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Accidents on Secondary Highways and Countermeasures, Phase II Identification of Promising Sites on Rural, Two-Lane Highways Using Inventory Data

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Identification of Promising Sites on Rural, Two-Lane Highways Using Inventory Data

Final Report

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Abstract

The purpose of this study is to investigate the feasibility and performance of roadway inventory methods in identifying hazardous road locations on rural secondary highways. The Tennessee Department of Transportation currently uses a collision-based method to identify possible "hazardous" locations for possible safety improvements. The roadway inventory-based methods have the desirable property of being proactive, as opposed to the reactive collision-based methods, in that they can identify potentially dangerous locations before crashes occur.

Our analysis begins with a literature review of alternative hazardous location identification methods. Several inventory-based hazardous location identification models for segments, curves and bridges are identified and chosen for further consideration. Two Tennessee counties are selected for analysis. Within these counties information is collected on physical roadway characteristics, average annual vehicle volumes, and motor-vehicle crash characteristics. This information supplies the data for developing hazard ratings from the inventory-based models. A comparison of the hazardous ratings for individual sites resulted in a list ten hazardous sites for further evaluation. In addition to the inventory-based models, a separate analysis was conducted using the Tennessee DOT's current (collision-based) method of identifying hazardous locations. This identification procedure resulted in a list of ten sites for further evaluation – although two of these sites were later discarded due to recent roadway improvements. There was no overlap between the top ten sites chosen by the two methods.

Photographs of the eighteen candidate sites were taken during a field visit to the two Tennessee counties. These photographs were included, along with other site information, in an "expert" questionnaire. Thirty-five surveys were mailed, twenty-four were returned. In these questionnaires, highway officials were asked to evaluate the sites and rank them according to their perceived hazardousness. The experts were also asked to recommend countermeasures for

each site. The recommended counter-measures were used to construct cost-effectiveness estimates based upon standard collisions-saved and cost of installing each countermeasure applied at that particular site.

The expert rankings were compared against the rankings from both the collision-based and the inventory-based methods, to compare the relative performance of the modeling strategies. Several tests of statistical comparison were used. The analysis of the data revealed that neither the collision-based nor the inventory-based method produced locations that were significantly more hazardous when controlling for the type of site selected. In other words, the experts believe that either method performs equally well in identifying the most hazardous sites. The inventory-based method identified bridge sites that were more cost effective to fix. We recommend that the inventory method be adopted as a complement to the collision-based method currently in use.

Chapter 1 - Introduction

In 1997, there were almost 7,000,000 reported motor vehicle collisions in the United States, resulting in 42,000 fatalities and 3,400,000 injuries.[1] Traffic fatalities are the leading cause of death of people between the ages of 6 and 27 in this country.[1] Fatality rates are especially problematic in rural areas and in the southeastern United States. According to the National Highway Traffic Safety Administration (NHTSA), only 38 % of the total vehicle miles traveled in 1995 were on rural roads, but 59 % of all traffic fatalities were on these roads.[2]

Two-lane, two-way roads account for 80 % of the roadway network in the United States, and 90 % of these secondary highways carry less than 1,000 vehicles per day.[3] These roads have low traffic volumes, but available information indicates they have higher collision rates than other highways. Between 1995 and 1997, the collision rate on primary routes in North Carolina was 184 collisions per 100 million vehicle-miles of travel (VMT), but the collision rate on rural, two-lane secondary roads was 262 collisions per 100 million VMT.[4] The fatality rate on the primary routes in North Carolina during the same time was 1.44 per 100 million VMT, but on rural, two-lane secondary roads, the fatality rate was 2.77 per 100 million VMT.[4] These statistics illustrate the safety problem on rural, two-lane highways that this work addresses.

To reduce the number of collisions, highway safety agencies use different methods to identify and correct hazardous sites. Almost all of the traditional hazardous site identification methods are based on collision data. This work describes the development of a method that was based on roadway inventory data instead of collision data. The potential advantages of this method are discussed later in this chapter, but first, a discussion of inventory data is presented.

1.1. Inventory data

Roadway inventory data are a quantitative description of dozens of typical roadway features, including lane width, shoulder width, vertical grade and degree of horizontal curvature.[5] The features along the road are typically measured by state DOT personnel, mileposted and saved in computerized spreadsheet files for reference. A roadway feature, such as lane width, is defined by a beginning and ending milepost, which are measured to the nearest hundredth of a mile. Table 1.1 is a portion of the horizontal curve inventory data file maintained by the Tennessee DOT.

