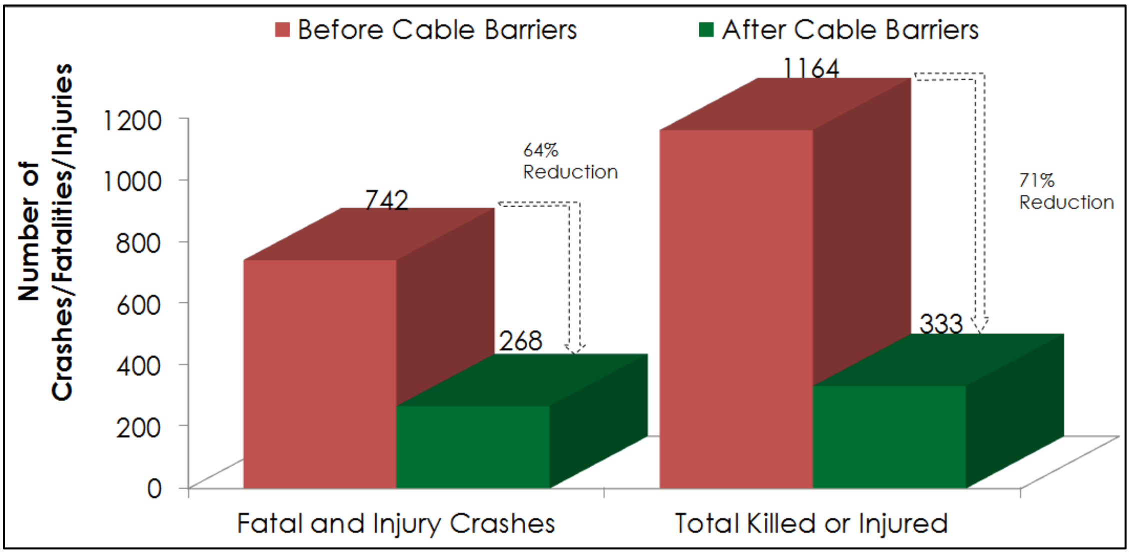


Figure 6.2: Reduction in Fatal & Injury Crashes and Total Killed or Injured

The number of segments which had at least one fatal crash before the cables were installed was reduced from 56 to just 7 after cable installation, an improvement of 88%. Figure 6.3 summarizes the number of segments which experienced crash reduction, no change in the number of crashes, and increase in the number of crashes after the installation of the cable barriers.

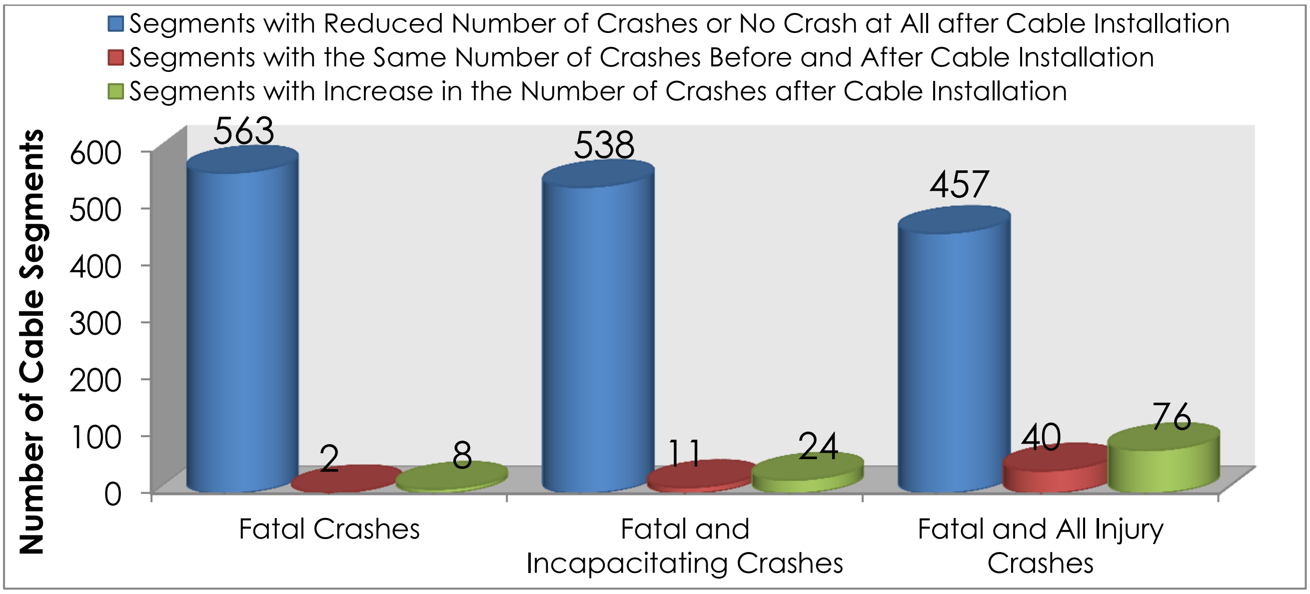


Figure 6.3: Brashes by Number of Segments Before and After Cables

As shown in Figure 6.3, a combination of segments with reduced number of crashes or no crashes at all after the cables were installed significantly surpasses segments which experienced increase in number of crashes after the cables. For instance, 563 median cable barrier segments (98%) resulted with reduction in fatal crashes or no fatal crashes at all after cables installation. Overall, 457 segments (80%) resulted with reduction of fatal and injury crashes compared with only 116 (20%) segments which experienced increase in the same type of crashes. This also highlights the effectiveness of the median cable barriers in Tennessee. Table 6.1 compares the number of median related crashes within the study period and percentage reductions per different routes before and after the installation of median cable barriers.

TABLE 6.1 Crashes by Routes Before and After Cable Barriers

Route	Crashes Before Cables	Crashes After Cables	% Reduction in Crashes
I0024	76	16	-79%
I0026	64	53	-17%
I0040	318	112	-65%
I0055	5	0	-100%
I0065	52	22	-58%
I0075	78	21	-73%
I0081	24	8	-67%
I0155	6	4	-33%
SR003	2	5	150% **(increase)**
SR006	16	0	-100%
SR385	32	17	-47%
SR386	48	4	-92%

6.3. Crashes with Respect to Number of Vehicles in Single Collision

Median crossing crashes sometimes involve multiple vehicles especially if the collision occurred in the opposite travel direction after crossing the median. Before and after median cable barrier crashes were therefore compared in terms of total number of vehicles involved in a crash. As shown in Figure 6.4, two-vehicle crashes were reduced by 91%, while crashes involving three or more vehicles were reduced by 93% after cable barriers installation. Median cable barriers contributed to these reductions highlighting their effectiveness.

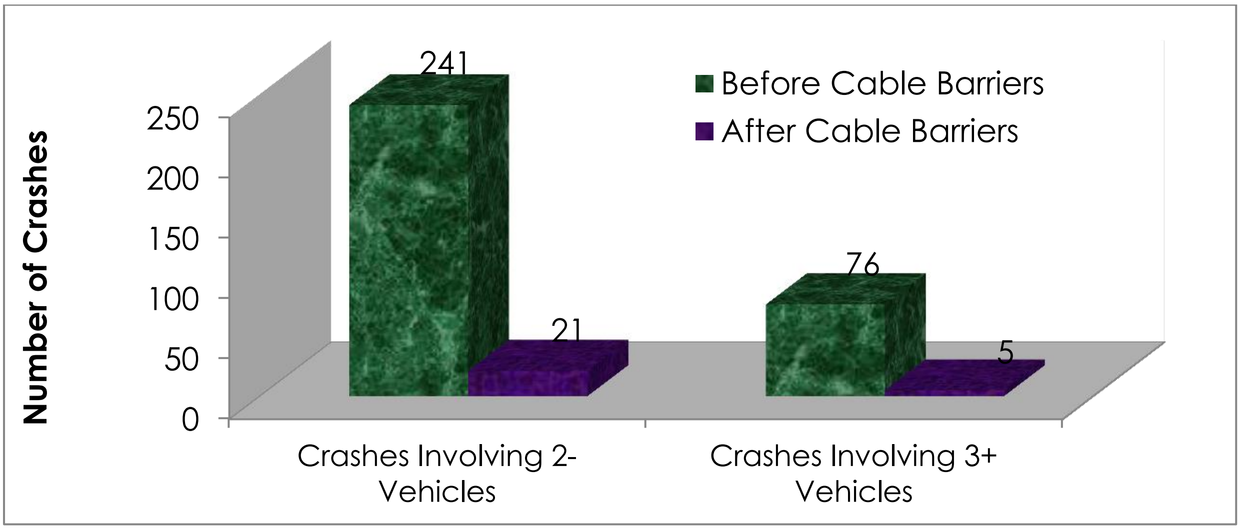


Figure 6.4: Crashes by the Number of Vehicles Involved

CHAPTER 7: DEVELOPING SAFETY PERFOMANCE FUNCTIONS (SPFs)

7.1. Overview

Safety Effectiveness evaluation of the cable barriers in Tennessee followed the procedures outlined in Chapter 9 of the Highway Safety Manual (2010 HSM) [2], as summarized in Table 7.1. As shown, development of crash prediction models is a key to successful safety effectiveness evaluation. Apart from the overall unbiased safety effectiveness, confidence level corresponding to the effectiveness was also determined.

Table 7.1: Overview of Empirical Bayes Before-After Safety Evaluation

Step 1	Calculate the predicted crash frequency for each cable segment during each year of the Before Period	EB Estimation of the Expected Crash Frequency in the Before Period
Step 2	Calculate the predicted crash frequency for each cable segment summed over the entire Before Period	
Step 3	Calculate the predicted crash frequency for each cable segment during each year of the After Period	EB Estimation of the Expected Crash Frequency in the After Period
Step 4	Calculate an adjustment factor to account for differences between the Before and After Periods	
Step 5	Calculate the expected crash frequency for each cable segment over the entire After Period in the absence of the cable	
Step 6	Calculate an estimate of the safety effectiveness in terms of odds ratio	Estimation of the Cable Barrier Effectiveness
Step 7	Calculate an estimate of the safety effectiveness at each cable segment as a percentage crash change	
Step 8	Calculate the overall effectiveness of the cables for all segments combined in terms of odds ratio	
Step 9	Perform adjustment to obtain an unbiased estimate of the cable safety effectiveness in terms of odds ratio	
Step 10	Calculate an overall unbiased safety effectiveness as a percentage change in crash frequency across all cable barrier segments	
Step 11	Calculate the variance of the unbiased estimated safety effectiveness as an odds ratio	Estimation of Precision of the Median Cable Barrier Effectiveness
Step 12	Calculate the standard error of the odds ratio from step 11	
Step 13	Calculate the standard error of the unbiased safety effectiveness as calculated in step 10	
Step 14	Assess the statistical significant of the estimated Median Cable Barrier safety effectiveness	

Source: 2010 Highway Safety Manual (HSM) [2]

7.2. Crash Prediction Modeling Basic Principles

As indicated in Table 7.1, EB safety effectiveness evaluation involves developing Safety Performance Functions (SPFs) or crash prediction models used to predict expected crash frequency for each cable segment over the analysis period. Generally, Poisson and Negative Binomial (NB) distributions are often more appropriate for modeling discrete counts of events such as crashes which are likely to be zero or a small integer during a given time period. However, the Poisson distribution is more appropriate for modeling cross-sectional crash data that has equality between mean and variance—a phenomenon called equidispersion. In many crash modeling situations the data generally exhibits extra variation, resulting in variance being greater than the mean—a phenomenon known as overdispersion. A negative binomial model is well suited for this case. The general Negative Binomial (NB) regression is given in equation 7.1, Chimba, et al. [12]:

$$p(y_i) = \frac{\Gamma(y_i+\alpha^{-1})}{\Gamma\left(\frac{1}{\alpha}\right)\Gamma(y_i+1)}\left(\frac{1}{1+\alpha\mu_i}\right)^{\frac{1}{\alpha}}\left(\frac{\alpha\mu_i}{1+\alpha\mu_i}\right)^{y_i} \qquad (7.1)$$

Where μ= (yi) =e $(Xi\ \beta)$ (7.2)

y_i is the number of crashes per cable barrier segment per year

μ_i Represents a mean rate of crashes,

X_i= variable which is related to the occurrence of crash (in this case AADT and length of the cable segment)

α is the over-dispersion parameter. If alpha α=0 then the mean is concentrated, it reduces to Poisson distribution

β=the coefficient of the corresponding variables (in this case the coefficients of AADT and length of the cable segment).

7.3. Prediction Model Parameters

As highlighted in section 7.2, data for which the variance exceeds the mean is said to be overdispersed, and the negative binomial distribution is very well suited for modeling overdispersed data. The degree of overdispersion in a negative binomial model is represented by a statistical parameter, known as the overdispersion factor that is estimated along with the coefficients of the model equation. The larger the value of the overdispersion parameter, the more the variation in crash data (non-uniform). The closer the overdispersion parameter is to zero, the more the uniformity in the crash data hence statistically reliable in developing SPFs (models). The overdispersion parameter is used to determine the values of weight factor for use in the EB safety effectiveness evaluation. The HSM safety performance function and overdispersion parameter for rural and urban multilanes are given as shown in equation 7.3 to 7.5;

$$N_{spf} = e^{(a+b*\ln(AADT)+\ln(L))} \quad (7.3)$$

Where:

- N_{spf} is the base total number of roadway segment crashes per year
- AADT is the annual average daily traffic on the roadway segment
- L is the length of the roadway segment (in miles)
- a, b are regression coefficients

Fitting the NB generates "alpha" value (α) which is then used to calculate the overdispersion parameter (k) for each of the cable barrier segment which is the function of the expected mean of the crash counts equal to:

$$k=1+\alpha*e^{(a+b*\ln(AADT)+\ln(L))} \quad (7.4)$$

The developed overdispersion parameter (k) for each of the cable segments is then modeled against the cable segment length as shown in equation 7.5:

$$k = \frac{1}{e^{(c+\ln(L))}} \quad (7.5)$$

Where:

- L is the length of the roadway segment (in miles)
- k is the overdispersion parameter associated with the roadway segment
- c is the regression coefficient

The EB method then uses this overdispersion parameter, *k* to calculate prediction model adjustment factor, *w* as:

$$w=\frac{1}{1+k\sum_{\text{All years}} N_{predicted}} \quad (7.6)$$

The weighted factor is then applied as follows:

$$N_{expected}=w*N_{predicted}+(1-w)*N_{observed} \quad (7.7)$$

7.4. Developed Prediction Model Coefficients

Development of the models was conducted using Stata statistical software [13] as well as Excel. The model coefficients were developed in Stata then copied to Excel for further analysis. This allowed the modification and the addition of data for different scenarios. As shown in equations 7.3 to 7.5, the data needed for model coefficients development are the segment length, AADT, and the number crashes by year (both before and after) for each of the cable segment. The cable barrier segment lengths were calculated from the beginning mile maker to the end mile maker while the AADT for each segment was downloaded from TDOT traffic database available online [11] using station numbers obtained through E-TRIMS. The crashes downloaded for each of the cable barrier site was split by individual years with the completion date used to separate before and after periods. Three months prior and post cable completion date was used as a separation of before and after. This eliminated potential biased results from where construction was taking place to build the system, and from where commuters were still getting used to or adjusting to the new effects of the system. The study developed prediction models using number of crashes under the following categories;

1) Fatal crashes only
2) Incapacitating injury crashes only
3) Non-incapacitating injury crashes only
4) Fatal and incapacitating injury crashes combined
5) Incapacitating and non-incapacitating injury crashes combined
6) Fatal and all injury crashes combined

The coefficients in Table 7.2 were therefore developed using the study data. All variables were significant above 95% confidence level. These study data developed model coefficients in Table 7.2 are used for Empirical Bayes (EB) Safety Effectiveness Evaluation.

Table 7.2: Study Data SPF Model Coefficients

	a	b	c
Fatal Only	-8.9126	0.7002	2.8549
Incapacitating Only	-8.5879	0.7279	2.8460
Non-Incapacitating Only	-10.6820	1.0797	2.7368
Fatal and incapacitating	-8.0531	0.7178	2.8563
Incapacitating and non-incapacitating	-9.8927	1.0234	2.6956
Fatal and All injuries	-9.6019	1.0045	2.6940

CHAPTER 8: MEDIAN CABLE BARRIERS SAFETY EFFECTIVENESS

8.1. Cable Barrier Safety Effectiveness Evaluation Steps

The first step in the safety effectiveness evaluation process was the development of prediction models (Safety Performance Functions, SPFs) as described in chapter 7 which incorporated number of crashes per segment, cable segment length and average annual daily traffic (AADT) per segment. The models built a baseline for the analysis using the before cable crashes then predicted the amount of crashes which should have occurred if the median cable barriers were not installed. Development of the model coefficients shown in Table 8.1 was performed using Stata statistical software. The following steps were applied to determine the safety effectiveness of the cable barriers using the model coefficients developed in Chapter 7 (Table 7.2 and Table 8.1) [2].

8.1.1. Step 1, Models for Predicting Crash Frequencies for Before Years

The SPFs for predicting expected crash frequency and overdispersion parameters were developed as shown in Table 7.2.

