SAFETY EFFECTIVENESS EVALUATION OF THE CABLE RAIL SYSTEMS IN TENNESSEE

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ABSTRACT

Performances and safety effectiveness evaluation results of median cable barrier systems in Tennessee are presented in this paper. Twenty seven segments with at least three years of complete crash data before and after cable installations were analyzed. The segments were evaluated in terms of descriptive statistics of factors associated with median crashes whose occurrences were influenced by the presence or absence of the median cable barriers. The cable systems were also evaluated in terms of percentage safety effectiveness and confidence levels comparing before and after cable conditions. The study involved review of crash report hard copies where only 24% were found to be relevant for median cable barriers evaluation, 76% were not related. Descriptive statistics compared the percentage of a certain type of crashes, crash attributes and other elements to the total crashes before and after the barriers were installed. To evaluate the safety effectiveness, the research applied crash modeling in the form of safety performance models, and observational Empirical Bayes (EB) before and after analysis. Safety effectiveness of the installed median cable barrier systems was found to be 93% for fatal crashes, 85% for fatal and incapacitating injury crashes combined and 51% for the combination of fatal and all injury crashes all above 95% confidence level. Study also found that combined fatal and injury crashes were reduced by 21% after median cable installations while fatal crashes only were reduced by 80%. Total number of people killed or injured was reduced by 29% after installation.
INTRODUCTION
For the past several years, Tennessee Department of Transportation (TDOT) has been installing Median Cable Rail Systems along some sections of the state interstate highways and freeways. Among the intended benefits of the cable rail systems was the mitigation 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 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. Therefore the objective of this research is to evaluate the safety effectiveness of these cable rail systems. To evaluate the effectiveness of these cable rail systems, this study applied different methodologies including descriptive statistics, crash modeling in the form of safety performance models and Empirical Bayes (EB) observational safety effectiveness evaluation. Empirical Bayes and Safety Performance Functions (SPFs) have been used widely for estimating safety impacts of different engineering improvements as defined in Highway Safety Manual (HSM) (1) and Safety Analyst Software, (2). Through EB, the study evaluated the performance of the cable rail systems while weighing the past performance before the cables were installed. The SPFs represent a statistical relationship between the predicted number of crashes by severity, and variables such as daily traffic volumes, length of the segment, roadway features, and environmental conditions. The study also focused on quantifying crash frequency, crash rates, crash types, injury severities with respect to geometric and operational factors that contribute to crash trends, and identifying other factors that influence the effectiveness of the cable rail systems. Furthermore, study results respond to the general public perception of the cable rail system program. As a result of this study, the public is expected to be informed on whether the system is significantly reducing crashes, collisions, or injury severity.

BACKGROUND
The first step leading to installation of the cable rail system is to identify crash patterns for the subject highway location. In one study conducted in Washington State, 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 rails (3). Median related crashes are important to identify due to their uniqueness compared to overall total crashes. A study in Minnesota reported that most states’ crash records did not explicitly identify median crossover crashes. The Minnesota study therefore used original accident reports to review the collision diagrams and crash notes to determine whether the crash was median related or not (4). The Washington and Minnesota studies highlighted the importance of developing lists of relevant crashes when conducting the analysis of the cable rail systems. Another important point which should be noted with
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with regard to median cable rail systems from other states is that the overall number of crashes in
the cable areas was seen to increase (mainly due to property damage crashes) after the
installation, but the severity of the crashes decreased (3). A study conducted in Washington
State (5) for instance theorized that this increase could be due to more property damage
crashes having to be reported once contact occurs with the cable barrier.

Background of EB Evaluation Methodologies

There is a long list of studies and researches focused purely on modeling or safety
effectiveness evaluation of median cable barriers (6-26). For instance Miaou et al. (14)
prepared median barrier guidelines for Texas by estimating median-related crash frequencies
using full Bayes approach for model specification. Their models for median barrier crash
frequency showed that the statistically significant explanatory variables were median width
and posted speed. The expected median barrier crash frequency was shown to decrease as the
median width increases. Donnell and Mason (19) investigated median barrier crash frequency
on Pennsylvania Interstate highways, including separate models for the Turnpike and all
other Interstate-designated highways. They found that as the speed limit increases on the non-
toll portion of the Interstate highway, the frequency of median barrier crashes increases.