Table 1.1. Sample of Tennessee DOT horizontal curve inventory file

nbr_tenn_cnty	nbr_rte	ha_beg_log_mle	ha_end_log_mle	dte_coll	deg_curve	lft_rgt
83	SR109	0.48	0.52	7/31/97	2.3	2
83	SR109	3.58	3.62	7/31/97	13.3	1
83	SR109	3.65	3.74	7/31/97	9.8	1
83	SR109	4.74	4.87	7/31/97	10	2

Note that 'nbr_tenn_cnty' refers to the county in Tennessee, and the 'nbr_rte' column contains the highway route number. The columns labeled 'ha_beg_log_mle' and 'ha_end_log_mle' contain the beginning and ending mileposts of the horizontal curve, respectively. The 'dte_coll' column indicates when the inventory data were collected. The 'deg_curve' column contains the degree of horizontal curvature. The 'lft_rgt' column indicates which direction the horizontal curve turns as the mileposts increase.

The highway mileposts are assigned directionally to locate the items in the inventory data. The Tennessee DOT starts at milepost 0.00 when the highway crosses a county line from the south or from the west. For north-south routes, the mileposts increase as the highway heads north, and for east-west routes, the mileposts increase as the highway heads east. When the highway crosses the next county line, the milepost resets to 0.00, then increases as before.

1.2. Collision data

Collision data contains many biases, and the quality of collision data varies from state to state. The errors associated with collision data are well documented, and Hughes et al.[6] discuss how collision data collection and administration practices are problematic. For example, the officer on the scene of a collision has many responsibilities, and completing the collision report has a lower priority than treating injuries and restoring traffic flow.

To highway safety engineers, collision location is arguably the most important piece of information in the collision report, and officers are often unable to accurately report the location without expensive equipment. Other important data such as vehicle type, driver information and the collision diagram are frequently missing, incomplete or incorrect. Also, reporting thresholds for property damage only (PDO) collisions vary from state to state and from year to year. As a result, many reportable collisions go unreported.

Errors are also introduced when a collision report is manually entered into the collision database. Portions of the hand-written report may be illegible, and a small percentage of the data is either entered incorrectly or not entered at all. On top of that, recent collision data are usually unavailable, and many states report backlogs of more than three months.[6]

There are emerging technologies that will improve the quality, accuracy and timeliness of collision data.[6] For example, the use of the Global Positioning System (GPS) allows officers to pinpoint collision location to within a few meters. The expanding implementation of laptop computers in patrol cars addresses legibility and timeliness issues. However, the hardware is prohibitively expensive for many police agencies, particularly in rural areas.

Another major problem with basing hazardous site identification methods on collision data is that collisions are very rare events. Very few collisions per year occur at most sites on rural, two-lane highways. Accurately judging the "hazardousness" of a site based on data on a few collisions is difficult.

1.3. Hazardous and 'promising' sites

There is an important distinction between a hazardous site and a 'promising' site that is referred to throughout this work. A hazardous site is one that has been identified by a particular method because collision data indicate a safety problem. A 'promising' site is a site where a cost-effective countermeasure can be installed to reduce collision frequency or severity.

Many highway safety agencies use hazardous site identification methods that only identify the hazardous sites in the highway network. However, some hazardous sites cannot be corrected adequately with a limited highway safety budget. Therefore, this work focused on the development and application of a 'promising' site identification method. Such a method was desirable because the goal was to identify sites where countermeasures can be installed in a cost-effective manner.

1.4. Potential advantages of using inventory data instead of collision data to identify 'promising' sites

A 'promising' site identification methodology based on inventory data was developed as an alternative to collision-based methods. The method presented here has three main advantages over traditional hazardous site identification methods. First, the quality and quantity of inventory data maintained by state DOTs across the country is steadily improving. Many states, like Tennessee, have comprehensive, accurate and up-to-date roadway inventories.

The second advantage is that the inventory method is proactive. Collision-based methods are reactive because collision data from collisions that have already occurred are required to perform the analysis. A method that prevents collisions by identifying hazardous sites before collisions occur is certainly more attractive.