Table 8.1: Safety Effectiveness Evaluation Models

Fatal crashes only	Fatal & incapacitating injury crashes combined	Fatal and all crashes combined
$N_{spf}=e^{(-8.9126+0.7002*\ln(AADT)+\ln(L)}$	$N_{spf}=e^{(-8.0531+0.7178*\ln(AADT)+\ln(L)}$	$N_{spf}=e^{(-9.6019+1.0045*\ln(AADT)+\ln(L)}$
$k=\frac{1}{e^{(2.8549+\ln(L))}}$	$k=\frac{1}{e^{(2.8563+\ln(L))}}$	$k=\frac{1}{e^{(2.694+\ln(L))}}$
Incapacitating injury crashes only	Non-incapacitating crashes only	Incapacitating and non-incapacitating injury crashes
$N_{spf}=e^{(-8.5879+0.7279*\ln(AADT)+\ln(L)}$	$N_{spf}=e^{(-10.682+1.0797*\ln(AADT)+\ln(L)}$	$N_{spf}=e^{(-9.8927+1.0234*\ln(AADT)+\ln(L)}$
$k=\frac{1}{e^{(2.846+\ln(L))}}$	$k=\frac{1}{e^{(2.7368+\ln(L))}}$	$k=\frac{1}{e^{(2.6956+\ln(L))}}$

Where:

N_{spf} = base total number of cable segment crashes per year
AADT = annual average daily traffic (AADT)
ln(AADT) =natural logarithm of AADT
L = length of the roadway segment (in miles)
ln(L) =natural logarithm of cable barrier segment length

8.1.2. Step 2, Weighted Adjustment for Expected Crashes Before Cables

The weighted adjustment factor (w) was calculated for each segment used to adjust the predicted number of crashes, $N_{predicted}$ (N_{spf}) and the observed number of crashes for entire before period $N_{observed,B}$ to determine the expected number of crashes for the before period, $N_{expected,B}$. The $N_{expected,B}$ value was used to predict crashes for the years after the cables were installed, $N_{expected,A}$. Adjustment factors were calculated using the following equation:

$$w=\frac{1}{1+k\sum_{Before\ years} N_{predicted}} \tag{8.1}$$

Calculated "w" was then used to calculate the expected number of crashes for each segment using the following equation;

$$N_{expected}=w*N_{predicted}+(1-w)*N_{observed} \tag{8.2}$$

8.1.3. Step 3, Predicted Average Crash Frequencies for After Period

The third step was to have the model predict the frequency of crashes for the years after the cables were installed, $N_{predicted,\ A}$. Crash and AADT data was labeled as 1-year after, 2-years after, and 3-years after the cables as the actual dates were different for each cable barrier based on their completion dates. The prediction was done the same way as in step one with exception that the AADT were for after years. The predicted crashes represented a scenario of crash occurring if the cable had not been installed.

8.1.4. Step 4, Adjustment Factor

The adjustment factor "r" to account for differences between the before and after periods and traffic volumes was developed. The adjustment factor expresses accurate prediction for the number of crashes for each segment.

$$r=\frac{\sum_{after\ years} N_{predicted}}{\sum_{before\ years} N_{predicted}} \tag{8.3}$$

8.1.5. Step 5, Expected Crash Frequencies for No Cable after Period

Once the adjustment factor "r" was developed the expected amount of crashes in the absence of the cable barriers being installed was calculated. The equation used the number of crashes the model expected before the cable barrier was installed and multiplied it by adjustment factor to get the expected number of crashes that would have occurred if the cable barrier system had not been installed.

$$N_{expected,\ after}=N_{expected,\ before}*r \tag{8.4}$$

8.1.6. Step 6, Odds Ratio Safety Effectiveness per Segment

From step 5, the number of expected crashes if the cables were not installed was predicted and compared against the actual number of crashes that occurred with the cables being installed. By comparing these numbers of crashes at each segment, the odds ratio (OR_i) was determined which ultimately lead to the safety effectiveness percentage.

$$OR_i = \frac{N_{\text{observed, A}}}{N_{\text{expected, A}}} \tag{8.5}$$

8.1.7. Step 7, Safety Effectiveness as a Percentage of Crash Changes

By knowing the odds ratio for each segment, the safety effectiveness at each segment was estimated as shown in the equation 8.6. This step demonstrates how effective the cable barrier was, with a positive value indicating effectiveness and a negative value representing not effective.

$$\text{Safety effectiveness} = 100 * (1 - OR_i) \tag{8.6}$$

8.1.8. Step 8, Overall (biased) Safety Effectiveness

The overall biased effectiveness of the cable barriers was determined using the following equation:

$$OR' = \frac{\sum_{\text{All sites}} N_{\text{observed, A}}}{\sum_{\text{All sites}} N_{\text{expected, A}}} \tag{8.7}$$

8.1.9. Step 9, Overall (unbiased) Safety Effectiveness

It is important to note that individual segments might have biased results due to localized conditions. Several segments were compared together to correct this and to provide an overall unbiased safety effectiveness percentage with a corresponding confidence level for the analysis. Before the unbiased odds ratio was determined the variance at each segment was determined then summed together. This was accomplished using the adjustment factor “r”, the weighted adjustment factor “w”, and the expected number of crashes before the cables were installed, as shown in equation 8.8;

$$\text{Var} \sum_{\text{all sites}} N_{\text{expected, A}} = \sum_{\text{all sites}} \left(r^2 * N_{\text{expected, B}} * (1 - w)\right) \tag{8.8}$$

By summing all the individual segments’ variances and expected number of crashes after the cables, the overall unbiased safety effectiveness of the cable barrier system was determined using the following equation.

$$OR = \frac{OR'}{1 + \frac{\text{Var} \sum_{\text{all sites}} N_{\text{expected,A}}}{\left(\sum_{\text{all sites}} N_{\text{expected,A}}\right)^2}} \tag{8.9}$$

8.1.10. Step 10, Overall (unbiased) Safety Effectiveness as a Percentage

The overall unbiased Safety Effectiveness of the cable barrier system as a percentage was then determined as;

$$\text{Safety Effectiveness}=100*(1-\text{OR}) \qquad (6.10)$$

To assess whether the estimated safety effectiveness of the cable barriers were statistically significant, precision was determined. The precision assess the statistical significant of the cable effectiveness estimated.

8.1.11. Step 11, Variance of the Unbiased Safety Effectiveness

The first step to assess significance was to determine the variance of the overall unbiased odds ratio as shown in equation 8.11;

$$\text{Var(OR)}=\frac{(\text{OR}')^{2}\left[\frac{1}{N_{\text{observed,A}}}+\frac{\text{Var}\,\Sigma_{\text{All sites}}N_{\text{expected,A}}}{\left(\Sigma_{\text{All sites}}N_{\text{expected,A}}\right)^{2}}\right]}{1+\frac{\text{Var}\,\Sigma_{\text{All sites}}N_{\text{expected,A}}}{\left(\Sigma_{\text{All sites}}N_{\text{expected,A}}\right)^{2}}} \qquad (8.11)$$

8.1.12. Step 12, Standard Error of the Variance

By knowing the variance of the odds ratio, the standard error was determined as;

$$\text{SE(OR)}=\sqrt{\text{Var(OR)}} \qquad (8.12)$$

8.1.13. Step 13, Standard Error of the Safety Effectiveness

The standard error of the safety effectiveness was calculated by converting the standard of error for the odds ratio into percentage (multiplying by 100) as shown in the equation.

$$\text{SE(Safety Effectiveness)}=100*\text{SE(OR)} \qquad (8.13)$$

8.1.14. Step 14, Statistical Significant of the Safety Effectiveness

By comparing the safety effectiveness determined in step 10 to the standard error of the safety effectiveness determined in step 13, the statistical significance was calculated. The absolute value of the ratio was compared by the following parameters to determine the level of confidence for the safety effectiveness calculated.

$$\left[\text{Abs}\ \frac{\text{Safety Effectiveness (Step 10)}}{\text{SE (Step 13)}}\right]<1.7\text{, not significant at 90\%} \qquad (8.14)$$

$$\left[\text{Abs}\ \frac{\text{Safety Effectiveness (Step 10)}}{\text{SE (Step 13)}}\right]\geq 1.7\text{,significant at 90\%} \qquad (8.15)$$

$$\left[\text{Abs}\ \frac{\text{Safety Effectiveness (Step 10)}}{\text{SE (Step 13)}}\right]\geq 2.0\text{, significant at 95\%} \qquad (8.16)$$

8.2. Safety Effectiveness Results

The six crash injury groups examined were fatal crashes only, incapacitating injury crashes only, non-incapacitating injury crashes only, fatal and incapacitating injury crashes combined, incapacitating and non-incapacitating injury crashes combined and fatal and all injury crashes combined. Evaluation allowed for the determination of effectiveness and degree of significance of the overall cable barrier systems (all segments combined), per individual cable barrier segments, averaged per TDOT regions, averaged per Counties, and averaged per individual routes. The positive percentage show effectiveness (crashes reduced) with the cable barriers whereas negative percentage indicates that the cable didn't make any improvement (crashes increased).

8.2.1. Overall Statewide Cable Barriers Safety Effectiveness

The overall statewide median cable barrier safety effectiveness percentages are shown in Table 8.2 and Figure 8.1. As shown, the statewide statistical safety effectiveness of cable barriers for fatal crashes is 94%, for fatal and incapacitating crashes combined is 92%, for incapacitating and non-incapacitating injury crashes combined is 85%, and for all fatal and injury crashes combined is 85%. Also shown are 92% safety effectiveness for incapacitating injury crashes only and 84% for non-incapacitating injury crashes. All these effectiveness are above 95% significance. These findings underline that the cable barriers in Tennessee are highly effective in reducing number of crashes and severity of median crossover related crashes.

Table 8.2: Statewide Median Cable Barrier Safety Effectiveness

Crash Type/Combination	Safety Effectiveness
Fatal Crashes Only	94%
Incapacitating Only	92%
Fatal and Incapacitating	92%
Fatal and All Injuries	85%
Incapacitating and Non-Incapacitating	85%
Non-Incapacitating Only	84%

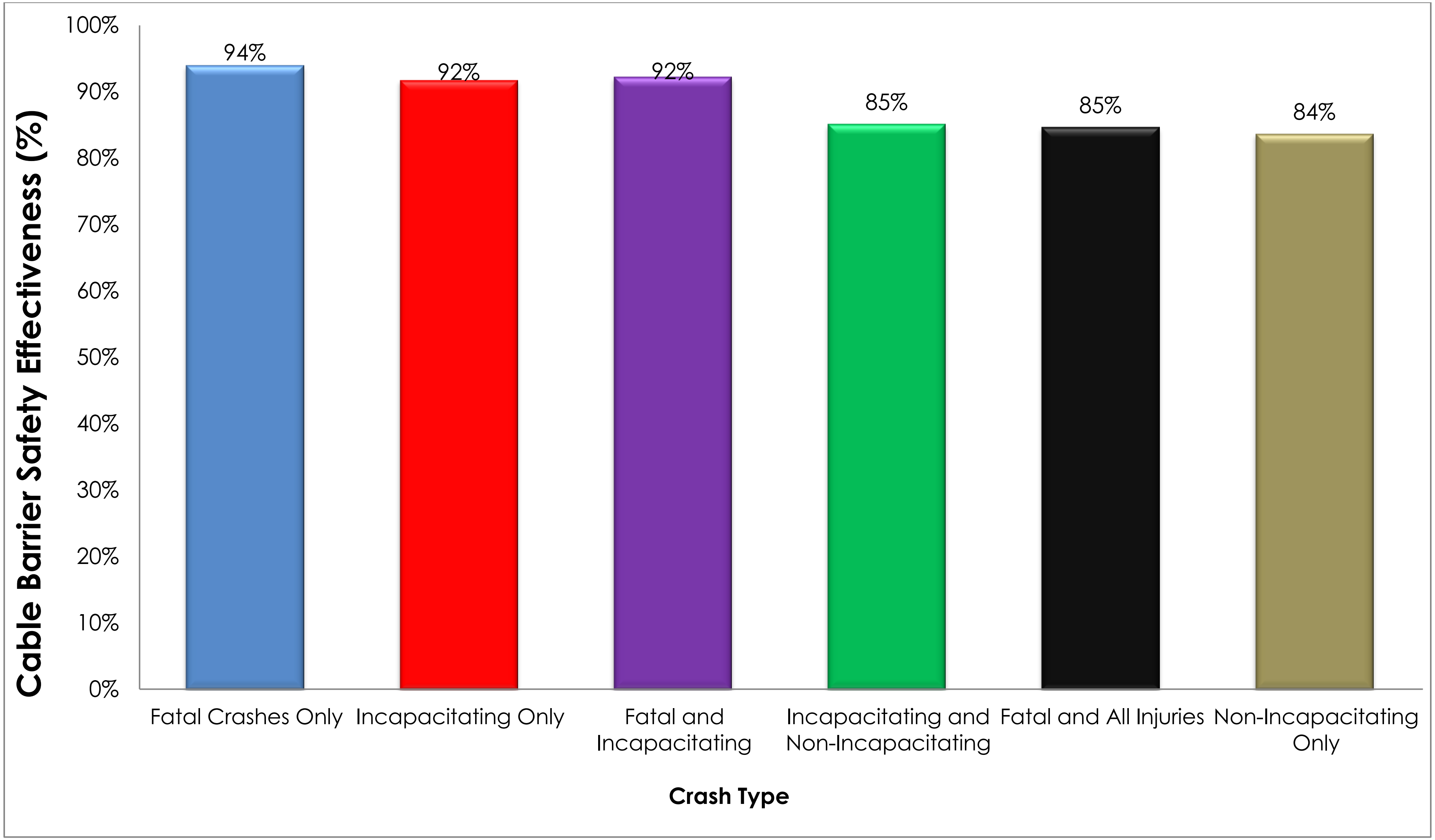


Figure 8.1: Statewide Median Cable Barrier Safety Effectiveness

8.2.2. Safety Effectiveness by TDOT Regions

Averaging individual cable segments safety effectiveness per TDOT regions resulted with effectiveness as shown in Figure 8.2. TDOT regions cater for variations in traffic operations, geometry complexity, population and topographical factors across the state which might cause variation in cable barrier performances. As shown all regions resulted with combined safety effectiveness above 80% with Region 3 and Region 4 having the largest fatal crashes effectiveness close to 100%. In general, the cables barriers resulted into positive effectiveness in all TDOT regions.

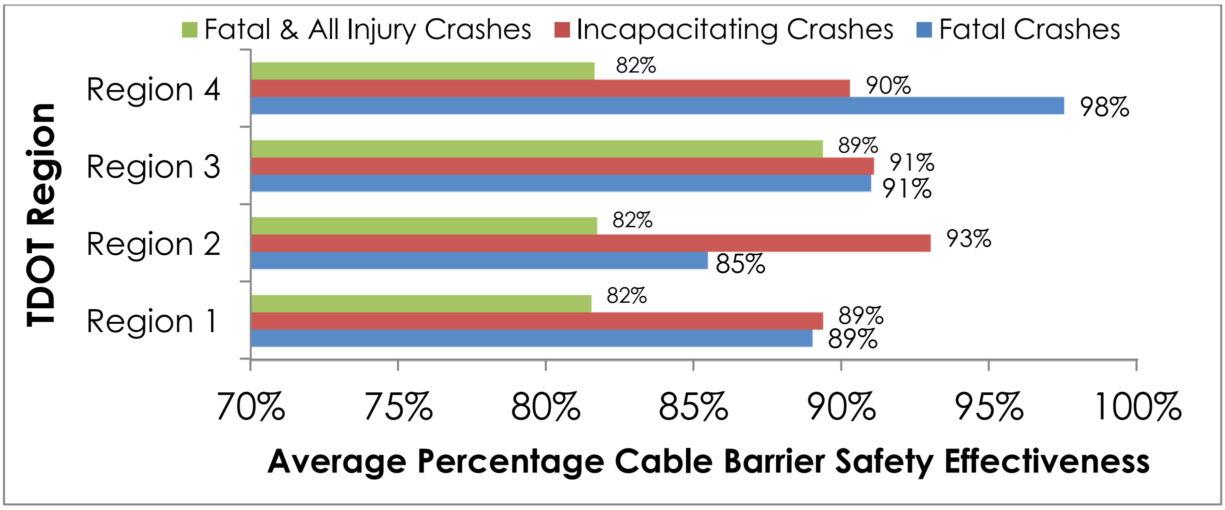


Figure 8.2: Averaged Safey Effectiveness per TDOT Regions

8.2.3. Safety Effectiveness by Counties

Safety effectiveness was also summarized by Counties where the analyzed cable segments are situated, Figure 8.3. Only Obion County resulted with negative safety effectiveness which came from the effect of fatal crash that occurred after the cables were installed as there was no fatal crash for the before condition. Cheatham County has the lowest averaged positive safety effectiveness for fatal crashes followed by Cocke County. Unicoi county also recorded low averaged effectiveness for incapacitating and non-incapacitating crashes compared to other counties. All other counties recorded overall combined positive safety effectiveness, most of them above 80% especially for fatal and incapacitating crashes.

8.2.4. Safety Effectiveness by Individual Routes

The averaged safety effectiveness per individual routes is shown in Figure 8.4. As shown all routes except SR-155 resulted with positive safety effectiveness for fatal and injury crashes though at varying percentages. SR-155 resulted with negative averaged effectiveness for fatal crashes.