Empirical Bayes is one of the relevant methodologies in examining the cable barrier
efficiency once it has been installed. This approach is 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. These results are then compared to the
actual crash count seen after the site has been treated to determine the system’s effectiveness
(30). 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 full removes much of this error in its analysis. More data yields more accurate
results (31). 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 (5).

Highway Safety Manual 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
(1) which include importance of prediction models, regression to the mean, weighted factor,
 crushed modification factors and the use of empirical bayes (EB). In EB analysis, the SPF s 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.
The negative binomial distribution is an extension of the Poisson distribution, and is better
suited than the Poisson distribution for modeling of crash data. The Poisson distribution is
appropriate when the mean and the variance of the data are equal. For crash data, the variance
typically exceeds the mean. 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 vary as compared to a Poisson distribution with the same
mean. The overdispersion parameter is used to determine the value of a weight factor for use
in the EB analysis (1). 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. 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 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 rail not been installed. 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 an SPF and weighting the observed crash frequency with the SPF-predicted average
crash frequency to obtain an expected average crash frequency. The weighted adjustment
factor, $w$, is a function of the overdispersion parameter, $k$ and is applied to predicted and
observed crashes as (1):

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

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

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. 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.

STUDY DATA

Crash data along the study segments was downloaded from Tennessee Roadway Information
Management System [TRIMS] database. The TRIMS database has crash data embedded with
attributes such as location, crash date, log mile, crash type, total injured, total killed, number
of vehicles involved in a crash, first harmful event, contributing causes, injury severities,
traffic and geometric characteristics among others. The data also have the exact log mile
where the crash occurred. The annual average daily traffic (AADT) was downloaded from
TDOT website which is available to the public (32). To fully assess safety effectiveness of
the median cable rails, segments with at least one year of complete crash data before and after
median cable rail installations is required. In coordination with TDOT officials involved with
the cable rail systems, project planning, safety office, and crash data management section, it
was revealed that many cable rail segments didn’t meet this criterion (lack of enough data
after cable rails were installed). This is because the available crash data in the database are
lagging at least several months to a year, or longer than that behind the current date.
Complete data for most segments was available (or accessible) only up to 2009, Table 1.

As shown in Table 1, research identified only twenty seven segments that definitely had
enough data satisfying evaluation criteria up to the end of 2009. These segments were located
in Shelby, Sullivan, Hamilton and Marion Counties (some of which were pilot segments) and
other sections in Washington County. Twenty seven segments with a total of 14.41 miles
covering five Counties and three interstate highways (I-40, I-26 and I-24) with three years of complete crash data before and after installation of the median cable rails were analyzed. Among the Counties analyzed, Washington had ten segments (on I-26) with a total distance of 5.51 miles, followed by Shelby with six different segments (on I-40) and a total of 3.3 miles in distance. Marion County had six segments (on I-24) with a total distance of 2.74 miles, while Sullivan had four cable rail segments (on I-26) with a total of 2.75 miles. As shown in Table1, fourteen cable rail study segments in Sullivan and Washington Counties were completed on 12/15/2006, six segments in Shelby County were completed on 3/15/2006, six segments in Marion County and one in Hamilton County were completed on 4/30/2006. Before and after crashes were defined using these completion dates as a threshold. Taking cable installation completion dates as a threshold, there were 507 total crashes along these segments before the cable rails were installed and 639 total crashes after the installation of the cable rails. These are total crashes without segregation by median related, type, severity, and other critical factors. A breakdown of these crashes by severity, type, and contribution causes showed reduction in number of crashes and severity when comparing before and after conditions.