The third advantage is the ability to identify 'promising' sites, not just hazardous sites. The collision-based methods that are in practice today are limited to identifying hazardous sites. However, if a site is repeatedly identified as hazardous, but cannot be corrected with a limited highway safety budget, then little progress is made. A 'promising' site is a site that is potentially hazardous where a cost-effective countermeasure can be installed to prevent future collisions.

1.5. Objectives, scope and organization

The main objective of this research was to compare the performance of a 'promising' site identification method that only requires roadway inventory data to a hazardous site identification method that was based on collision data. The method was developed and applied to two counties in Tennessee, while a collision-based hazardous site identification method was applied to the same two counties. The ten most 'promising' sites were identified with the Inventory Method and the eight most hazardous sites were identified with the collision-based method. Then, a questionnaire was mailed to dozens of highway safety experts to determine if one method identified sites that were more 'promising' than the other method.

The scope of the project was limited by three main factors. First, the study area was limited to two counties in Tennessee. Second, the study highway network consisted of the rural, two-lane highways with average annual daily traffic (AADT) of 5,000 vehicles per day or less in the two counties. Third, only mid-block sections of these highways were studied. Intersections were excluded from the analysis because these sites tend to have collision patterns that are much different than mid-block sites.

This work describes the development and application of the methodology, and feedback from a panel of highway safety experts across the southeastern United States. Chapter 2 presents a review of the existing literature that formed the theoretical foundation of this research effort. Chapter 3 outlines the main contribution of this research, which is a seven-step methodology used to identify 'promising' sites using roadway inventory data. Chapter 4 discusses the application of the method to two counties in Tennessee. Chapter 5 describes the questionnaire that was mailed to 35 highway safety experts in eight southeastern states. Chapter 6 provides results and analyses of the responses. Finally, Chapter 7 states the main conclusions and proposes recommendations for future research.

Chapter 2 - Literature Review

The first step of the research was to conduct a thorough review of the existing literature to document hazardous site identification methods that have been developed and tested by other researchers. Another objective of the literature review was to research collision prediction models for sites on rural, two-lane highways upon which the method presented in this work was based. First, traditional hazardous site identification programs are described, and then a 'promising' site identification method is discussed. This project focused on the development of a 'promising' site identification method using only roadway inventory data, and the collision prediction models that were the foundation of the methodology are presented later in this chapter.

2.1. Common collision-based hazardous site identification methods

Most highway safety agencies use hazardous site identification methods that are based on collision data. These include Frequency, Rate, Frequency Rate, Rate Quality Control and Severity methods. All five of these methods are described by Khisty and Lall[7] and by Parker et al.[8] After the most common methods are discussed, other methods that emerged from the literature are highlighted.

The Frequency method is based on the number of reported collisions that have occurred at each site during the study period, which is typically at least three years. This method is also called 'cluster' or 'black spot' analysis. Sites that exceed a predetermined threshold frequency are tagged as hazardous and investigated. However, the effectiveness of this method is dependent on the collision data, which is subject to the multitude of errors discussed in Chapter 1.

The Rate method is very similar to the Frequency method, but it also requires traffic volume data for each site, which may be unavailable. For highway sites that are considered spots, such as bridges, the collision rate is expressed in terms of collisions per million vehicles. For highway sections, the rate is in terms of collisions per million vehicle-miles. The collision rate is calculated for each site, using the following equations:

$$R_{spot} = \frac{A(1{,}000{,}000)}{365TV}$$

$$R_{section} = \frac{A(1{,}000{,}000)}{365TVL}$$

where

R_{spot} is the collision rate for spot sites, in collisions per million vehicles
$R_{section}$ is the collision rate for section sites, in collisions per million vehicle-miles
A is the collision frequency during the study period
T is the length of the time period, in years
V is the AADT for the site
L is the length of the section, in miles

The sites with collision rates that are higher than the critical rate are investigated. Again, this method is based on collision data, which are unreliable.

The Frequency Rate method considers both the collision frequency and the collision rate to identify hazardous sites. For each site, the collision frequency is plotted on the x-axis and the collision rate is plotted on the y-axis. The sites in the upper right portion of the plot have the combination of high collision frequencies and rates. These sites are flagged as the most hazardous, and investigated further.