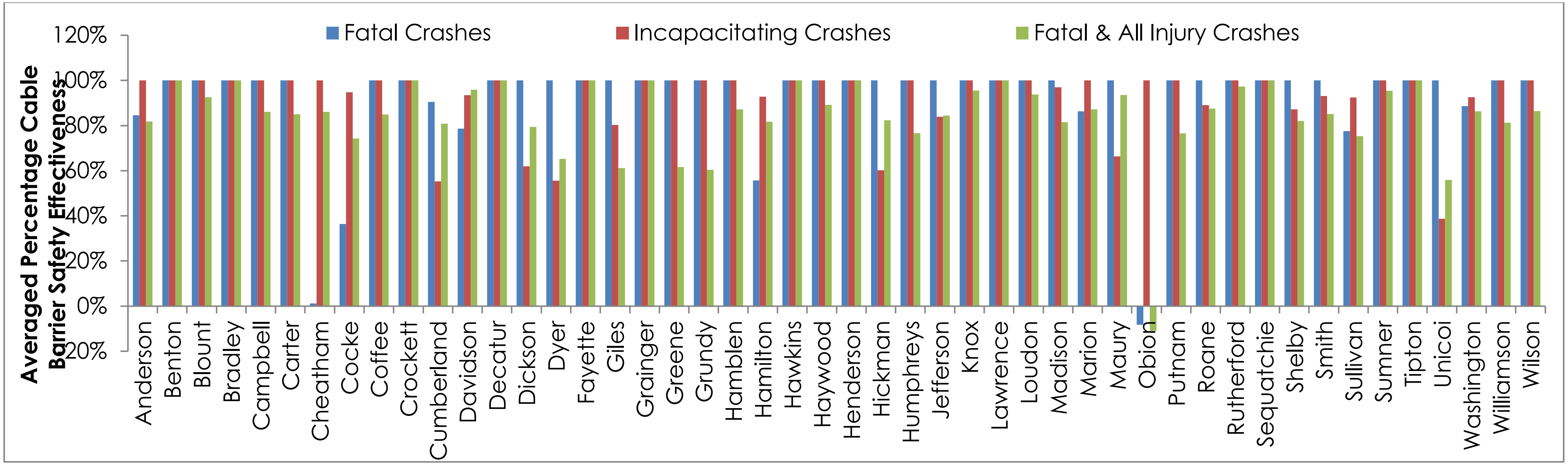


Figure 8.3: Averaged Safety Effectiveness per Counties

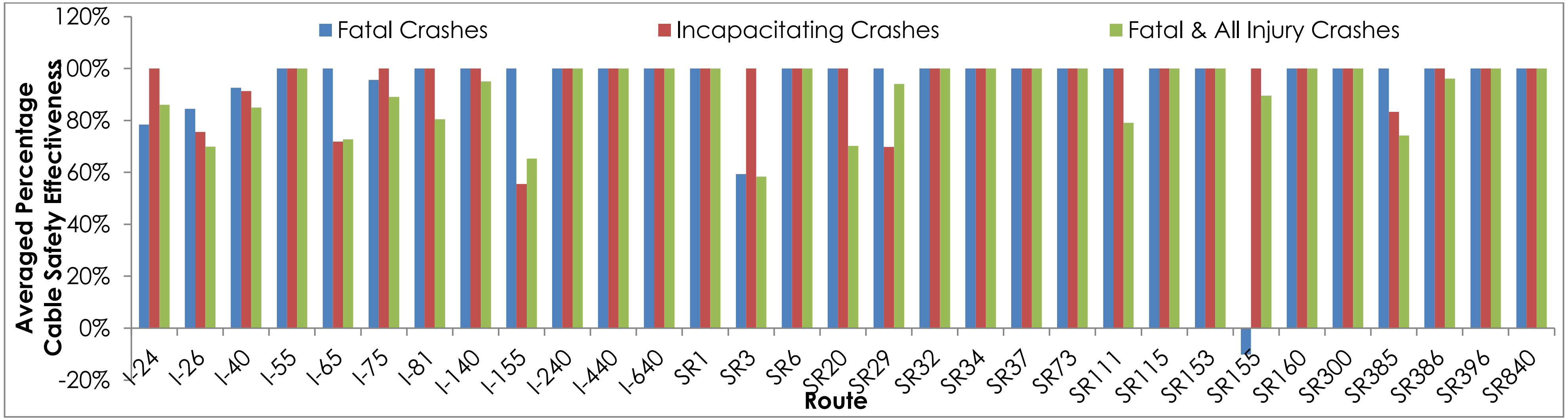


Figure 8.4: Averaged Safety Effectiveness per Routes

CHAPTER 9: IMPACT OF GEOMETRIC FEATURES TO CABLE PERFORMANCES

9.1. Modeling Data Overview

The research evaluated the impact of cable offset (the distance from the end of the travel lane to the cable barrier location), differential elevation (difference of elevation between the centerline of opposite travel directions), and the degree of curve (the curve sharpness) to the safety performance of the cable barriers. In addition to these geometric features, the study evaluated the impact of number of lanes, inside shoulder width, median width and traffic characteristics (traffic volume and posted speed limits) to the safety effectiveness performance of the cable barriers. The effect of horizontal curve was accounted through the degree of horizontal curve. The length of cable segment was used as offset or exposure. Roadway geometry data was therefore obtained from TRIMS/ETRIMS database which has all roadway information. Two fields in the database namely roadway geometrics and roadway characteristics, each with different set of information were used.

The roadway geometry gave information concerning the AADT, number of lanes, speed limit, illumination, land use characteristics and the information on the truck speed limit. The roadway characteristics gave information on median width and shoulder width (both inside and outside width). Such geometric features were matched with the cable barrier information and then excel spreadsheet was used to relate the cable barrier segments with such information. Degree of curve and the differential elevation data were obtained from different TDOT data sources. The elevation, degree of curve (DOC) and grade data saved in text format from TDOT was exported to excel and matched with the study cable barrier segments. The data was provided per travel directions which helped in the calculation of differential elevations. Traffic volume data was taken from the ETRIMS database as well as from the TDOT website in GIS shapefiles. For some segments, the AADT numbers were not available for certain study covered years. In such cases, approximations were made from the AADT in the nearby stations.

To evaluate the variables, individual crashes (1010 fatal and injury) were merged into 577 roadway segments where these occurred based on the crash county, highway, and beginning and ending mileposts (Appendix A). Table 9.1 is the summary statistics of the crashes and the variables evaluated.

Table 9.1: Median Barrier Crash Data Summary Statistics by Segment

Variable	Mean	Std. Dev.	Min	Max
Fatal and Injury Crashes After Cables	0.464	0.881	0	6
Injury Crashes After Cables	0.445	0.856	0	6
Fatal and Injury Crashes Before Cables	1.286	1.660	0	13
Injury Crashes Before Cables	1.182	1.585	0	13
Cable Segment Length	0.525	0.417	0.003	2.819
AADT Before Cables (vpd)	37,669	19,502	3,254	150,121
AADT After Cables (vpd)	37,319	19,017	3,361	147,141
Median Width (ft)	42.965	11.316	10.67	60
Shoulder Width (ft)	4.515	1.798	0	14.67
Cable Offset from End of Travel Lane (ft)	9.413	3.272	1.07	16.96
Degree of Curve	0.914	1.160	0	5.7
Differential Elevation (ft)	58.958	50.020	0	170
Number of Lanes	4.215	0.735	3	8
Posted Speed Limit (mph)			55	70

9.2. Statistical Distributions of Crashes

The impact of cross section features and traffic characteristics to the performance of the cable barriers were evaluated through statistical modeling. The impact of the variables was analyzed using Negative Binomial (NB) models. The NB model followed closely the trend of the observed crash probability distributions for both before and after cable barrier conditions (Figure 9.1 and 9.2).

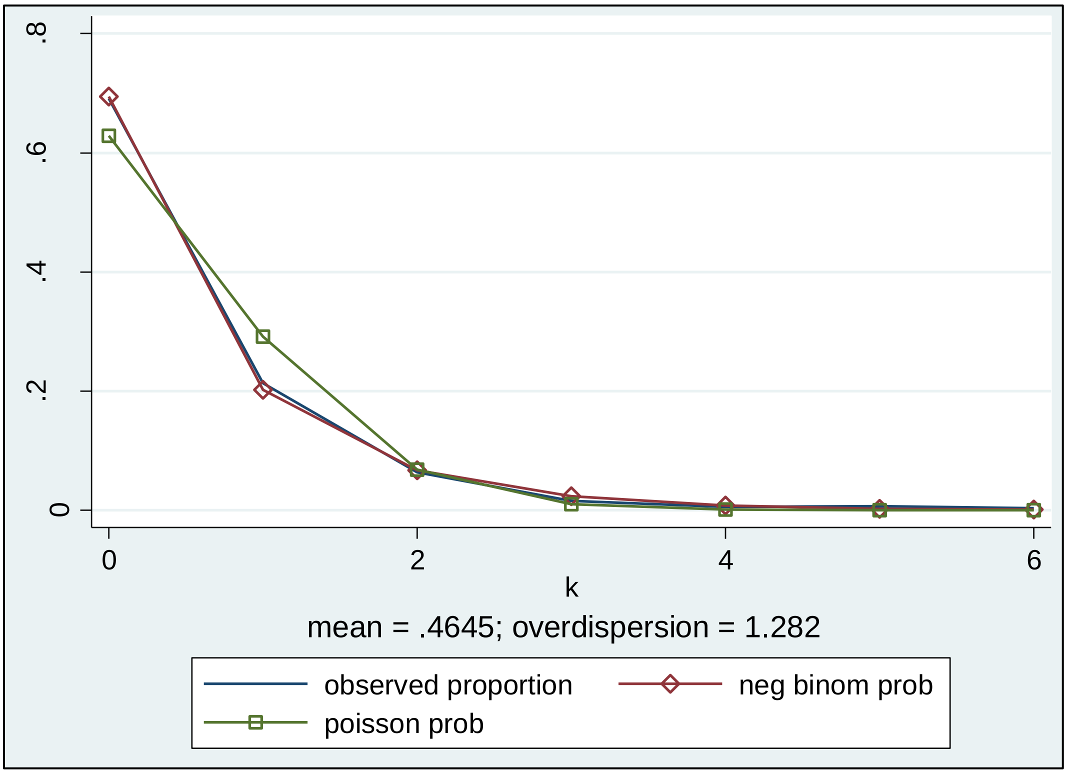


Figure 9.1: Distribution Probability of Total Crashes after Cable Barriers

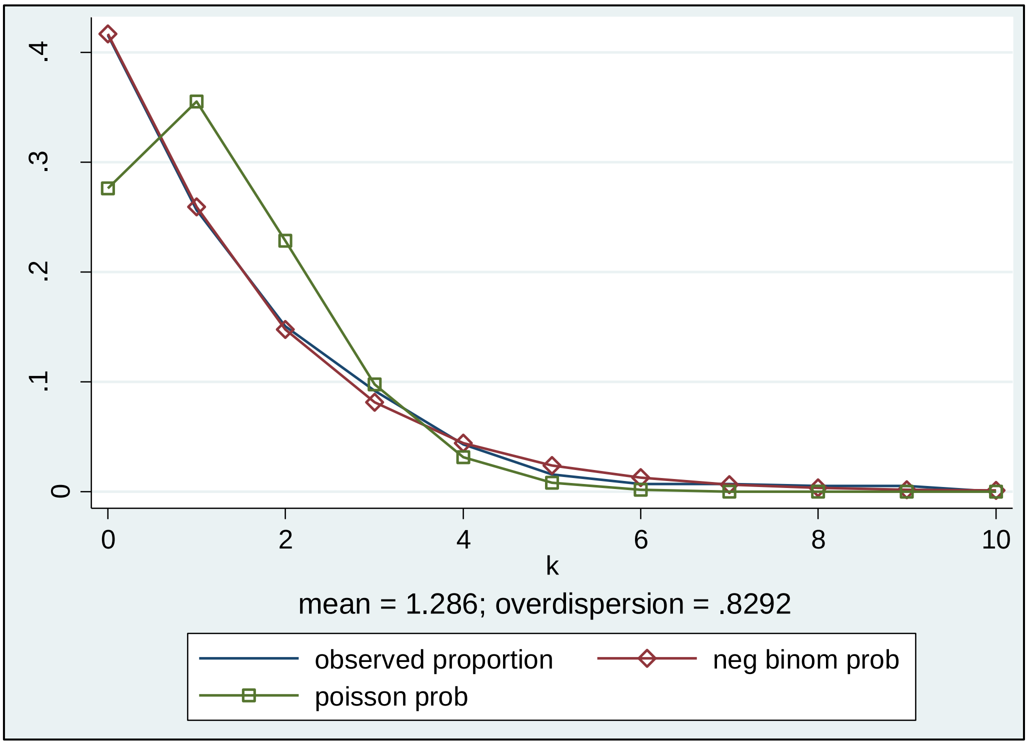


Figure 9.2: Distribution Probability of Total Crashes before Cable Barriers

9.3. Impact Of Geometric Features and Traffic to Crash Frequency

The primary objective of this modeling effort was to evaluate the impact of different variables to median crash frequency. The frequency here is defined as the number of crashes before or after the cable installation. As expected, not all variables were statistically significant in the models; hence the presented results show some significant and non-significant variables. The impact and significant of each of the variable retained in the model to crash frequencies are summarized in Tables 9.2.

Table 9.2: Impact of Traffic and Geometric Features to Cable Performances

All Fatal and Injury Crashes	After Cable Barriers			Before Cable Barriers	
	Coefficient	Z-Statistic		Coefficient	Z-Statistic
Median Width (ft)**	-0.006	-0.63		-0.004	-0.65
Cable Offset (ft)	-0.009	-0.35		—	—
Traffic Volume per Lane	1.4E-05	0.53		1.0E-04	5.55
Inside Shoulder Width (ft)	-0.107	-1.68		-0.015	-0.51
Differential Elevation (ft)	0.004	2.17		0.001	1.11
Degree of the Curve	0.011	0.14		0.043	0.83
60+ MPH Posted Speed Limit	0.564	1.97		0.215	1.23
Constant	-1.493	-2.13		-1.241	-3.21
Cable Segment Length (mile)	Offset			Offset	

***taken as median width minus the cable offset in After Cable Barriers model*

9.3.1. *Impact of Cable Offset and Median Width*

Cable barrier offsets were calculated as the distance from the end of the travel lanes to the location of the cable barriers, thus the variable appears on the after cable barrier model only. Median width appears in the before cable model while median offset which is the median width minus the cable offset appears in the after cable model. As shown in Table 9.2, the wider the cable offset the lower the number of fatal and injury crashes involving vehicles hitting cable barriers (negative coefficient). However, the impact of offset distance is not significant as indicated by low z-statistic. This is also the same for wider medians/median offsets which tend to lower the frequency of median cross-over fatal and injury crashes but are not significant factors. The findings on the impact of median width and cable offset in this study are consistent with that by Miao et al [14] which found that increasing the median barrier offset from the left-edge of the travel way decreases median related crash frequency. Figure 9.3 shows the distribution of the number of crashes (whose first harmful event is indicated as Cable Barrier) with cable offsets. As shown, most of the crashes are peaked between 8 and 10 feet cable offsets (many cable segments falls within that range too).

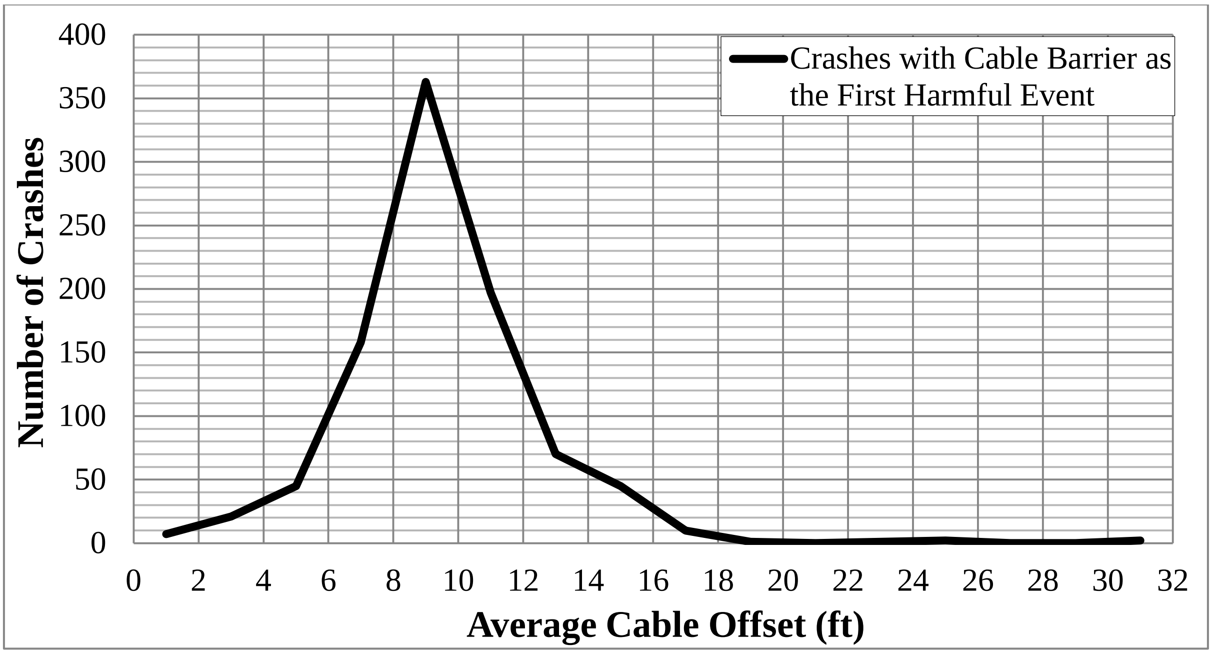


Figure 9.3: Distribution of Crashes by Cable Offsets

9.3.2. *Impact of Inside Shoulder Width*

Segments with wider shoulder widths also experienced fewer number of crashes compared to narrow shoulder width segments as indicated by negative coefficient in the model. In fact inside shoulder width is a significant factor for after cable barrier model. However the impact of the inside shoulders widths is highly correlated with that of cable offset; hence their impact tells the same thing. From the hard copy collision reports, it was observed that a wider inside shoulder width gave drivers the perception that they could carefully maneuver their errant vehicle within the shoulder. Most of drivers that strayed into the inside shoulder either managed to control their vehicles within the shoulder or corrected their errant vehicles into the travel lanes which eventually avoided the crashes.

9.3.3. Impact of Differential Elevation

Differential elevation was calculated by taking the difference between the elevation of the centerline of the opposite travel directions (data was provided by TDOT). Table 9.2 shows high differential elevations increases the likelihood of median related crashes. However, the impact of differential elevation to crash occurrence is significant and much consequential after the cables were installed compared to before cable conditions (high positive coefficients and z-statistic). The cable barriers installed along the segments with high differential elevations experienced many severe crashes compared to low differential elevation segments.

9.3.4. Impact of Degree of the Curve

Curved segments appear to have higher probability of fatal and injury crashes compared to straight segments as in Table 9.2. The degree of the curve have positive coefficient meaning as the sharpness of the curve increases, the likelihood of crashes also increases. Therefore cable segments installed on segments with high degree of curves experienced relatively high number of crashes compared to cable barriers installed along straight segments. However degree of the curve is not significant with respect to fatal and injury crashes as indicated by low z-statistics. Direction of turn of the curve was available and evaluated for the 27 pilot segments only. Both directions of turn of the curves were found to have positive coefficients but with varying magnitudes. The left turning curves were found to have a much higher magnitude of the coefficient implying that they increase the probability of median crashes much more than the right turning curves.