### TABLE 1 Study Cable Rail Locations

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<th>End Log Mile</th>
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*Three Years Interval from Cable Completion Date

Paper revised from original submittal.
To ensure the crashes analyzed were in any case related to median, the research requested hard copies of all fatal and injury (incapacitating and non-incapacitating) crashes which occurred within these segments for the analysis period from TDOT. Crash collision diagrams, officer and crash witness narratives were the basis of hard copy reviews. Collision diagrams proved to be the most useful tool in understanding the location and progression of events in a crash. Along with the police narrative, a sequence of events can be examined to help determine what the contributing factors were and where the injury occurred. This is extremely useful in developing a conclusion of whether presence or absence of the cable barriers influenced the course of events that led to the final outcome of the crash. Sometimes additional statements from the drivers, passengers, or witnesses as recorded in the crash hard copy provided additional perspectives about the crash.

DESCRIPTIVE STATISTICS
The study compared injury severity levels and the impact of various roadway features, environmental conditions, vehicular activities, and driver characteristics before and after median cable rails were installed. Descriptive and comparative analysis helped in determining which parameters were more detrimental compared to others with respect to reducing the number of crashes and injury severities. Percent reduction in number of crashes and injury severity after cable rail installation is taken as an indicator of positive contribution of the cable rails. Overall, fatal and injury crashes were reduced by 21% as a result of median cable rails installation.

Crashes with Respect to Collision Type
Most crashes involved collision between vehicles and roadside objects including cable barriers. For non vehicle to vehicle collisions, the notable numbers are the reduction in sideswipe, rear end, angle and head-on crashes after cable barriers were installed. Head-on and angle crashes were reduced by 50% while rear end and sideswipe crashes were all reduced by 100%. A slight increase (by one crash) was seen with non-vehicular collisions (which include collisions with fixed objects).

Crash by Injury Severity
Crash injury severities are categorized into four ranks by TDOT, namely 1) fatal, 2) incapacitating, 3) non-incapacitating and 4) property damage only (PDO). Analysis shows that fatal crashes were reduced by 4 (80%) while number of persons killed was reduced by 7 (87.5%) after median cables were installed along these analyzed segments relative to before conditions. In total, the number of segments with at least one fatal crash was reduced from 5 before cable rails were installed to 1 after installation, an improvement of 80%. Reduction of fatal crashes and number of individuals killed in those fatal crashes highlights the safety effectiveness of the median cable rails.

Figure 1 highlights distribution of injury and fatal crashes as well as the number of people injured or killed in the crashes. As shown, fatal & injury crashes were reduced from 42 to 33 crashes (approximately 21% reduction) after cable rail installations. The total number of people killed or injured in these crashes was reduced by 16 (approximately 29% reduction). Comparison shows that a combination of no change and reduction significantly surpasses segments with increased percentages. For instance, 26 median cable rail segments resulted with no changes or reduction in number of persons killed compared to only 1 segment with an increase. Nineteen segments showed no increase or reduction of total injured compared with only 8 segments which showed increase in number of injuries. This also can be
highlighted as one of the effectiveness of the median cable rails. As pointed out before, PDO crashes were not screened. PDO crashes increased from 345 to 481 (approximately 39%) after cable rail installations. Increase in PDO crashes could be due to reported collisions with the cable barriers. In other words, after the installation of the cables, any contact between the vehicle and the cable rails was reported as property damage which created new category of crashes not previously reported before the cables were mounted.

**FIGURE 1 Overall Crashes by Injury Severities**

**Crashes by First Harmful Event**
First harmful event describes first action which led to the respective crash. Most of the collisions (19%) involved “vehicles in transportation”, another 19% “other traffic barrier”, 16% guardrail face and 25% combined entering ditch or hitting embankment. Entering the ditch, collisions on the earth embankments, and overturning crashes were some of the first harmful events which were reduced with cable rails installation. These types of crashes were also those expected to be reduced by the median cable barriers.

**Crashes with Respect to Roadway Location**
Almost 40.5% of all crashes occurred on the travel lanes before cable rails were installed compared to only 15.2% after cable rail installation. Crashes on the left side of the roadway saw the greatest increase from 36.4% to 14.3% after the cable rails were installed. This increase in the left side crashes can be attributed to collision with the cable rails which were now reported compared to before condition. Statistics also show that off roadway crashes increased compared to pre-median cable conditions.

**Crashes with Respect to Number of Vehicles in the Collision**
Median crossing crashes were expected to involve several vehicles especially if the collision occurred in the opposite travel direction after crossing the median. Before and after crashes were therefore compared in terms of total number of vehicles involved in a crash. Though collisions involving one vehicle was reduced by one crash only, two-vehicle crashes were reduced by 37.5%, while crashes involving three or more vehicles were eliminated all together (100%) after cable rails installation.
DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS

As discussed previously, the paper adopted safety effectiveness evaluation using procedures outlined in the Highway Safety Manual (HSM). 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 NB regression is by Cameron and Trivedi (33) as:

\[
p(y) = \frac{\Gamma(y+\alpha^{-1})}{\Gamma(\alpha^{-1})\Gamma(y+1)} \left( \frac{1}{1+\alpha\mu} \right)^{1/\alpha} \left( \frac{\alpha\mu}{1+\alpha\mu} \right)^y \\
y = 0, 1, 2, \ldots \quad (3)
\]

If \( \alpha = 0 \) means the mean is concentrated in the point, then it reduces to Poisson distribution. The mean parameter is given as \( \mu = e^{\sum X_i \beta} \) where

\[
Y_i = a \text{ random variable representing number of crashes per cable rail segment}
\]
\[
X_i = variable \text{ which is related to the occurrence of crash (AADT and length of the segment)}
\]
\[
\beta = the \text{ coefficient of the corresponding variables (coefficients of AADT and length)}
\]

Safety Performance Functions Coefficients

The prediction models incorporate different highway aspects (length, AADT, rural/urban, number of lanes, lane width, right shoulder width, and median width). As highlighted above, data for which the variance exceeds the mean are 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 regression equation. The larger the value of the overdispersion parameter, the more the variation in crash data (non-uniformity). The closer the overdispersion parameter is to zero, the more the uniformity in the crash data hence statistically reliable is the developed SPF. The overdispersion parameter is used to determine the value of a weight factor for use in the EB safety effectiveness evaluation. The safety performance function and overdispersion parameter for multilane roads are given as shown in equation 4 and 5 (1):

\[
N_{spf} = e^{(a+b*\ln(AADT)+\ln(L))} \quad (4)
\]
\[
k = \frac{1}{e^{(c+\ln(L))}} \quad (5)
\]

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)
- \( k \) is the overdispersion parameter associated with the roadway segment
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- a, b and c are regression coefficients

The HSM developed coefficients (a, b, c) are shown in Table 2. Safety Performance Functions were further developed using the study data. HSM recommends the use of local data to develop SPF if available rather than using general coefficients in the manual. Development of the SPF was conducted using Stata statistical software 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 was for HSM approach, the minimum data needed for model development are the length of the cable segment, AADT, and number crashes by year (both before and after). The cable barrier segment lengths were calculated from the beginning log mile to the end log mile. The study developed SPF using number of crashes under the following categories, 1) Fatal & All Injury Crashes, 2) Fatal and Incapacitating Injury Crashes and 3) Fatal Only crashes. The coefficients developed using Tennessee study data are shown in Table 2.

<table>
<thead>
<tr>
<th>HSM Coefficients</th>
<th>Severity Level</th>
<th>a</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Crashes</td>
<td>-9.025</td>
<td>1.049</td>
<td>1.549</td>
</tr>
<tr>
<td></td>
<td>Fatal &amp; Injury Crashes</td>
<td>-8.837</td>
<td>0.958</td>
<td>1.687</td>
</tr>
<tr>
<td></td>
<td>*KABCO Fatal and Injury</td>
<td>-8.505</td>
<td>0.874</td>
<td>1.740</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tennessee Study Data Coefficients</th>
<th>Fatal &amp; All Injury Crashes</th>
<th>5.447</th>
<th>-0.464</th>
<th>2.075</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal &amp; Incapacitating Injury Crashes</td>
<td>5.447</td>
<td>-0.464</td>
<td>2.075</td>
</tr>
<tr>
<td></td>
<td>Fatal Only Crashes</td>
<td>4.124</td>
<td>-0.522</td>
<td>4.457</td>
</tr>
</tbody>
</table>