9.3.5. Impact of Traffic Volume per Lane to Safety Performances

As shown in Table 9.2, number of crashes increased with increase in traffic volume (AADT) as indicated with positive coefficients. However the contributing effect of traffic volume to crash occurrence along these segments was significant before the cables compared to after cable barrier situations as shown in the z-statistics of the two models. That means, though segments with high traffic volumes per lane experiences more crashes compared to light traffic segments; the effect is not significant after the cable barriers installation compared to before. Separate analysis however showed high volume segments had fewer fatal and incapacitating injury crashes compared to non-incapacitating and PDO crashes. While congested segments experienced many crashes, severity was moderate compared to low volume segments. This finding is consistent with findings from other researchers such as Ulfarsson and Shankar [15].

9.3.6. *Impact of Speed Limit to Safety Performances*

Cable barriers installed along segments with 60+ mph speed limits (which were 78% of all segments analyzed) experienced more crashes compared to segments with lower speed limits. This is a significant variable for after cable crash occurrences. The finding align with those by Donnel and Mason [16] who found that as speed limit increases the number of median related crashes also increases.

CHAPTER 10: CRASH MODIFICATION FACTORS (CMF)

10.1. CMF Development Overview

Highway Safety Manual [2] provides a guide for Crash Modification Factors (CMFs) development that represents the relative change in the crash frequency due to change in one specific condition. Crash Modification Factors (CMFs) development guide states that the CMFs should be applied only to the specific crash type and severity they represent. Different crash types and severities are associated with different CMFs since a given countermeasure can have a different influence on the different types of crashes. A similar approach was used by Gan et al [17] when developing Crash Reduction Factors (CRFs) for Florida. It is important to develop the CMFs depending on the target crashes of the countermeasure. For the case of cable barriers, the installation targets the median-related crashes especially reduction of cross-median crashes. In this study, head-on collision and sideswipe opposite direction crashes were used in some cases to estimate the effect of the countermeasure through median-related crashes. It is also known that cable barriers usually do not result in the reduction of type of crashes; instead, they can cause increase in total crashes by increase in PDOs. However they have a significant impact on reduction of the severity (fatalities and severe injury) of median-related crashes. This lead into more understanding of the vehicle-cable collisions and how they are influenced with terrain, geometry, installation criteria used, traffic as well as vehicle type.

This study developed Crash Modification Factors (CMFs) for cable barriers that represents the change in safety caused by cable barrier system installation and provides a way of estimating crash reductions through before-and-after analysis. The report titled “Guide to Development of Quality Crash Modification Factors” for Federal Highway Administration (FHWA) [18] is used as a guide. The developed CMFs are able to estimate the change in crashes and injury severity as a result of the cable barrier installations. CMFs were developed for seven categories of crashes; all crashes combines, fatal, fatal and incapacitating combined, fatal and all injuries combined, property damage only (PDO), head-on collision and head-on and sideswipe combined. The CMF is multiplied by the expected crash frequency obtained from segments before barriers to get the number of crashes expected after the application of the cable barriers.

Literature indicates that, if a countermeasure is installed at a site due to its identified history as a high crash location, then the development of CMF based on such sites might overestimate the effectiveness. For that case, application of such CMF to other areas with comparatively lower crash frequency might not be practical. Hauer [19] suggests that a choice of site for analysis should be as diverse as possible. This study involved 577 different segments with different crash histories and site characteristics which reduces the biasness potential.

10.2. CMF Study Design

CMF's can either be developed using the experimental or observational approach. For the experimental approach, sites are selected before application of the cables (both cable group and a comparative group). Many agencies install countermeasures not specifically related to traffic studies, but for the aim of improving safety. In that case, the studies are no longer experimental but observational. In the observational approach, both cable and non-cable segments are selected after installation of the countermeasure. This study focuses on the observational studies that can be done through either before-after studies or cross-sectional studies. In cross-sectional studies, the crash data for the current period is utilized. The crashes at the cable segments are compared to that at the chosen comparative segments during the same study period. However, this method assumes that the comparative and cable segments have the same characteristics. This may not be a practical assumption because of varying conditions between the cable and comparison segments. Regression models can be used to take such variation into account [20]. However, it is applicable when there is not enough historical crash and traffic data [2]. Before-after study approach considers the history of crashes, that is, it considers not just the crashes that have happened in any particular year, but also several years before and after cables. It can be done through Empirical Bayes method or through the use of Comparison group method which is applied in this study.

10.3. The Before-After with a Comparison Group

This approach requires a comparison group in the determination of CMF. Ezra Hauer proposed a method to identify the comparison group by performing comparability tests [19]. These are done for the before period through a comparison of the time series of target crashes for a cable group and a candidate comparison group. The suggested approach is to compute the odds ratio for each of the before-after pair in the time series before cables. From this, the sample mean and standard errors are computed. Sum of the observed crashes for both before and after period are respectively computed. The next step is to calculate the expected number of crashes that would have happened at the cable segment if no cable was done. The variance is then calculated and CMF computed. The quality of the CMF developed depends on factors such as type of crash considered, injury severity and development methodology [19].

10.4. CMF Development Process

The CMF development utilized the method of before-after observational studies with comparison group. A group of segments qualifies as the comparison group if the ratio between the expected crashes of the "after" period to that of "before" period is similar to ratio of the same in the cable segments group, had the cables not been installed. The comparison group method used in this study contains more number of comparison segments than cable segments which has been proved to increase accuracy in determination of the CMF. The choice of comparative segments followed before-after comparative group method which is proposed in the CMF development guide [18]. The method is clearly explained by Hauer [19] in his book titled "Observational Before-After Studies in Road Safety". The process starts with the choice of possible comparative segments before selecting the segments to be used as comparison group.

10.4.1. Step 1: Choice of Possible Comparative Segments

The first step involves selecting the roadway segments from Tennessee Roadway System that meet median width, segment length and traffic volume criteria. A segment was chosen to be a possible comparative segment if it met all of the following criteria:

- The median width is equal to the width of the cable barrier segment plus or minus 10 ft.
- The segment length is equal to the segment of the cable barrier segment plus or minus 20 ft.
- The AADT is equal to that of the cable barrier segment plus or minus 1000 vehicles per day.

A total of 4,047 segments met the above criteria. Each segment was assigned an identifier which reflected its respective County and Route. Such location identifier is important to make sure that comparison segments are at similar locality to the existing cable barrier segment (cable segments).

10.4.2. Step 2: Preparation of Possible Comparison and Cable Groups

This step began with the assignment of group numbers to the each existing cable barrier segment (treatment segment) and possible comparative segment. The group numbers were set according to the classification of the median width and the AADT. This ensured that the cable segments are grouped together with the comparison segments which have comparable AADT and median width, Table 10.1. Each segment (comparative and cable barrier segment) was assigned a group number depending on the characteristic median width and AADT as shown in Table 10.1. For example, the segment with 45ft median width and 45,000 AADT was assigned a group number 20. The segments with same group numbers (similar characteristics) and location were grouped together using the above-mentioned group numbers and location identifiers. The segments with the same group number falling in the same route and counties were grouped together to form cable groups and their corresponding comparative. This process was done through comparison of developed identifiers of location and of characteristics.

The two ID's are used to ensure that the segments grouped together are similar in median width and AADT (GroupID), and fall into the same route and county (ID2). As an explanation of the steps used, first the comparative segments (which are many) with their group numbers and IDs were arranged on the left most columns and then separated in groups of similar segments. Next, the cable barrier segments (cable segments) were added towards the right of the table ensuring that the segments belonging to the same group lies side by side. Excel functions were used to attach all the segments to the corresponding comparative segments and a total of 527 cable barrier segments were effectively assigned to their corresponding grouping segments. Some group segments in the comparative side which didn't have at least one similar cable segment were subsequently removed.

TABLE 10.1 Comparison Segments Classification Table for AADT and Median Width

	AADT						
Median Width (ft)	0-5,000	5,001-10,000	10,001-20,000	20,001-30,000	30001-40,000	40,001-50,000	>=50,000
0-30.01	1	2	3	4	5	6	7
30.00-40.01	8	9	10	11	12	13	14
40.00-50.01	15	16	17	18	19	20	21
50.00-60.01	22	23	24	25	26	27	28
60.00-70.01	29	30	31	32	33	34	35
70.00-80.01	36	37	38	39	40	41	42
>=80	43	44	45	46	47	48	49

10.4.3. Step 3: Determination of Odds ratio

The next step was to find the odds ratios associated with crash frequency for selected years in the before period. The odds ratio tests the similarity of the trends of traffic for both the cable group and comparison groups for the period before installations of the cable barriers. Most of the cable barriers were installed from 2009 to 2010 which are mainly adopted in this report; the other segments installed prior to 2009 were left out to give a room of four years before the cables ranging from 2005 to 2008. The crash data within the study range amounted to the total of 10,122 crashes for cable barrier segments and 78,214 crashes for the comparison segments. The total crash for each groups developed was determined for the calculation of odds ratio [19].

$$Sample\ odds\ ratio = \frac{(Treatment_{before}Comparison_{after})/(Treatment_{after}Comparison_{before})}{1+\frac{1}{Treatment_{after}}+\frac{1}{Comparison_{before}}} \qquad (10.1)$$

Where

$Cable_{before}$ = total crashes for the cable group in year *i*

$Cable_{after}$ = total crashes for the cable group in year *j*

$Comparison_{before}$ = total crashes for the comparison group in year *i*

$Comparison_{after}$ = total crashes for the comparison group in year *j*

For the duration of n time intervals in the before period, n-1 odds ratios and their mean and standard error are determined. If the value is statistically equal to 1 then there is no significant difference between the crash frequencies for the said period and the group of segments qualify as the cable group.

The odds ratios were then calculated following the formula presented in equation 10.1. However, there was a problem with division by zero for some groups. This is due to the fact that, for some segments, there were no observed crashes in one or all of the three years. To overcome this problem, a value of one was added to each segment such that, each group has either 1 or more crashes. Olson [21] used the same zero correction approach when determining the safety effectiveness of red light installation where he added a single crash to each of before-after periods to all intersections with zero crashes. The same concept is used in Bayesian statistics analysis to avoid zero probabilities.

10.4.4. Step 4: Choice of Suitable Comparative and Cable groups

The last step was to choose the groups that will be used in the determination of the Crash Modification Factors. The odds ratio has to be close to one for the comparative group to be selected [18]. This implies a comparable time series variation of crash frequencies for the variables. A range of odds ratio chosen were from 0.75 to 1.25. For this criteria a total of 83 groups were chosen, making a total of 1116 segments for comparison segments and 341 segments for the cable barrier segments. The variance of the odds ratio was also determined that helped in determining the range of possible values of odds ratio at 95% confidence level. Further review of the selected groups was done to ensure that the cable barrier segments for each group had the same completion date to avoid some possible issues in the counts of the crashes for the before and after periods of the comparison segments. This is because the comparison segments don’t have any particular completion date but rather follow that of the cable barrier segments. If there existed two or more different completion dates in the same group, it becomes difficult to know which date to be adopted for before-after count of crashes for the comparative segments. After this review, the candidate segments for the cable barrier segment groups were reduced to 316 segments. The before and after crashes for both the cable barrier segments and comparative groups with different crash types is as shown in Table 10.2.

TABLE 10.2 Before-after crashes for comparison and cable barrier segments

Segments	Fatal & Incapacitating Injury		Non-incapacitating Injury		Property Damage Only (PDO)	
	Before	After	Before	After	Before	After
Cable Barrier Segments	55	17	979	857	2487	2562
Comparison	134	86	2908	2300	7361	6421

10.5. Determination of the Crash Modification factors

After obtaining the comparison segments, the Crash Modification Factors (CMFs) were developed. The crash counts for the after period of the comparison and cable barrier segments were then added and the CMFs calculated. The calculation of the CMFs uses the crashes for the cable barrier segments and comparison group for both the before and after periods. Pair of before-after crashes for both comparison and the cable groups was determined. The CMFs and the corresponding variance and hence confidence intervals were then determined. A series of equations (2 to 5) taken from the CMF Development Guide ([18] [19]) was utilized. Equations 2 and 3 represent the determination of expected number of crashes for the cable barrier group. The expected number of crashes for cable barrier segments group refers to the number of crashes that could have happened had the barriers not installed. The observed crash frequencies are used to determine the expected crashes which are then used to determine the CMF. Equations 10.4 and 10.5 calculate the CMF and the corresponding variance:

$$N_{expected,T,A} = N_{observed,TB}(N_{observed,C,A}/N_{observed,C,B}) \qquad (10.2)$$

$$Var(N_{expected,T,A}) = {N_{expected,T,A}}^2(1/N_{observed,T,B} + 1/N_{observed,CB} + 1/N_{observed,C,A}) \qquad (10.3)$$

$$CMF = (N_{observed,T,A}/N_{expected,T,A})/(1 + (Var(N_{expected,T,A})/{N_{expected,T,A}}^2)) \qquad (10.4)$$

$$Variance(CMF) = \frac{CMF^2[(1/N_{observed,T,A}) + (Var(N_{expected,T,A})/{N_{expected,T,A}}^2)]}{[1 + Var(N_{expected,T,A})/{N_{expected,T,A}}^2]^2} \qquad (10.5)$$

Where

Nobserved,T,B = the observed number of crashes in the before period for the cable barriers group

Nobserved,T,A = the observed number of crashes in the after period for the cable barriers group

Nobserved,C,B = the observed number of crashes in the before period in the comparison group

Nobserved,C,A = the observed number of crashes in the after period in the comparison group

Nexpected,T,A = the expected number of crashes that would have happened at the cable segment had the cable not applied

Var(Nexpected,T,A) = The variance of the expected number of crashes to the cable segment

CMF = Crash Modification Factors

Variance(CMF) = Variance of the obtained Crash Modification factor

The CMF clearinghouse website [22] provides a guide on how to provide and document the CMFs. With this, the quality of the CMFs vary depending on how they were produced. In this study, the CMFs were produced following different categorization of crash types and severities to get the feeling on how the cable barriers influence different types of crashes.

10.6. Crash Modification Factors using Median Related Crashes

The CMFs calculated using median-related crashes are shown Table 10.3. A crash was considered median related if it met the following criteria [12]: the vehicle's first action ("first harmful event" or the initial action of the crash) was that it entered the median, if the "most harmful event" was located in the median or opposite travel lanes and if the vehicle sustained significant damage once it entered the median although this act may not have been the "first harmful event." This criterion was used to determine whether the presence/absence (after/before installation) of the cable barrier had an impact on the crash severity. The CMF numbers in Table 10.3 shows the cable barriers are highly effectiveness in reducing severe crashes such as fatal and incapacitating crashes. With a CMF of 0.04, the cable barrier reduced median crossover fatal crashes by 96% (e.g. reduction = 1-0.04 =0.96) while fatal and all injury crashes were reduced by 86%. PDO crashes were not evaluated for screen crashes.

Table 10.3 Crash Modification Factors with Median Related Crashes

Severity	CMF
Fatal	0.04
Incapacitating Injury	0.09
Fatal and Incapacitating	0.07
Non-Incapacitating Injury	0.15
Incapacitating and Non-Incapacitating	0.12
Fatal and All Injury	0.14

CHAPTER 11: CONCLUSIONS AND RECOMMENDATIONS

11.1. Overview

This report summarizes some key findings of safety effectiveness evaluation of the median cable barriers in Tennessee. Presented are findings from descriptive statistics of the crash reduction after the cables compared to before period as well as safety effectiveness percentages calculated through Empirical Bayes (EB) approach using Highway Safety Manual (HSM) procedures. The study findings are important in helping TDOT to determine which highway locations, roadway and traffic factors played role in improving or worsening performance of the median cable barriers in the state. The study also highlights which cable types, cable segments, TDOT regions, counties and routes met or didn't meet the safety performance thresholds as expected by TDOT officials. Segments, routes, TDOT regions and counties that showed increase in crashes or negative effectiveness are compared to those which showed reduced crashes or positive effectiveness in terms of location, installation specifications, materials, designs, geometry, traffic and other related factors. The findings allow TDOT to determine important factors to consider when expanding installation of the cable systems in the future.

11.2. Analyzed Median Cable Barrier Segments and Crash Data

The following are the statistics of cable barrier segments analyzed;

- A total of 577 median cable barrier segments from 48 counties and 32 different routes covering approximately 302 miles in length and about 0.524 miles average length per segment.
- The earliest cable installation was completed on 3/15/2006 and the latest completed on 12/31/2010.
- About 12,037 crashes reviewed three years before and after the cables.
- To identify median related crashes for before cables period, crash hard copies were reviewed utilizing collision diagrams and the narratives.
- Median related crashes for after cables period were identified using "cable barrier" as the first and most harmful events in the crash database.
- About 1007 crashes were found to be median related with 742 occurring before cables period and 268 after the cables were installed.
- Ranking of the cable segments based on crash frequency and crash rate was established whereby cable segments in Madison (I-40), Sullivan (I-26), Shelby (SR 385 and I-40) and Cumberland (I-40) counties dominated the top 50 segments with highest number of crashes. Some other segments which topped the ranking included those in Campbell (I-75), Putnam (I-40), Anderson (I-75), Marion (I-24), Sumner (I-65), Cocke (I-40), Washington (I-26), Williamson (I-65), and Smith (I-40) counties among others.