*The KABCO scale is a measure of the injury level at the crash scene

SAFETY EFFECTIVENESS EVALUATION THROUGH EB

Safety effectiveness evaluation of the cable rail systems followed the procedures outlined in the Highway Safety Manual (1) as summarized in Table 3. Apart from the overall unbiased safety effectiveness, confidence level corresponding to the effectiveness was also determined. As shown in Table 3, the first step in the evaluation was the prediction model which incorporates different aspects of each site segment (length, AADT, lane width, right shoulder width, and median width). This built a baseline for the analysis using the known/existing crashes and the model then predicts the amount of crashes which should have occurred if the median barriers were not installed. Excel spreadsheets were set up and organized reflecting data appropriate category. Total number of crashes per segment for before and after periods was summed for later use in the analysis. The three crash groups examined were fatal, fatal & incapacitating injuries, and fatal & all injuries crashes. Evaluation allowed for the determination of effectiveness and degree of significance of overall cable rail systems (all segments combined), by TDOT regions, by Counties and by individual segments under the three crash data categories. The negative percentage indicates the cable didn’t make improvement (crashes increased), whereas positive percentage show an increase in effectiveness (crashes reduced) with the cable rail system.
**TABLE 3  Overview of EB Before-After Safety Evaluation**

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

*Source: 2010 Highway Safety Manual (HSM)*

**Overall Cable Rail Safety Effectiveness**

It is important to note that coefficients taken from the HSM were developed from safety data collected across the nation while the study data used only Tennessee crashes. Safety effectiveness was calculated using both HSM and study developed coefficients through steps in Table 2. The overall median cable rail barrier effectiveness's are shown in Figure 2. As shown, the cable rails improved safety effectiveness by more than 50% for all crash data categories. Fatal crashes were improved by 93%, combination of fatal and incapacitating injury crashes were improved by 85% and combination of fatal and all injury crashes was improved by 51% using study data coefficients. Using HSM coefficients showed even more positive results with 98%, 83% and 55% safety effectiveness for fatal, fatal & non-incapacitating and fatal & all injury crashes respectively, Figure 2. The overall safety effectiveness of the cable barrier segments in reducing number and severity of crashes were found to be significant above 95% confidence level. The confidence levels are high for both study data and HSM used model coefficients. This indicates that the installed cables were highly effective/influential especially in reducing fatal and injury crashes.
Safety Effectiveness by Individual Segments
The safety effectiveness breakdown by individual cable rail segments shows 26 out of 27 segments (96%) resulted with positive safety effectiveness for fatal and non-incapacitating crashes. For fatal and all injury crashes combined, 21 out of 27 segments (78%) resulted with positive safety effectiveness. Knowing individual segment safety performances is important in helping determine which factors played a role in improving or worsening the situation. Segments that showed negative results can be compared to those which showed positive results in terms of installation specifications, material, design, geometry and other related factors. This will allow TDOT to determine which factors are most important to consider when installing these cable rail systems, for example the manufacturer, distance from roadway, spacing of the cable columns etc. In addition to being able to recommend critical factors, outside controls can also be identified to determine whether anything could have been done to improve the system, such as local weather (higher elevation, fog, etc.), terrain, or out of state traffic unfamiliar with the section of highway.

CONCLUSIONS
Tennessee Department of Transportation installed median cable rail systems with the intention of preventing or reducing median crashes which occurs when a vehicle leaves its travel way, crosses the median dividing the highway directional lanes and collide with vehicle in the opposite direction. Apart from cross-median crash reductions, reduced injury severity e.g. reduction of fatal and incapacitating crashes or certain types of crashes are as well some of the expected benefits of cable rail systems. This study utilized median cable rails in the State of Tennessee to determine safety effectiveness in reducing significant number of collisions and injury severities as initially intended. In the course of the study process, contradicting statistics were found when all data within cable rail segment log miles were used in the analysis. This is because not all data falling within the cable segment log miles were median related relevant for evaluating safety effectiveness of cable barriers. The
use of all data within the segment produced significantly different results compared to the
hard copy reviewed data. Only 23.5% of all crash data within the cable segments were found
to be relevant, being affected by the presence or absence of the median cable barriers, 76.5%
was not related. The screened data only were then retained for descriptive statistics and safety
effectiveness evaluations. The following can be concluded from the descriptive and
comparative analysis;