11.3. Findings from Before and After Crash Reductions

The following are findings from the descriptive and comparative analysis;

- Installation of median cable barriers substantially reduced fatal and injury crashes, and the number of people killed or injured.
- Median related fatal crashes were reduced from 60 before cables to just 11 crashes after cables (an 82% reduction) as a result of median cable barriers.
- Incapacitating injury crashes were reduced from 112 before cables to 27 crashes after cables (a 76% reduction).
- Non-Incapacitating crashes were reduced from 570 before cables to 230 crashes after cables (a 60% reduction).
- Overall, fatal and all injury crashes were reduced by 64% as a result of median cable barriers installation.
- The number of segments which had at least one fatal crash before was reduced from 56 to 10 after cable installation, an improvement of 82%.
- PDO crashes increased after the cable barriers compared to before period. This may be due to collisions involving vehicles and the barriers counted as PDO which were not there before cables were installed.
- Crashes involving two or more vehicles were reduced by 92% with the installation of median cable barriers.

11.4. Findings from Empirical Bayes Safety Effectiveness Evaluation

The following are the statewide median cable barriers Safety Effectiveness:

- Safety effectiveness of the cable barriers for fatal crashes only is 94%.
- Safety effectiveness of the cable barriers for the fatal and incapacitating injury crashes combined is 92%
- Safety effectiveness of the cable barriers for fatal and all injury crashes combined is 85%
- Safety effectiveness for incapacitating injury crashes only is 92%
- Safety effectiveness non-incapacitating injury crashes only is 84%
- Safety effectiveness of the cable barriers for incapacitating and non-incapacitating injury crashes combined is 85%
- The Safety effectiveness for fatal crashes only averaged per TDOT regions are above 90% in all regions while those for fatal and injury crashes combined are above 80% in all regions.
- Only one county out of forty eight resulted with negative averaged effectiveness, all remaining forty seven counties resulted with averaged positive effectiveness for fatal and all injury crash categories.
- The averaged safety effectiveness per individual routes showed thirty one out of thirty two highways resulted with positive effectiveness except SR-155 which resulted with negative for fatal crashes.

11.5. Findings from Impact of Roadway Features

The study evaluated the impact of roadway cross-sectional and geometric features, traffic characteristics and median cable barrier placement to the frequency of median related crashes through statistical modeling. Apart from number of lanes, inside shoulder width, median width, AADT, and posted speed limit, the modeling included cable offset, horizontal curve data and differential elevation. The following are the overall impact of these variables to median cable barrier performances:

- Cable barrier segments located further from the travel lanes resulted in less number of crashes compared to those which were closer to the travel lanes.
- Segments with high differential elevations between two travel directions significantly resulted with more crashes compared to level or small differences.
- Segments with sharper curves resulted with more crashes compared to straight and gentle curve segments.
- The wider the median and inside shoulders, the lower the crash frequency compared to segments with narrow median and inside shoulder widths.
- Segments with a posted speed limit of 60+mph experienced more crashes compared to low posted speed segments.
- Segments with high traffic volumes experienced more crashes compared to low volume segments.

11.6. Developed Crash Modification Factors (CMFs)

Crash Modification Factors (CMF) is developed as a quantitative measure of reduction or increase in number of crashes due to installation of a countermeasure. CMF with value greater than one implies that there is an increase in the number of crashes due to the installation of such countermeasure. Using median cross-over related crashes, the CMF for fatal crashes was found to be 0.04 translating that the fatal crash reduction is 96% with cable barrier installation. Other noticeable developed CMFs include 0.07 for fatal and incapacitating crashes combined and 0.14 for fatal and all injuries combined. These CMFs are in line with some of the findings from other states which found relatively similar numbers for median cable barriers [22]. For instance, Villwock et al [23] found the CMF of 0.09 for cross median, frontal and opposing direction sideswipe and head on. Cooner et al [24] found the CMF of 0.07 for fatal crashes and 0 for serious injury while Elvik et al. [25] found a CMF of 0 for the same type of crashes (fatal). Furthermore, the crash reduction factors extracted from these CMFs are within the range of the percentage safety performance effectiveness found in this same study and presented to TDOT [19]. The developed CMFs responds to the intended benefits of the median cable barriers to prevent cross-median crashes which occurs when a vehicle leaves its travel way enters or crosses the median dividing the highway directional lanes and collides with vehicles in the opposite direction.

REFERENCES

[1] Tennessee Executive Leadership Academy Class of 2101 Cable Barrier Study Team (TELA), "Cable Barrier Rail Pilot Projects," Tennessee Department of Transportation (TDOT), 2011.

[2] AASHTO, Highway Safety Manual, Washington, DC: AASHTO, 2010.

[3] Washington Department of Transportation, "The evolution of WSDOT's use of cable median barriers and current performance data on serious crashes averted," [Online]. Available: http://www.wsdot.wa.gov/publications/fulltext/cablemedianbarrier/06_Chap3_Reduced.pdf. [Accessed 17 February 2015].

[4] J. Miller, R. Khandelwal and N. Garber, "Safety Impacts of Photo-Red Enforcement at Suburban Signalized Intersections and Empirical Bayes Approach," *Transportation Research Record,* vol. 1969, pp. 27-34, 2006.

[5] AASHTO, Roadside Design Guide, 4th ed., Washington DC, 2011.

[6] G. Davis and J. Pei, "Bayesian Reconstruction of Median-Crossing Crashes and Potential Effectiveness of Cable Barriers," *Transportation Research Record,* vol. 1908, pp. 141-147, 2005.

[7] B. Persaud, B. Craig and L. Ravibhim, "Comparison of Empirical Bayes and Full Bayes approaches for before-after safety evaluations," *Accident Analysis and Prevention,* pp. 38-43, 2009.

[8] E. Hauer, D. Harwood, F. Council and M. Griffith, "Estimating Safety by the Empirical Bayes Method, a Tutorial," *Transportation Research Record,* vol. 1784, 2002.

[9] California Department of Transportation, "Traffic Safety Systems," in *Traffic Manual*, California, 2012, pp. 7-35 to 7-48.

[10] Florence & Hutcheson, "Cable Median Barrier Summary Report," Tennessee Department of Transportation, 2010.

[11] Tennessee Department of Transportation, "Traffic History," 2014. [Online]. Available: http://www.tdot.state.tn.us/traffichistory. [Accessed 3 March 2015].

[12] D. Chimba, D. Emaasit, S. Allen, B. Hurst and M. Nelson, "Safety Effectiveness Evaluation of the Cable Rail Systems in Tennessee," in *TRB 2013 Annual Meeting*, Washington, DC, 2013.

[13] Stata Software, "STATA," www.stata.com.

[14] S.-P. Miao, R. Bligh and D. Lord, "Roadside Safety Design: Developing Guidlines for Median Barrier Installation: Benefit-Cost Analysis with Texas Data," *Transportation Research Record,* vol. 1904, 2005.

[15] U. Gudmundur and V. Shankar, "Accident Count Model Based on Multiyear Cross-Sectional Roadway Data with Serial Correlation," *Transportation Research Record (TRR),* vol. 1840, 2003.

[16] E. Donnell and J. Mason, "Methodology to Develop Median Barrier Warrant Criteria," *Journal of Transportation Engineering,* vol. 132, no. 4, pp. 269-281, 2006.

[17] A. Gan, J. Shen and A. Rodriguez, "Update of Florida Crash Reduction Factors and Countermeasures to improve the Development of District Safety Improvement Projects," Florida Department of Transportation, Tallahassee, FL, 2005.

[18] F. Gross, B. Persaud and C. Lyon, "A Guide to Developing Quality Crash Modification Factors," Federal Highway Administration (FHWA), Washington, DC, 2010.

[19] E. Hauer, Observational Before-After Studies in Road Safety, Oxford, UK: Pegamon Press, 1997.

[20] R. Elvik, "Assessing causality in multivariate accident models," *Accident Analysis and Prevention,* no. 43, p. 253–264, 2011.

[21] C. S. Olson, "Safety Effectiveness of Red Light Treatments for Red Light Running," Portland State University;Dissertations and Theses, Portland, OR, 2012.

[22] FHWA, "Crash Modification Factors ClearingHouse," [Online]. Available: www.cmfclearinghouse.org/. [Accessed 15 8 2017].

[23] N. Villwock, N. Blond and A. Tarko, "Safety Impact of Cable Barriers on Rural Interstates," in *Transportation Research Board*, Washington DC, 2009.

[24] S. A. Cooner, Y. K. Rathod, D. C. Alberson, R. P. Bligh, S. E. Ranft and D. Sun, "Performance Evaluation Of Cable Median Barrier Systems In Texas," Texas Department of Transportation, Austin, Texas, 2009.

[25] R. Elvik, A. Hoye, T. Vaa and M. Sorensen, The Handbook of Road Safety Measures, Oxford University, 2004.

APPENDIX 1

Ranking of the Cable Barrier Segments Based on Vehicle-Cable Barrier Collision Frequency

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
1	SHE34	Shelby	SR385	10.49	12.377	1.887	38554	0	1	5	22	28	1.054
2	CAM07	Campbell	I0075	2.802	4.851	2.049	31993	0	0	6	16	22	0.919
3	SHE13	Shelby	I0040	23.905	25.831	1.926	51535	0	1	7	14	22	0.607
4	SHE30	Shelby	SR385	6.863	8.256	1.393	36626	0	0	2	19	21	1.128
5	CUM13	Cumberland	I0040	30.324	32.031	1.707	30576	1	0	1	18	20	1.050
6	PUT04	Putnam	I0040	8.781	9.573	0.792	37242	0	0	5	15	20	1.858
7	SUL09	Sullivan	I0026	6.347	7.064	0.717	38594	0	1	1	16	18	1.782
8	SUL11	Sullivan	I0026	7.133	7.665	0.532	38594	0	0	3	13	16	2.135
9	AND06	Anderson	I0075	3.148	3.87	0.722	39200	0	0	3	12	15	1.452
10	MAD07	Madison	I0040	6.572	7.516	0.944	39350	0	0	0	15	15	1.106
11	MAD26	Madison	I0040	19.783	21.146	1.363	40005	0	0	1	14	15	0.754
12	SUL39	Sullivan	I0026	5.64	6.18	0.54	41411	0	0	3	12	15	1.838
13	WAS03	Washington	I0026	1.459	2.304	0.845	41492	0	0	0	15	15	1.172
14	MAR16	Marion	I0024	30.365	31.061	0.696	43698	0	0	0	14	14	1.261
15	WILL04	Williamson	I0065	5.935	8.754	2.819	61896	0	0	5	9	14	0.220
16	CUM03	Cumberland	I0040	12.401	13.228	0.827	30298	0	0	3	10	13	1.421
17	HAY04	Haywood	I0040	6.119	7.131	1.012	35509	0	0	2	11	13	0.991
18	MAD04	Madison	I0040	2.946	4.783	1.837	39350	0	0	0	13	13	0.493
19	SHE11	Shelby	I0040	22.517	23.126	0.609	56640	0	1	3	9	13	1.033
20	SUL12	Sullivan	I0026	7.227	8.156	0.929	38594	0	0	1	12	13	0.993
21	SUM02	Sumner	I0065	1.061	2.451	1.39	58056	0	0	1	12	13	0.441
22	COC15	Cocke	I0040	4.336	5.5	1.164	24514	0	0	1	11	12	1.152
23	WAS01	Washington	I0026	0.135	1.028	0.893	44976	0	0	2	10	12	0.819
24	WAS08	Washington	I0026	4.234	4.742	0.508	54868	0	0	2	10	12	1.180
25	SHE04	Shelby	I0040	7.554	8.14	0.586	90534	0	0	2	9	11	0.568
26	SMI03	Smith	I0040	1.663	4.117	2.454	44290	0	0	2	9	11	0.277
27	CUM07	Cumberland	I0040	25.033	25.827	0.794	30576	0	0	1	9	10	1.129
28	HAY05	Haywood	I0040	7.163	8.854	1.691	35850	0	0	1	9	10	0.452
29	MAD08	Madison	I0040	7.548	8.305	0.757	39662	0	0	1	9	10	0.913
30	MAD14	Madison	I0040	12.06	13.262	1.202	50150	0	0	1	9	10	0.454
31	MAD16	Madison	I0040	13.316	14.688	1.372	50624	0	0	3	7	10	0.394
32	PUT22	Putnam	I0040	35.799	36.316	0.517	23783	0	0	0	10	10	2.228
33	SUL03	Sullivan	I0026	1.534	2.026	0.492	24366	2	0	1	7	10	2.285
34	SUL07	Sullivan	I0026	4.429	5.386	0.957	41411	0	1	2	7	10	0.691
35	WAS06	Washington	I0026	3.227	3.521	0.294	54868	1	0	1	8	10	1.698
36	WILL03	Williamson	I0065	4.87	5.83	0.96	61896	0	0	5	5	10	0.461
37	COC05	Cocke	I0040	3.072	4.336	1.264	27746	0	1	2	6	9	0.703
38	HAY08	Haywood	I0040	15.827	16.884	1.057	35415	0	0	0	9	9	0.659
39	MAD01	Madison	I0040	0.004	1.133	1.129	39396	0	0	0	9	9	0.554
40	MAD02	Madison	I0040	1.178	2.002	0.824	39396	0	0	1	8	9	0.760
41	MAD12	Madison	I0040	10.61	11.08	0.47	44920	0	0	1	8	9	1.168
42	MAD20	Madison	I0040	16.037	16.49	0.453	54527	0	0	1	8	9	0.998
43	SHE12	Shelby	I0040	23.215	23.861	0.646	56640	0	1	1	7	9	0.674
44	SMI02	Smith	I0040	1.088	1.729	0.641	44290	0	0	0	9	9	0.869
45	SMI05	Smith	I0040	5.09	6.015	0.925	35069	0	1	0	8	9	0.760
46	COC03	Cocke	I0040	0.784	1.685	0.901	26894	0	0	3	5	8	0.905
47	CUM02	Cumberland	I0040	2.938	3.912	0.974	23783	0	0	1	7	8	0.946
48	LOU03	Loudon	I0040	0.787	2.015	1.228	40882	0	0	0	8	8	0.437
49	MAD06	Madison	I0040	5.603	6.555	0.952	39350	0	1	1	6	8	0.585
50	MAD10	Madison	I0040	8.765	9.275	0.51	44943	0	0	0	8	8	0.956
51	MAD13	Madison	I0040	11.235	11.913	0.678	44920	0	0	2	6	8	0.720
52	MAD19	Madison	I0040	14.786	15.967	1.181	55064	0	0	0	8	8	0.337
53	MAR10	Marion	I0024	28.312	28.751	0.439	43698	0	0	1	7	8	1.143
54	MAR14	Marion	I0024	29.651	30.142	0.491	43698	0	0	0	8	8	1.022
55	PUT09	Putnam	I0040	22.589	22.841	0.252	33595	0	0	1	7	8	2.589
56	ROA11	Roane	I0040	16.323	17.249	0.926	40865	0	0	2	6	8	0.579
57	SHE28	Shelby	SR385	5.28	6.011	0.731	57036	0	0	1	7	8	0.526
58	SUL04	Sullivan	I0026	2.036	3.481	1.445	24366	0	1	1	6	8	0.622
59	SUL22	Sullivan	I0081	3.321	4.973	1.652	34102	0	0	3	5	8	0.389
60	SUL26	Sullivan	I0081	11.225	12.368	1.143	29427	0	0	2	6	8	0.652
61	WAS24	Washington	I0026	13.362	13.761	0.399	40925	0	0	1	7	8	1.342
62	CAM10	Campbell	I0075	13.9	14.58	0.68	25383	0	0	1	6	7	1.111
63	HAMB04	Hamblen	I0081	0.927	1.89	0.963	26915	0	0	3	4	7	0.740
64	HAY01	Haywood	I0040	0.822	1.984	1.162	25977	0	0	0	7	7	0.635
65	HAY03	Haywood	I0040	5.853	6.072	0.219	35509	0	0	1	6	7	2.466
66	HEN04	Henderson	I0040	17.999	20.329	2.33	35236	0	0	0	7	7	0.234
67	JEF07	Jefferson	I0040	16.84	18.838	1.998	26894	0	0	2	5	7	0.357
68	LOU07	Loudon	I0040	3.932	4.177	0.245	40882	0	0	2	5	7	1.915

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
69	MAD24	Madison	I0040	17.605	18.783	1.178	44296	0	0	1	6	7	0.368
70	MAR12	Marion	I0024	29.206	29.597	0.391	43698	0	0	0	7	7	1.122
71	PUT23	Putnam	I0040	36.337	36.833	0.496	23783	0	0	2	5	7	1.626
72	SHE08	Shelby	I0040	8.646	9.26	0.614	89852	0	1	1	5	7	0.348
73	SHE29	Shelby	SR385	6.183	6.801	0.618	39467	0	0	1	6	7	0.786
74	SHE31	Shelby	SR385	8.349	9.461	1.112	36626	0	0	1	6	7	0.471
75	SHE33	Shelby	SR385	9.91	10.407	0.497	38554	0	0	0	7	7	1.001
76	SMI01	Smith	I0040	0	1.015	1.015	44290	0	0	0	7	7	0.427
77	SUL02	Sullivan	I0026	1.076	1.59	0.514	24366	0	0	1	6	7	1.531
78	SUL06	Sullivan	I0026	4.344	4.579	0.235	41411	0	0	2	5	7	1.971
79	WILS03	Wilson	I0040	6.29	7.388	1.098	69369	0	0	1	6	7	0.252
80	WILS11	Wilson	I0040	15.141	16.392	1.251	54563	0	0	1	6	7	0.281
81	BRA01	Bradley	I0075	3.828	4.81	0.982	59720	0	0	0	6	6	0.280
82	COC02	Cocke	I0040	0.243	0.712	0.469	26894	0	0	2	4	6	1.303
83	COF03	Coffee	I0024	13.417	14.033	0.616	38995	0	0	3	3	6	0.684
84	GRU01	Grundy	I0024	3.007	3.283	0.276	32665	1	1	2	2	6	1.823
85	HAMI11	Hamilton	I0075	14.254	14.467	0.213	59720	0	0	1	5	6	1.292
86	HAMI17	Hamilton	SR111	4.787	6.406	1.619	9998	0	0	1	5	6	1.016
87	HAY07	Haywood	I0040	9.01	10.198	1.188	35850	0	0	0	6	6	0.386
88	MAD23	Madison	I0040	17.09	17.559	0.469	54527	0	0	1	5	6	0.643
89	OBI01	Obion	SR003	22.653	23.81	1.157	10849	1	0	3	2	6	1.310
90	ROA07	Roane	I0040	12.369	12.951	0.582	45822	0	0	1	5	6	0.616
91	ROA09	Roane	I0040	13.95	15.156	1.206	45822	0	0	1	5	6	0.297
92	ROA20	Roane	I0040	21.407	22.265	0.858	41648	0	0	1	5	6	0.460
93	SHE35	Shelby	SR385	12.513	12.835	0.322	22352	0	0	1	5	6	2.284
94	SHE36	Shelby	SR385	12.773	13.256	0.483	22352	0	1	1	4	6	1.523
95	SHE56	Shelby	SR385	14.66	15.25	0.59	10326	0	0	1	5	6	2.698
96	SMI04	Smith	I0040	4.151	5.033	0.882	35069	0	0	1	5	6	0.531
97	SMI08	Smith	I0040	7.565	8.027	0.462	35069	0	0	1	5	6	1.015
98	SMI12	Smith	I0040	13.712	14.194	0.482	32868	0	0	1	5	6	1.038
99	SUL08	Sullivan	I0026	6.181	6.281	0.1	41411	0	0	0	6	6	3.970
100	SUM11	Sumner	SR386	7.88	9.289	1.409	40776	0	0	2	4	6	0.286
101	SUM13	Sumner	SR386	9.672	10.869	1.197	40776	0	0	2	4	6	0.337
102	UNI06	Unicoi	I0026	3.173	3.828	0.655	19839	0	0	2	4	6	1.265
103	UNI12	Unicoi	I0026	6.349	7.34	0.991	20352	0	0	1	5	6	0.815
104	WAS05	Washington	I0026	2.469	3.165	0.696	41492	0	0	0	6	6	0.569
105	WAS09	Washington	I0026	4.798	5.026	0.228	54868	0	0	2	4	6	1.314
106	WILS02	Wilson	I0040	5.045	6.233	1.188	69435	0	0	1	5	6	0.199
107	BRA03	Bradley	I0075	10.047	11.053	1.006	46431	0	0	0	5	5	0.293
108	CHE01	Cheatham	I0040	2.714	3.503	0.789	44998	0	0	1	4	5	0.386
109	COC16	Cocke	I0040	5.57	6.168	0.63	24514	0	0	1	4	5	0.887
110	DIC02	Dickson	I0040	7.25	8.44	1.19	30521	0	0	0	5	5	0.377
111	DIC07	Dickson	I0040	17.594	17.824	0.23	35987	0	1	1	3	5	1.655
112	GIL05	Giles	I0065	16.082	16.928	0.846	17060	0	0	1	4	5	0.949
113	GIL07	Giles	I0065	17.303	18.225	0.922	17060	0	1	1	3	5	0.871
114	HAMB03	Hamblen	I0081	0.42	0.843	0.423	26915	0	0	1	4	5	1.203
115	HAMI12	Hamilton	SR029	2.526	3.263	0.737	27322	0	1	0	4	5	0.680
116	JEF03	Jefferson	I0040	13.469	13.987	0.518	35516	0	1	1	3	5	0.745
117	KNO15	Knox	I0140	5.55	6.759	1.209	43786	0	0	0	5	5	0.259
118	MAD11	Madison	I0040	9.271	9.955	0.684	44943	0	0	0	5	5	0.446
119	MAR13	Marion	I0024	29.291	29.685	0.394	43698	0	0	2	3	5	0.796
120	MAR18	Marion	I0024	31.209	31.584	0.375	43698	0	0	2	3	5	0.836
121	PUT02	Putnam	I0040	6.986	8.493	1.507	36966	0	0	0	5	5	0.246
122	PUT06	Putnam	I0040	18.988	19.44	0.452	41556	0	0	1	4	5	0.729
123	PUT19	Putnam	I0040	32.615	33.11	0.495	33595	0	0	1	4	5	0.824
124	ROA10	Roane	I0040	15.238	16.19	0.952	46619	0	1	1	3	5	0.309
125	ROA21	Roane	I0040	22.339	22.804	0.465	41648	0	1	1	3	5	0.707
126	SHE02	Shelby	I0040	5.727	6.854	1.127	87190	0	0	1	4	5	0.139
127	SHE06	Shelby	I0040	8.211	8.574	0.363	90541	0	0	0	5	5	0.417
128	SHE52	Shelby	SR385	10.552	11.909	1.357	10814	0	0	0	5	5	0.934
129	SHE55	Shelby	SR385	13.65	14.53	0.88	9021	0	1	1	3	5	1.726
130	SHE59	Shelby	SR385	16.676	17.696	1.02	10326	0	0	0	5	5	1.301
131	SHE61	Shelby	SR385	18.502	20.742	2.24	8868	0	0	1	4	5	0.690
132	SUL05	Sullivan	I0026	3.57	3.985	0.415	24226	0	0	0	5	5	1.363
133	SUL13	Sullivan	I0026	8.206	8.377	0.171	38594	0	0	1	4	5	2.076
134	SUL25	Sullivan	I0081	5.746	6.488	0.742	33196	0	0	1	4	5	0.556
135	UNI16	Unicoi	I0026	8.017	8.559	0.542	17832	0	1	3	1	5	1.417
136	WAS11	Washington	I0026	5.78	6.627	0.847	54868	0	0	0	5	5	0.295

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
137	WAS12	Washington	I0026	6.868	7.63	0.762	56060	0	0	0	5	5	0.321
138	WAS15	Washington	I0026	9.206	9.853	0.647	48978	0	0	2	3	5	0.432
139	AND07	Anderson	I0075	3.966	4.723	0.757	41102	0	0	0	4	4	0.352
140	BEN02	Benton	I0040	6.012	6.812	0.8	35700	0	0	0	4	4	0.384
141	CAM11	Campbell	I0075	14.843	16.22	1.377	25573	0	0	1	3	4	0.311
142	COC01	Cocke	I0040	0	0.197	0.197	26894	1	0	2	1	4	2.068
143	CUM08	Cumberland	I0040	25.944	26.279	0.335	30576	0	0	0	4	4	1.070
144	CUM12	Cumberland	I0040	29.994	30.385	0.391	30576	0	1	0	3	4	0.917
145	DAV14	Davidson	I0065	21.105	21.39	0.285	72488	0	1	1	2	4	0.530
146	DIC03	Dickson	I0040	8.382	8.927	0.545	30521	0	0	1	3	4	0.659
147	GIL01	Giles	I0065	0.009	0.91	0.901	15628	0	0	2	2	4	0.778
148	GIL02	Giles	I0065	0.887	1.458	0.571	15628	0	0	0	4	4	1.228
149	GIL06	Giles	I0065	16.975	17.356	0.381	17060	0	0	2	2	4	1.686
150	LOU04	Loudon	I0040	2.086	3.136	1.05	40882	0	0	2	2	4	0.255
151	MAD05	Madison	I0040	4.931	5.544	0.613	39350	0	0	1	3	4	0.454
152	MAD25	Madison	I0040	18.82	19.69	0.87	44296	0	0	1	3	4	0.284
153	MAR07	Marion	I0024	17.53	18.05	0.52	44489	0	0	0	4	4	0.474
154	OBI02	Obion	SR003	23.738	24.618	0.88	9786	0	0	0	4	4	1.273
155	RUT06	Rutherford	I0024	11.093	12.438	1.345	102106	0	0	1	3	4	0.080
156	SEQ03	Sequatchie	SR111	2.059	2.794	0.735	8798	0	0	0	4	4	1.695
157	SHE16	Shelby	I0040	27.996	28.748	0.752	51535	0	0	1	3	4	0.283
158	SHE40	Shelby	SR385	4.608	6.132	1.524	8485	0	0	0	4	4	0.847
159	SHE53	Shelby	SR385	12.27	12.66	0.39	10814	0	0	0	4	4	2.599
160	SUM04	Sumner	SR386	2.338	2.968	0.63	54768	0	1	2	1	4	0.318
161	SUM07	Sumner	SR386	3.983	4.692	0.709	52551	0	0	0	4	4	0.294
162	UNI08	Unicoi	I0026	4.12	4.924	0.804	19330	0	0	0	4	4	0.705
163	UNI09	Unicoi	I0026	4.86	5.482	0.622	19330	0	0	1	3	4	0.911
164	UNI14	Unicoi	I0026	7.646	7.774	0.128	20352	0	1	0	3	4	4.207
165	WAS10	Washington	I0026	5.096	5.452	0.356	54868	0	0	1	3	4	0.561
166	WAS20	Washington	I0026	11.429	12.154	0.725	52612	0	0	1	3	4	0.287
167	WAS25	Washington	I0026	13.839	13.933	0.094	40885	0	0	0	4	4	2.852
168	WILL02	Williamson	I0065	0.14	0.75	0.61	29609	0	0	1	3	4	0.607
169	AND02	Anderson	I0075	0.956	1.834	0.878	41102	0	0	1	2	3	0.228
170	BEN01	Benton	I0040	0	0.855	0.855	35700	0	0	0	3	3	0.269
171	BLO04	Blount	I0140	1.585	2.216	0.631	37623	0	0	1	2	3	0.346
172	CAM08	Campbell	I0075	4.86	5.57	0.71	31993	0	0	1	2	3	0.362
173	CAM14	Campbell	I0075	12.95	13.9	0.95	25383	0	0	0	3	3	0.341
174	CAR09	Carter	I0026	1.558	1.88	0.322	19429	0	0	0	3	3	1.314
175	CHE04	Cheatham	I0040	5.623	6.096	0.473	53926	0	0	2	1	3	0.322
176	COC07	Cocke	I0040	6.202	7.129	0.927	24514	0	0	0	3	3	0.362
177	COC08	Cocke	I0040	7.203	8.923	1.72	24514	0	0	0	3	3	0.195
178	COC10	Cocke	I0040	9.859	10.535	0.676	24514	0	0	1	2	3	0.496
179	COF01	Coffee	I0024	5.998	6.987	0.989	37440	0	0	0	3	3	0.222
180	COF05	Coffee	I0024	14.41	15.297	0.887	37369	0	0	1	2	3	0.248
181	CRO04	Crockett	SR020	10.339	10.986	0.647	9881	0	0	0	3	3	1.286
182	CUM10	Cumberland	I0040	28.913	29.168	0.255	30576	0	0	0	3	3	1.054
183	DIC06	Dickson	I0040	9.169	9.495	0.326	39442	0	1	1	1	3	0.639
184	DYE02	Dyer	I0155	1.727	2.329	0.602	9123	0	1	0	2	3	1.497
185	DYE05	Dyer	I0155	4.497	5.439	0.942	9123	0	0	1	2	3	0.956
186	DYE06	Dyer	I0155	5.645	6.228	0.583	9123	0	0	1	2	3	1.545
187	DYE07	Dyer	I0155	6.356	7.196	0.84	9123	0	0	0	3	3	1.073
188	DYE09	Dyer	I0155	7.52	8.352	0.832	9376	0	0	0	3	3	1.054
189	GIL03	Giles	I0065	1.504	2.003	0.499	16049	0	0	0	3	3	1.026
190	HAMI07	Hamilton	I0024	3.589	4.185	0.596	67197	0	0	1	2	3	0.205
191	HAMI18	Hamilton	SR111	6.446	7.04	0.594	9998	0	0	1	2	3	1.384
192	HEN03	Henderson	I0040	6.038	6.314	0.276	30749	0	0	0	3	3	0.968
193	JEF01	Jefferson	I0040	12.247	12.796	0.549	34804	0	0	2	1	3	0.430
194	LOU06	Loudon	I0040	3.445	3.872	0.427	40882	0	0	0	3	3	0.471
195	MAD09	Madison	I0040	8.453	8.733	0.28	39662	0	0	1	2	3	0.740
196	MAD21	Madison	I0040	16.579	16.802	0.223	54527	0	0	0	3	3	0.676
197	MAD27	Madison	I0040	21.158	21.501	0.343	40053	0	0	1	2	3	0.598
198	MAD29	Madison	SR020	2.499	2.655	0.156	13942	0	0	3	0	3	3.779
199	MAR01	Marion	I0024	0.05	0.64	0.59	32398	1	0	1	1	3	0.430
200	MAR04	Marion	I0024	6.66	7.49	0.83	32894	0	0	0	3	3	0.301
201	MAU01	Maury	I0065	10.286	10.889	0.603	23933	0	1	0	2	3	0.570
202	PUT17	Putnam	I0040	31.942	32.177	0.235	33595	0	0	1	2	3	1.041
203	PUT18	Putnam	I0040	32.146	32.688	0.542	33595	0	0	0	3	3	0.451
204	ROA08	Roane	I0040	12.976	13.898	0.922	45822	0	0	0	3	3	0.195

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
205	ROA13	Roane	I0040	17.649	18.403	0.754	40865	0	0	0	3	3	0.267
206	ROA15	Roane	I0040	19.093	19.678	0.585	40865	0	0	0	3	3	0.344
207	ROA16	Roane	I0040	19.717	20.36	0.643	40865	0	0	1	2	3	0.313
208	SEQ02	Sequatchie	SR111	0.079	2.006	1.927	8798	0	0	0	3	3	0.485
209	SHE14	Shelby	I0040	27.156	27.383	0.227	51535	0	0	1	2	3	0.703
210	SHE18	Shelby	I0040	29.036	29.394	0.358	28323	0	0	1	2	3	0.811
211	SHE39	Shelby	SR385	4.2	4.48	0.28	8485	0	0	1	2	3	3.459
212	SHE47	Shelby	SR385	8.84	9.26	0.42	13463	0	0	0	3	3	1.454
213	SMI06	Smith	I0040	6.062	6.957	0.895	35069	0	0	0	3	3	0.262
214	SMI09	Smith	I0040	8.43	8.926	0.496	32868	0	0	2	1	3	0.504
215	SMI11	Smith	I0040	13.216	13.644	0.428	32868	0	0	0	3	3	0.584
216	SMI13	Smith	I0040	16.402	17.074	0.672	32868	0	0	1	2	3	0.372
217	SUL15	Sullivan	I0026	8.518	8.691	0.173	45892	0	0	2	1	3	1.035
218	SUL21	Sullivan	I0081	2.487	3.306	0.819	28586	0	0	0	3	3	0.351
219	UNI01	Unicoi	I0026	0	0.432	0.432	19839	0	0	2	1	3	0.959
220	UNI03	Unicoi	I0026	1.274	2.091	0.817	19839	0	2	1	0	3	0.507
221	UNI11	Unicoi	I0026	6.041	6.456	0.415	20352	0	0	1	2	3	0.973
222	UNI13	Unicoi	I0026	7.358	7.583	0.225	20352	0	0	1	2	3	1.795
223	UNI17	Unicoi	I0026	8.695	9.287	0.592	17832	0	0	2	1	3	0.779
224	UNI18	Unicoi	I0026	9.776	10.324	0.548	16298	0	1	0	2	3	0.920
225	UNI19	Unicoi	I0026	10.33	11.273	0.943	16298	0	0	1	2	3	0.535
226	WAS07	Washington	I0026	3.621	4.057	0.436	54868	0	0	0	3	3	0.344
227	WAS13	Washington	I0026	7.879	8.653	0.774	56060	0	0	0	3	3	0.189
228	WAS16	Washington	I0026	9.93	10.256	0.326	48978	0	1	0	2	3	0.515
229	WAS19	Washington	I0026	11.01	11.261	0.251	52612	0	0	1	2	3	0.622
230	WAS23	Washington	I0026	12.832	12.937	0.105	50316	0	0	1	2	3	1.556
231	WILS12	Wilson	I0040	16.441	16.73	0.289	54563	0	0	0	3	3	0.521
232	AND13	Anderson	I0075	11.348	11.568	0.22	42609	0	0	0	2	2	0.585
233	BRA02	Bradley	I0075	9.419	9.924	0.505	46431	0	0	0	2	2	0.234
234	CAM01	Campbell	I0075	0.045	0.222	0.177	42609	0	0	0	2	2	0.727
235	CAM04	Campbell	I0075	0.683	1.602	0.919	42609	0	0	0	2	2	0.140
236	CAM05	Campbell	I0075	2.08	2.3	0.22	42609	0	0	1	1	2	0.585
237	CAM06	Campbell	I0075	2.22	2.68	0.46	42609	0	0	0	2	2	0.280
238	CAM09	Campbell	I0075	5.829	6.789	0.96	31993	0	0	1	1	2	0.178
239	CAR05	Carter	I0026	1.985	2.334	0.349	19429	0	0	1	1	2	0.808
240	COC11	Cocke	I0040	10.574	11.011	0.437	22922	0	0	0	2	2	0.547
241	CUM05	Cumberland	I0040	23.468	23.932	0.464	29297	0	1	0	1	2	0.403
242	DAV10	Davidson	I0040	0.52	0.97	0.45	53495	0	0	0	2	2	0.228
243	DEC01	Decatur	I0040	4.636	5.586	0.95	35612	0	0	0	2	2	0.162
244	DYE04	Dyer	I0155	3.389	4.358	0.969	9123	0	0	0	2	2	0.620
245	GRE03	Greene	I0081	26.997	27.161	0.164	24574	0	0	1	1	2	1.360
246	HAMI01	Hamilton	I0024	0.001	0.011	0.01	43698	0	0	1	1	2	12.540
247	HAMI04	Hamilton	I0024	1.995	2.194	0.199	64578	0	0	1	1	2	0.426
248	HAMI05	Hamilton	I0024	2.335	2.84	0.505	64578	0	0	0	2	2	0.168
249	HAY06	Haywood	I0040	8.9	8.957	0.057	35850	0	0	0	2	2	2.681
250	HAY10	Haywood	I0040	23.701	23.889	0.188	38771	0	0	0	2	2	0.752
251	HUM01	Humphreys	I0040	4.323	5.098	0.775	28460	0	0	0	2	2	0.248
252	JEF02	Jefferson	I0040	12.819	13.472	0.653	34804	0	0	1	1	2	0.241
253	JEF08	Jefferson	I0040	19.28	20.108	0.828	26894	0	0	1	1	2	0.246
254	KNO01	Knox	I0040	28.271	28.916	0.645	75180	0	0	0	2	2	0.113
255	KNO14	Knox	I0140	4.981	5.476	0.495	43786	0	0	0	2	2	0.253
256	LOU05	Loudon	I0040	3.152	3.443	0.291	40882	0	0	0	2	2	0.461
257	LOU11	Loudon	I0075	14.433	15.073	0.64	54729	0	0	0	2	2	0.156
258	LOU17	Loudon	I0040	0.62	0.787	0.167	40882	0	0	0	2	2	0.803
259	MAD03	Madison	I0040	1.985	2.794	0.809	39350	0	0	2	0	2	0.172
260	MAR06	Marion	I0024	16.9	17.48	0.58	33026	0	0	0	2	2	0.286
261	MAR09	Marion	I0024	27.316	27.405	0.089	47321	0	0	2	0	2	1.301
262	MAU02	Maury	I0065	10.972	12.137	1.165	29609	0	0	0	2	2	0.159
263	MAU05	Maury	SR006	26.07	26.3	0.23	29564	0	0	0	2	2	0.806
264	OBI03	Obion	SR003	24.668	24.994	0.326	9786	0	0	2	0	2	1.718
265	PUT03	Putnam	I0040	8.566	8.751	0.185	36966	0	0	0	2	2	0.801
266	PUT12	Putnam	I0040	24.583	24.85	0.267	33595	0	0	1	1	2	0.611
267	PUT14	Putnam	I0040	29.954	30.656	0.702	33595	0	0	1	1	2	0.232
268	PUT20	Putnam	I0040	33.057	33.477	0.42	33595	0	1	1	0	2	0.388
269	PUT21	Putnam	I0040	33.514	33.729	0.215	31206	0	0	0	2	2	0.817
270	PUT24	Putnam	I0040	36.831	37.087	0.256	23783	0	0	0	2	2	0.900
271	ROA02	Roane	I0040	7.437	7.692	0.255	36489	0	0	0	2	2	0.589
272	ROA06	Roane	I0040	11.663	12.284	0.621	44036	0	0	0	2	2	0.200