• Installation of cable barriers substantially reduced fatal and injury crashes, and number of
  people killed or injured. Overall, fatal and injury crashes were reduced by 21% as a result
  of median cable rails installation.
• PDO crashes increased after cable rails were installed. This may be due to crashes
  involving vehicles with the cable rails installed which are counted as PDO. Before the
  cable rails were installed, these crashes were not there.
• As expected, crashes on the left side of the roadway increased after cable installation
  while outside shoulder and right side crashes decreased.
• Crashes involving more than two vehicles were reduced with the installation of barriers.
• Entering the ditch, collisions on the earth embankments, and overturning crashes were
  some of the first harmful events which were reduced with cable rails installation.
• Head-on and angle crashes were reduced by 50% while rear end, and sideswipe crashes
  were all reduced by 100%.
• Combination of segments with no change or reduction in number of fatal/injury crashes,
total injured and total killed significantly surpassed segments with increased percentages.

The empirical bayes (EB) before and after safety effectiveness evaluation was used to
compare crash frequencies before and after the cable rails were installed. Analysis considered
three categories of crash frequencies; 1) fatal crashes only, 2) fatal and incapacitating crashes
combined and 3) fatal and all injury crashes combined. The following are the conclusion
extracted from the (EB) before and after safety effectiveness evaluation:

• Safety effectiveness of the installed median cable barrier systems was 93% for fatal
  crashes, with confidence level above 95%.
• Safety effectiveness of the cable rails for the fatal & incapacitating injury crashes was
  85%, with confidence level above 95%.
• Safety effectiveness of the cable rails for the combination of fatal and all injury crashes
  was 51%, with confidence level above 95%.
• Almost every County of the segments analyzed (except one) reported 100% effectiveness
  in reducing fatal crashes after cable installation.
• Segments in Washington County reported the highest cable rail effectiveness of 95% for
  fatal & injury crashes followed by Marion (86%), Sullivan (85%) and Shelby (85%).
• Segments in Washington County reported the highest cable rail effectiveness of 88% for
  fatal & all injury crashes followed by Sullivan (85%), Marion (45%) and Shelby (16%).
• Most of individual segments resulted with positive safety effectiveness except one in
  Washington County (-19% for fatal and all injuries), two in Shelby County (-96% and -
  43% both for fatal and all injuries) and two in Marion County (-66% and -21% both for
  fatal and all injuries).

Recommendations for Future Studies
This study was the first part of the two phase study. Safety effectiveness with respect to cable
designs, installation procedures, material types, and other technical specifications were not
covered in this phase. Also not covered include economic analysis in terms of cost-
effectiveness and benefit cost ratio of the cable rail systems as part of the evaluation. This
study also didn’t cover Crash Modification Factors (CMFs). Next part of the study is expected to develop the CMFs which represent the change in safety caused by cable rail system installation and provide a way of estimating crash reductions through EB’s before-and-after analysis comparisons. For benefit-cost analysis, the change in crash frequency and severity will be converted to monetary values, summed and compared to the cost of installation of the cable rails. Cost effectiveness is expected to analyze the changes in crash frequency compared directly to the cost of implementing and installation of the cable rails. Median cable barrier segments will be ranked in terms of monetary value benefit cost ratio (B/C ratio) and cost-effectiveness index, and net present value. Ranking is expected to assist TDOT in selecting the most effective cable rail installed segments, effective cable rail manufacturer/designer, effective cable rail installation procedures and other related criteria. Further studies should include CMF for different cable designs, roadway conditions, so that the predicted SPF is not overly simplistic or likely flawed

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