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
273	ROA14	Roane	I0040	18.491	19.145	0.654	40865	0	0	0	2	2	0.205
274	ROA17	Roane	I0040	20.401	20.747	0.346	41623	0	0	1	1	2	0.380
275	RUT05	Rutherford	I0024	10.45	11.058	0.608	97338	0	0	2		2	0.093
276	SHE03	Shelby	I0040	6.899	7.479	0.58	87193	0	0	1	1	2	0.108
277	SHE15	Shelby	I0040	27.46	27.95	0.49	51535	0	0	1	1	2	0.217
278	SHE19	Shelby	I0040	30.205	30.599	0.394	28353	0	0	0	2	2	0.491
279	SHE37	Shelby	SR385	13.28	14.39	1.11	22352	0	0	0	2	2	0.221
280	SHE54	Shelby	SR385	12.7	13.61	0.91	10814	0	0	0	2	2	0.557
281	SHE57	Shelby	SR385	15.269	16.011	0.742	10326	0	0	0	2	2	0.715
282	SHE58	Shelby	SR385	16.055	16.795	0.74	10326	0	0	0	2	2	0.717
283	SMI07	Smith	I0040	7.107	7.606	0.499	35069	0	0	0	2	2	0.313
284	SUL17	Sullivan	I0026	8.961	9.279	0.318	45892	0	0	0	2	2	0.375
285	SUL18	Sullivan	I0026	9.176	9.543	0.367	45892	0	0	0	2	2	0.325
286	SUL20	Sullivan	I0081	1.495	2.406	0.911	28586	0	0	0	2	2	0.210
287	SUL23	Sullivan	I0081	5.037	5.356	0.319	34102	0	0	0	2	2	0.504
288	SUL24	Sullivan	I0081	5.431	5.584	0.153	34102	0	0	1	1	2	1.050
289	SUL27	Sullivan	I0081	12.442	12.718	0.276	29427	0	0	0	2	2	0.675
290	SUL28	Sullivan	I0081	12.726	13.095	0.369	29427	0	0	0	2	2	0.505
291	SUM01	Sumner	I0065	0.045	0.98	0.935	67063	0	0	1	1	2	0.087
292	SUM06	Sumner	SR386	3.47	4.01	0.54	52551	0	0	0	2	2	0.193
293	UNI07	Unicoi	I0026	3.765	4.096	0.331	19330	0	0	0	2	2	0.856
294	UNI20	Unicoi	I0026	11.26	11.746	0.486	16298	0	0	0	2	2	0.692
295	UNI21	Unicoi	I0026	11.878	12.097	0.219	10890	0	0	0	2	2	2.298
296	WAS02	Washington	I0026	0.962	1.279	0.317	44976	0	0	1	1	2	0.384
297	WAS17	Washington	I0026	10.362	10.498	0.136	52612	0	0	0	2	2	0.766
298	WILL01	Williamson	I0040	0.069	0.339	0.27	35987	0	0	2	0	2	0.564
299	WILS04	Wilson	I0040	8.412	9.044	0.632	69369	0	0	0	2	2	0.125
300	WILS05	Wilson	I0040	9.11	9.81	0.7	58613	0	0	0	2	2	0.134
301	WILS07	Wilson	I0040	13.008	13.588	0.58	70889	0	0	0	2	2	0.133
302	WILS08	Wilson	I0040	13.608	14.683	1.075	70889	0	0	1	1	2	0.072
303	AND01	Anderson	I0075	0.506	0.776	0.27	41102	0	0	0	1	1	0.247
304	AND03	Anderson	I0075	1.946	2.184	0.238	41102	0	0	1	0	1	0.280
305	AND05	Anderson	I0075	2.56	3.1	0.54	41102	0	0	0	1	1	0.123
306	AND09	Anderson	I0075	10.077	10.353	0.276	44600	0	0	1	0	1	0.223
307	AND14	Anderson	I0075	11.657	12.117	0.46	42609	0	0	1	0	1	0.140
308	CAM02	Campbell	I0075	0.237	0.505	0.268	42609	0	0	0	1	1	0.240
309	CAR02	Carter	I0026	0.309	0.541	0.232	19429	0	0	0	1	1	0.608
310	CAR04	Carter	I0026	1.006	1.558	0.552	19429	0	0	1	0	1	0.255
311	CHE02	Cheatham	I0040	3.577	3.938	0.361	44998	0	0	0	1	1	0.169
312	CHE03	Cheatham	I0040	4.115	4.469	0.354	53495	0	0	0	1	1	0.145
313	COC04	Cocke	I0040	2.399	2.996	0.597	27746	0	0	0	1	1	0.165
314	COC09	Cocke	I0040	8.991	9.564	0.573	24514	0	0	0	1	1	0.195
315	COF02	Coffee	I0024	13.176	13.345	0.169	37468	0	0	0	1	1	0.433
316	CRO01	Crockett	SR020	8.84	9.203	0.363	9054	0	0	0	1	1	0.834
317	CUM06	Cumberland	I0040	24.488	24.948	0.46	29297	0	0	0	1	1	0.203
318	DAV11	Davidson	I0040	1.23	2.424	1.194	58603	0	0	0	1	1	0.039
319	DAV15	Davidson	I0065	21.464	21.547	0.083	67063	0	0	0	1	1	0.492
320	DIC04	Dickson	I0040	8.939	9.052	0.113	30521	0	0	0	1	1	0.794
321	DYE03	Dyer	I0155	2.367	3.313	0.946	9123	0	0	1	0	1	0.317
322	GIL08	Giles	I0065	18.235	19.391	1.156	17060	0	0	0	1	1	0.139
323	GRA02	Grainger	SR032	1.929	2.03	0.101	19450	0	0	0	1	1	1.395
324	GRE01	Greene	I0081	25.944	26.456	0.512	23936	0	0	0	1	1	0.224
325	GRU03	Grundy	I0024	3.933	4.292	0.359	32665	0	0	0	1	1	0.234
326	GRU04	Grundy	I0024	4.227	4.529	0.302	32665	0	0	1	0	1	0.278
327	GRU05	Grundy	I0024	4.534	5.141	0.607	32665	0	0	1	0	1	0.138
328	GRU06	Grundy	I0024	6.728	7.262	0.534	32665	0	0	0	1	1	0.157
329	HAMB01	Hamblen	I0081	0.003	0.211	0.208	46496	0	0	0	1	1	0.283
330	HAMB02	Hamblen	I0081	0.278	0.355	0.077	46496	0	0	0	1	1	0.765
331	HAMI02	Hamilton	I0024	0.005	0.161	0.156	43698	1	0	0	0	1	0.402
332	HAMI09	Hamilton	I0075	13.888	14.164	0.276	59720	0	0	0	1	1	0.166
333	HAMI13	Hamilton	SR029	21.379	21.557	0.178	17329	0	0	0	1	1	0.888
334	HAMI16	Hamilton	SR029	23.647	23.717	0.07	17329	0	0	0	1	1	2.259
335	HAMI19	Hamilton	SR111	7.076	7.35	0.274	9998	0	0	0	1	1	1.000
336	HAY02	Haywood	I0040	5.538	5.811	0.273	35509	0	0	0	1	1	0.283
337	HEN02	Henderson	I0040	5.839	6.02	0.181	30749	0	0	0	1	1	0.492
338	HIC01	Hickman	I0040	0.114	0.776	0.662	29583	0	1	0	0	1	0.140
339	HIC03	Hickman	I0040	1.237	1.667	0.43	29583	0	0	1	0	1	0.215
340	HUM02	Humphreys	I0040	6.649	7.091	0.442	28522	0	0	1	0	1	0.217

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
341	JEF04	Jefferson	I0040	14.055	14.417	0.362	34804	0	0	0	1	1	0.217
342	JEF10	Jefferson	I0040	18.838	19.28	0.442	26894	0	0	0	1	1	0.230
343	KNO03	Knox	I0040	29.166	29.38	0.214	71468	0	0	1	0	1	0.179
344	KNO04	Knox	I0075	0.543	0.899	0.356	72739	0	0	1	0	1	0.106
345	KNO08	Knox	I0075	1.456	1.689	0.233	72874	0	0	0	1	1	0.161
346	KNO12	Knox	I0075	2.415	2.746	0.331	72874	0	0	1	0	1	0.114
347	KNO13	Knox	I0075	8.209	9.439	1.23	44284	0	0	0	1	1	0.050
348	LOU01	Loudon	I0040	0.037	0.297	0.26	41648	0	0	0	1	1	0.253
349	LOU09	Loudon	I0075	7.068	7.543	0.475	46503	0	0	0	1	1	0.124
350	LOU14	Loudon	SR073	3.166	3.286	0.12	9284	0	0	0	1	1	2.459
351	MAR03	Marion	I0024	6.361	6.61	0.249	32894	0	0	0	1	1	0.334
352	MAR08	Marion	I0024	26.87	27.029	0.159	47321	0	0	0	1	1	0.364
353	MAR11	Marion	I0024	28.423	28.936	0.513	43698	0	0	0	1	1	0.122
354	MAR15	Marion	I0024	29.878	30.354	0.476	43698	0	0	0	1	1	0.132
355	PUT07	Putnam	I0040	19.647	19.892	0.245	42040	0	0	1	0	1	0.266
356	PUT10	Putnam	I0040	22.828	23.542	0.714	34467	0	0	0	1	1	0.111
357	PUT13	Putnam	I0040	24.938	25.218	0.28	33595	0	0	0	1	1	0.291
358	PUT16	Putnam	I0040	31.558	31.862	0.304	33595	0	0	0	1	1	0.268
359	ROA03	Roane	I0040	8.447	8.928	0.481	36489	0	0	0	1	1	0.156
360	ROA04	Roane	I0040	9.457	9.575	0.118	36489	0	0	0	1	1	0.636
361	ROA05	Roane	I0040	10.037	10.134	0.097	36489	0	0	0	1	1	0.774
362	ROA18	Roane	I0040	20.795	21.065	0.27	41623	0	0	1	0	1	0.244
363	ROA19	Roane	I0040	21.102	21.346	0.244	41623	0	0	0	1	1	0.270
364	ROA22	Roane	I0040	22.854	22.947	0.093	41648	0	0	0	1	1	0.707
365	SHE07	Shelby	I0040	8.275	8.63	0.355	89847	0	0	0	1	1	0.086
366	SHE09	Shelby	I0040	8.705	9.301	0.596	89857	0	0	0	1	1	0.051
367	SHE10	Shelby	I0040	9.307	9.388	0.081	89863	0	0	0	1	1	0.376
368	SHE17	Shelby	I0040	28.785	28.93	0.145	28323	0	0	0	1	1	0.667
369	SHE22	Shelby	I0055	9.74	9.94	0.2	57441	0	0	0	1	1	0.238
370	SHE27	Shelby	SR385	4.97	5.151	0.181	57036	0	0	0	1	1	0.265
371	SHE38	Shelby	SR385	3.932	4.217	0.285	8485	0	0	0	1	1	1.133
372	SHE42	Shelby	SR385	6.447	6.766	0.319	8485	0	0	1	0	1	1.012
373	SHE44	Shelby	SR385	7.258	7.85	0.592	13463	0	0	1	0	1	0.344
374	SHE45	Shelby	SR385	7.905	8.491	0.586	13463	0	0	0	1	1	0.347
375	SHE48	Shelby	SR385	9.286	9.542	0.256	13463	0	0	1	0	1	0.795
376	SHE51	Shelby	SR385	10.38	10.73	0.35	10814	0	0	0	1	1	0.724
377	SHE60	Shelby	SR385	17.98	18.61	0.63	8868	0	0	0	1	1	0.490
378	SUL14	Sullivan	I0026	8.221	8.442	0.221	38594	0	0	0	1	1	0.321
379	SUM15	Sumner	SR386	11.944	12.207	0.263	40776	0	0	0	1	1	0.255
380	TIP04	Tipton	SR003	10.33	10.42	0.09	16034	0	0	0	1	1	1.899
381	UNI04	Unicoi	I0026	2.324	2.503	0.179	19839	0	0	0	1	1	0.771
382	UNI15	Unicoi	I0026	7.668	7.989	0.321	20352	0	0	1	0	1	0.419
383	UNI22	Unicoi	I0026	12.133	12.841	0.708	10890	0	0	0	1	1	0.355
384	WAS04	Washington	I0026	1.507	2.321	0.814	41492	0	0	0	1	1	0.081
385	WAS14	Washington	I0026	8.717	9.083	0.366	56060	0	0	0	1	1	0.134
386	WAS18	Washington	I0026	10.587	10.877	0.29	52612	0	0	0	1	1	0.180
387	WAS21	Washington	I0026	12.226	12.365	0.139	53871	0	0	0	1	1	0.366
388	WAS22	Washington	I0026	12.518	12.582	0.064	50316	0	0	0	1	1	0.851
389	WAS26	Washington	I0026	14.03	14.087	0.057	19429	0	0	0	1	1	2.474
390	WAS27	Washington	I0026	14.694	14.912	0.218	19429	0	0	0	1	1	0.647
391	WAS28	Washington	I0026	14.829	15.136	0.307	19429	0	0	0	1	1	0.459
392	WAS30	Washington	SR034	0.181	0.312	0.131	11655	0	0	0	1	1	1.794
393	WAS31	Washington	I0026	0.03	0.134	0.104	44976	0	0	0	1	1	0.586
394	WILS06	Wilson	I0040	12.176	12.917	0.741	70889	0	0	0	1	1	0.052
395	WILS13	Wilson	I0040	16.85	17.236	0.386	44290	0	0	1	0	1	0.160
396	AND04	Anderson	I0075	2.297	2.543	0.246	41102	0	0	0	0	0	0.000
397	AND08	Anderson	I0075	9.743	9.971	0.228	44600	0	0	0	0	0	0.000
398	AND10	Anderson	I0075	10.283	10.612	0.329	41329	0	0	0	0	0	0.000
399	AND11	Anderson	I0075	10.703	10.868	0.165	41329	0	0	0	0	0	0.000
400	AND12	Anderson	I0075	10.911	11.287	0.376	41329	0	0	0	0	0	0.000
401	BLO01	Blount	I0140	0.443	0.777	0.334	43786	0	0	0	0	0	0.000
402	BLO02	Blount	I0140	0.861	1.255	0.394	37623	0	0	0	0	0	0.000
403	BLO03	Blount	I0140	1.286	1.506	0.22	37623	0	0	0	0	0	0.000
404	CAM03	Campbell	I0075	0.52	0.646	0.126	42609	0	0	0	0	0	0.000
405	CAM12	Campbell	I0075	16.538	16.855	0.317	25573	0	0	0	0	0	0.000
406	CAM13	Campbell	I0075	19.818	20.149	0.331	26165	0	0	0	0	0	0.000
407	CAR01	Carter	I0026	0.005	0.256	0.251	19429	0	0	0	0	0	0.000
408	CAR03	Carter	I0026	0.783	1.073	0.29	19429	0	0	0	0	0	0.000

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
409	CAR06	Carter	I0026	2.253	2.689	0.436	19429	0	0	0	0	0	0.00
410	CAR07	Carter	SR037	13.59	13.691	0.101	6999	0	0	0	0	0	0.00
411	CAR08	Carter	SR037	13.711	13.856	0.145	6999	0	0	0	0	0	0.00
412	COC06	Cocke	I0040	6.169	6.186	0.017	24514	0	0	0	0	0	0.00
413	COC12	Cocke	I0040	13.17	13.308	0.138	22922	0	0	0	0	0	0.00
414	COC13	Cocke	I0040	13.373	13.681	0.308	23946	0	0	0	0	0	0.00
415	COC14	Cocke	I0040	0.713	0.784	0.071	26894	0	0	0	0	0	0.00
416	COF04	Coffee	I0024	14.101	14.339	0.238	38995	0	0	0	0	0	0.00
417	CRO02	Crockett	SR020	9.24	9.355	0.115	9054	0	0	0	0	0	0.00
418	CRO03	Crockett	SR020	9.5	10.295	0.795	9054	0	0	0	0	0	0.00
419	CUM01	Cumberland	I0040	0	0.003	0.003	23783	0	0	0	0	0	0.00
420	CUM04	Cumberland	I0040	23.194	23.273	0.079	29297	0	0	0	0	0	0.00
421	CUM09	Cumberland	I0040	26.331	26.432	0.101	30576	0	0	0	0	0	0.00
422	CUM11	Cumberland	I0040	29.333	29.473	0.14	30576	0	0	0	0	0	0.00
423	DAV01	Davidson	I0024	2.451	2.924	0.473	52624	0	0	0	0	0	0.00
424	DAV02	Davidson	I0024	3.023	3.37	0.347	61764	0	0	0	0	0	0.00
425	DAV03	Davidson	I0024	3.487	3.704	0.217	61764	0	0	0	0	0	0.00
426	DAV04	Davidson	I0024	8.148	8.488	0.34	61764	0	0	0	0	0	0.00
427	DAV05	Davidson	I0024	8.962	9.53	0.568	60258	0	0	0	0	0	0.00
428	DAV06	Davidson	I0024	10.786	10.928	0.142	60258	0	0	0	0	0	0.00
429	DAV07	Davidson	I0024	11.157	11.541	0.384	50201	0	0	0	0	0	0.00
430	DAV08	Davidson	I0024	11.617	12	0.383	50201	0	0	0	0	0	0.00
431	DAV09	Davidson	I0024	12.243	12.408	0.165	50201	0	0	0	0	0	0.00
432	DAV12	Davidson	I0040	2.634	3.121	0.487	58603	0	0	0	0	0	0.00
433	DAV13	Davidson	I0040	3.435	4.285	0.85	58603	0	0	0	0	0	0.00
434	DAV16	Davidson	I0065	21.606	22.119	0.513	67063	0	0	0	0	0	0.00
435	DAV17	Davidson	I0440	7.52	7.62	0.1	99264	0	0	0	0	0	0.00
436	DAV18	Davidson	SR006	11.509	11.792	0.283	42207	0	0	0	0	0	0.00
437	DAV19	Davidson	SR006	12.48	12.6	0.12	17205	0	0	0	0	0	0.00
438	DAV20	Davidson	SR006	13.152	13.357	0.205	39198	0	0	0	0	0	0.00
439	DAV21	Davidson	SR006	13.425	13.936	0.511	35660	0	0	0	0	0	0.00
440	DAV22	Davidson	SR006	13.998	14.193	0.195	35660	0	0	0	0	0	0.00
441	DAV23	Davidson	SR006	14.24	14.652	0.412	35660	0	0	0	0	0	0.00
442	DAV24	Davidson	SR006	14.56	14.78	0.22	33483	0	0	0	0	0	0.00
443	DAV25	Davidson	SR006	14.838	15.046	0.208	33483	0	0	0	0	0	0.00
444	DAV26	Davidson	SR006	15.158	15.449	0.291	33483	0	0	0	0	0	0.00
445	DAV27	Davidson	SR155	26.105	26.379	0.274	42835	0	0	0	0	0	0.00
446	DAV28	Davidson	SR155	26.505	26.728	0.223	42835	0	0	0	0	0	0.00
447	DAV29	Davidson	SR155	26.754	26.92	0.166	42835	0	0	0	0	0	0.00
448	DAV30	Davidson	SR155	27.06	27.38	0.32	42835	0	0	0	0	0	0.00
449	DAV31	Davidson	SR155	27.46	27.71	0.25	42835	0	0	0	0	0	0.00
450	DAV32	Davidson	SR155	27.73	27.95	0.22	36105	0	0	0	0	0	0.00
451	DEC02	Decatur	I0040	5.655	5.68	0.025	35700	0	0	0	0	0	0.00
452	DIC01	Dickson	I0040	6.973	7.176	0.203	30521	0	0	0	0	0	0.00
453	DIC05	Dickson	I0040	9.136	9.157	0.021	39442	0	0	0	0	0	0.00
454	DYE01	Dyer	I0155	1.494	1.707	0.213	9330	0	0	0	0	0	0.00
455	DYE08	Dyer	I0155	7.24	7.4	0.16	9123	0	0	0	0	0	0.00
456	FAY01	Fayette	I0040	0.001	0.299	0.298	28353	0	0	0	0	0	0.00
457	GIL04	Giles	I0065	13.732	14.03	0.298	15938	0	0	0	0	0	0.00
458	GRA01	Grainger	SR032	1.725	1.854	0.129	19450	0	0	0	0	0	0.00
459	GRE02	Greene	I0081	26.644	26.898	0.254	23936	0	0	0	0	0	0.00
460	GRU02	Grundy	I0024	3.253	3.503	0.25	32665	0	0	0	0	0	0.00
461	HAMB05	Hamblen	SR160	3.11	3.31	0.2	3254	0	0	0	0	0	0.00
462	HAMI03	Hamilton	I0024	1.3	1.669	0.369	64578	0	0	0	0	0	0.00
463	HAMI06	Hamilton	I0024	2.935	3.506	0.571	67197	0	0	0	0	0	0.00
464	HAMI08	Hamilton	I0024	4.258	4.626	0.368	73066	0	0	0	0	0	0.00
465	HAMI10	Hamilton	I0075	14.189	14.239	0.05	59720	0	0	0	0	0	0.00
466	HAMI14	Hamilton	SR029	21.633	21.763	0.13	17329	0	0	0	0	0	0.00
467	HAMI15	Hamilton	SR029	23.437	23.632	0.195	17329	0	0	0	0	0	0.00
468	HAMI20	Hamilton	SR153	7.596	7.751	0.155	45974	0	0	0	0	0	0.00
469	HAMI21	Hamilton	SR153	7.803	7.916	0.113	45974	0	0	0	0	0	0.00
470	HAW01	Hawkins	SR1	38.62	38.85	0.23	31897	0	0	0	0	0	0.00
471	HAY09	Haywood	I0040	16.93	17.27	0.34	35775	0	0	0	0	0	0.00
472	HEN01	Henderson	I0040	4.011	5.703	1.692	34240	0	0	0	0	0	0.00
473	HIC02	Hickman	I0040	0.73	1.48	0.75	29630	0	0	0	0	0	0.00
474	HIC04	Hickman	I0040	1.69	2.05	0.36	29630	0	0	0	0	0	0.00
475	JEF05	Jefferson	I0040	15.663	15.925	0.262	26894	0	0	0	0	0	0.00
476	JEF06	Jefferson	I0040	15.928	16.756	0.828	26894	0	0	0	0	0	0.00

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate MVMT
477	JEF09	Jefferson	I0081	7.19	7.54	0.35	46496	0	0	0	0	0	0.00
478	KNO02	Knox	I0040	28.982	29.142	0.16	71468	0	0	0	0	0	0.00
479	KNO05	Knox	I0075	0.856	0.951	0.095	72739	0	0	0	0	0	0.00
480	KNO06	Knox	I0075	1.04	1.28	0.24	72739	0	0	0	0	0	0.00
481	KNO07	Knox	I0075	1.168	1.393	0.225	72874	0	0	0	0	0	0.00
482	KNO09	Knox	I0075	1.658	2.025	0.367	72874	0	0	0	0	0	0.00
483	KNO10	Knox	I0075	2.074	2.217	0.143	72874	0	0	0	0	0	0.00
484	KNO11	Knox	I0075	2.264	2.364	0.1	72874	0	0	0	0	0	0.00
485	KNO16	Knox	I0640	6.8	6.94	0.14	48733	0	0	0	0	0	0.00
486	KNO17	Knox	SR115	1.46	1.64	0.18	44132	0	0	0	0	0	0.00
487	LAW01	Lawrence	SR006	32.724	32.923	0.199	9503	0	0	0	0	0	0.00
488	LAW02	Lawrence	SR006	32.943	33.112	0.169	9503	0	0	0	0	0	0.00
489	LOU02	Loudon	I0040	0.342	0.53	0.188	41648	0	0	0	0	0	0.00
490	LOU08	Loudon	I0075	6.874	6.982	0.108	46503	0	0	0	0	0	0.00
491	LOU10	Loudon	I0075	7.989	8.126	0.137	46503	0	0	0	0	0	0.00
492	LOU12	Loudon	I0075	15.123	15.573	0.45	54729	0	0	0	0	0	0.00
493	LOU13	Loudon	SR073	2.43	2.79	0.36	9284	0	0	0	0	0	0.00
494	LOU15	Loudon	SR073	3.303	3.378	0.075	9284	0	0	0	0	0	0.00
495	LOU16	Loudon	SR073	3.39	3.489	0.099	9284	0	0	0	0	0	0.00
496	MAD15	Madison	I0040	13.12	13.25	0.13	50150	0	0	0	0	0	0.00
497	MAD17	Madison	I0040	13.51	14.56	1.05	50624	0	0	0	0	0	0.00
498	MAD18	Madison	I0040	14.59	14.7	0.11	50624	0	0	0	0	0	0.00
499	MAD22	Madison	I0040	16.839	16.987	0.148	54527	0	0	0	0	0	0.00
500	MAD28	Madison	SR020	2.32	2.44	0.12	13942	0	0	0	0	0	0.00
501	MAD30	Madison	I0040	1.134	1.177	0.043	39396	0	0	0	0	0	0.00
502	MAR02	Marion	I0024	0.65	1.211	0.561	32398	0	0	0	0	0	0.00
503	MAR05	Marion	I0024	7.763	8.504	0.741	33026	0	0	0	0	0	0.00
504	MAR17	Marion	I0024	30.402	31.071	0.669	43698	0	0	0	0	0	0.00
505	MAR19	Marion	I0024	31.216	31.588	0.372	43698	0	0	0	0	0	0.00
506	MAR20	Marion	I0024	31.987	32.025	0.038	43698	0	0	0	0	0	0.00
507	MAR21	Marion	I0024	32.056	32.129	0.073	43698	0	0	0	0	0	0.00
508	MAR22	Marion	I0024	32.06	32.129	0.069	43698	0	0	0	0	0	0.00
509	MAU03	Maury	SR006	0	0.14	0.14	18323	0	0	0	0	0	0.00
510	MAU04	Maury	SR006	0.23	0.47	0.24	11305	0	0	0	0	0	0.00
511	MAU06	Maury	SR396	2.361	3.201	0.84	28533	0	0	0	0	0	0.00
512	PUT01	Putnam	I0040	6.508	6.951	0.443	36966	0	0	0	0	0	0.00
513	PUT05	Putnam	I0040	9.05	9.59	0.54	37242	0	0	0	0	0	0.00
514	PUT08	Putnam	I0040	21.494	21.716	0.222	34467	0	0	0	0	0	0.00
515	PUT11	Putnam	I0040	24.333	24.681	0.348	33595	0	0	0	0	0	0.00
516	PUT15	Putnam	I0040	30.998	31.636	0.638	33595	0	0	0	0	0	0.00
517	ROA01	Roane	I0040	6.477	6.57	0.093	28183	0	0	0	0	0	0.00
518	ROA12	Roane	I0040	17.293	17.635	0.342	40865	0	0	0	0	0	0.00
519	RUT01	Rutherford	I0024	4.69	4.77	0.08	106838	0	0	0	0	0	0.00
520	RUT02	Rutherford	I0024	5.3	5.67	0.37	106838	0	0	0	0	0	0.00
521	RUT03	Rutherford	I0024	6.31	6.74	0.43	106838	0	0	0	0	0	0.00
522	RUT04	Rutherford	I0024	7.17	7.49	0.32	97338	0	0	0	0	0	0.00
523	RUT07	Rutherford	I0024	32	32.353	0.353	35653	0	0	0	0	0	0.00
524	RUT08	Rutherford	SR840	12.537	13.31	0.773	21152	0	0	0	0	0	0.00
525	SEQ01	Sequatchie	SR111	0.013	0.067	0.054	8798	0	0	0	0	0	0.00
526	SHE01	Shelby	I0040	4.85	4.938	0.088	102835	0	0	0	0	0	0.00
527	SHE05	Shelby	I0040	7.62	8.199	0.579	90538	0	0	0	0	0	0.00
528	SHE20	Shelby	I0055	6.53	6.61	0.08	83629	0	0	0	0	0	0.00
529	SHE21	Shelby	I0055	9.33	9.69	0.36	57441	0	0	0	0	0	0.00
530	SHE23	Shelby	I0055	9.97	10.24	0.27	57441	0	0	0	0	0	0.00
531	SHE24	Shelby	I0240	9.19	9.24	0.05	150121	0	0	0	0	0	0.00
532	SHE25	Shelby	SR300	0.67	0.76	0.09	23376	0	0	0	0	0	0.00
533	SHE26	Shelby	SR300	0.74	0.83	0.09	23376	0	0	0	0	0	0.00
534	SHE32	Shelby	SR385	9.337	9.778	0.441	36626	0	0	0	0	0	0.00
535	SHE41	Shelby	SR385	6.22	6.421	0.201	8485	0	0	0	0	0	0.00
536	SHE43	Shelby	SR385	6.922	7.16	0.238	13463	0	0	0	0	0	0.00
537	SHE46	Shelby	SR385	8.579	8.973	0.394	13463	0	0	0	0	0	0.00
538	SHE49	Shelby	SR385	9.55	9.81	0.26	10814	0	0	0	0	0	0.00
539	SHE50	Shelby	SR385	10.106	10.446	0.34	10814	0	0	0	0	0	0.00
540	SMI10	Smith	I0040	9.007	9.502	0.495	32868	0	0	0	0	0	0.00
541	SUL01	Sullivan	I0026	0.028	0.169	0.141	24366	0	0	0	0	0	0.00
542	SUL10	Sullivan	I0026	6.429	7.097	0.668	38594	0	0	0	0	0	0.00
543	SUL16	Sullivan	I0026	8.745	8.857	0.112	45892	0	0	0	0	0	0.00
544	SUL19	Sullivan	I0026	9.6	9.841	0.241	45892	0	0	0	0	0	0.00

Ranking of the Cable Barrier Segments Based on Crash Frequency

Rank	CableID	County	Route	Start Log	End Log	Length	Ave. AADT	Fatal Crash	Incapac Injury	Non Incap	PDO	Total	Crash Rate 10MVMT
545	SUL29	Sullivan	SR001	17.947	18.229	0.282	10704	0	0	0	0	0	0.00
546	SUL30	Sullivan	SR001	18.247	18.403	0.156	10704	0	0	0	0	0	0.00
547	SUL31	Sullivan	SR001	19.999	20.102	0.103	10704	0	0	0	0	0	0.00
548	SUL32	Sullivan	SR001	20.118	20.371	0.253	10704	0	0	0	0	0	0.00
549	SUL33	Sullivan	SR001	20.36	20.58	0.22	10704	0	0	0	0	0	0.00
550	SUL34	Sullivan	SR001	20.497	20.702	0.205	10704	0	0	0	0	0	0.00
551	SUL35	Sullivan	SR001	21.78	21.86	0.08	12357	0	0	0	0	0	0.00
552	SUL36	Sullivan	SR001	21.93	21.999	0.069	12357	0	0	0	0	0	0.00
553	SUL37	Sullivan	SR001	22.081	22.134	0.053	12357	0	0	0	0	0	0.00
554	SUL38	Sullivan	SR001	22.158	22.308	0.15	12357	0	0	0	0	0	0.00
555	SUM03	Sumner	SR386	2.068	2.319	0.251	54768	0	0	0	0	0	0.00
556	SUM05	Sumner	SR386	3.019	3.425	0.406	55317	0	0	0	0	0	0.00
557	SUM08	Sumner	SR386	4.777	4.852	0.075	52551	0	0	0	0	0	0.00
558	SUM09	Sumner	SR386	4.898	5.696	0.798	40776	0	0	0	0	0	0.00
559	SUM10	Sumner	SR386	5.762	6.493	0.731	40776	0	0	0	0	0	0.00
560	SUM12	Sumner	SR386	9.402	9.628	0.226	40776	0	0	0	0	0	0.00
561	SUM14	Sumner	SR386	11	11.886	0.886	40776	0	0	0	0	0	0.00
562	SUM16	Sumner	SR386	12.294	12.421	0.127	40776	0	0	0	0	0	0.00
563	TIP01	Tipton	SR003	10.05	10.125	0.075	16034	0	0	0	0	0	0.00
564	TIP02	Tipton	SR003	10.158	10.244	0.086	16034	0	0	0	0	0	0.00
565	TIP03	Tipton	SR003	10.265	10.303	0.038	16034	0	0	0	0	0	0.00
566	TIP05	Tipton	SR003	10.44	11.26	0.82	16034	0	0	0	0	0	0.00
567	UNI02	Unicoi	I0026	0.522	1.244	0.722	19839	0	0	0	0	0	0.00
568	UNI05	Unicoi	I0026	2.566	3.149	0.583	19839	0	0	0	0	0	0.00
569	UNI10	Unicoi	I0026	5.519	5.91	0.391	19330	0	0	0	0	0	0.00
570	UNI23	Unicoi	I0026	2.092	2.17	0.078	19839	0	0	0	0	0	0.00
571	WAS29	Washington	SR034	0.09	0.14	0.05	11655	0	0	0	0	0	0.00
572	WILL05	Williamson	I0065	8.77	10.96	2.19	69165	0	0	0	0	0	0.00
573	WILL06	Williamson	I0065	11.04	11.78	0.74	69165	0	0	0	0	0	0.00
574	WILS01	Wilson	I0040	4.748	5.026	0.278	69435	0	0	0	0	0	0.00
575	WILS09	Wilson	I0040	14.731	14.873	0.142	59690	0	0	0	0	0	0.00
576	WILS10	Wilson	I0040	15.001	15.096	0.095	59690	0	0	0	0	0	0.00
577	WILS14	Wilson	I0040	27.336	27.346	0.01	44290	0	0	0	0	0	0.00