The Rate Quality Control Method groups similar sites together, then uses a statistical test to determine if any sites have collision rates that deviate significantly from the collision rates of the other sites in the group. The critical rate is calculated with the following equation:

$$R_c = R_a + K\left(\frac{R_a}{M}\right)^{\frac{1}{2}}$$

where

R_c is the critical collision rate
R_a is the mean collision rate for all similar sites

K is a probability factor determined by the desired level of significance
M is the millions of vehicles entering a spot or millions of VMT over a section

It is assumed that the collision frequency at each site follows a Poisson distribution. The Rate Quality Control Method attempts to filter out the sites with high collision rates that are a result of random collisions.

In a paper for the Transportation Research Record, Hauer[9] points out the major flaw in the Frequency Rate and the Rate Quality Control methods. Besides relying on collision data, both methods compare collision rates for sites with similar characteristics, such as horizontal curves. Hauer suggests that studying the time-series of collision frequency and rates at individual sites is a more logical approach because every site has a unique collision history. A gradual or sudden increase in collision frequency or rate at a specific site indicates a safety problem only at that site. The method presented by Hauer[9] was not used in this research because it is also based on collision data.

Deacon et al.[10] developed a Severity Method, or Equivalent Property Damage Only (EPDO) Method, which is also based on collision data. Each site is given an overall severity rating with the formula:

$$EPDO = 9.5(F + A) + 3.5(B + C) + PDO$$

where

EPDO is the severity rating
F is the number of collisions that resulted in fatalities during the study period
A is the number of collisions that resulted in A-type injuries during the study period
B is the number of collisions that resulted in B-type injuries during the study period
C is the number of collisions that resulted in C-type injuries during the study period
PDO is the number of PDO collisions that occurred during the study period

An A-type injury includes major injuries such as broken bones. B-type injuries are less severe, and include minor bruises and abrasions, while a C-type injury is only a complaint of an injury. All sites are ranked by EPDO, and the sites at the top of the list are selected for further study. The Severity Method is questionable because the equivalency coefficients (i.e., 9.5 and 3.5) vary among different highway safety agencies. Saccomanno, Nassar and Shortreed[11] tested the validity of more complex severity models with collision data from Ontario, Canada. This method was not used because it relies on accurate collision data, and the coefficients in the model are subjective.

2.2. Other hazardous site identification methods

Hauer and Persaud[12] developed a variation of the Frequency Rate method that was compared to a sieve. The objective was to 'catch' all of the hazardous sites, while letting the non-hazardous sites 'fall through' the sieve. The authors derived a model predicting the long-run expected collision frequency at sites given the actual collision data from highway ramps in Ontario, Canada. The three measures of effectiveness for this method were the number of correct positives, false positives and false negatives that the statistical sieve identified. In general, a false negative result is more harmful than a false positive. A false negative means a truly hazardous site has escaped detection, but at least a false positive site is looked at more closely before deciding it is not hazardous. A good sieve identifies hazardous sites correctly with relative few false negatives and false positives.

Another project by Hauer and Persaud[13] studied the safety problems of at-grade railroad crossings. The authors used a statistical method to identify hazardous railroad crossings among a population of almost 10,000 urban railroad crossings in the United States. The authors' present results from a group of before-and-after experiments to evaluate the effectiveness of crossbucks, flashers and flashers with gates at railroad crossings. They concluded that converting warning devices from crossbucks to flashers, crossbucks to gates and flashers to gates reduced collision frequencies at railroad crossings by 51, 69 and 45 %, respectively.

Higle and Hecht[14] evaluated the effectiveness of three statistical methods to identify hazardous sites based on three years of collision data at 192 signalized intersections in Arizona. The authors attempted to identify the most hazardous sites using collision rates generated by 30 simulations based on the actual collision rates. The actual data were assumed to be the 'true' data, and the objective was to compare the results of the simulations with the 'true' data to identify the sites that were truly hazardous. One classical technique produced an excessive number of false negative results, but another classical method and a Bayesian method performed very well because they produced few false positive and false negative results. This method was not applicable to this work because it was based on collision data.

Taylor and Thomson[15] developed a well-known model for ranking hazardous sites on all highway facilities except freeways and central business districts. The model predicts the degree of hazardousness at a given site based on nine indicator variables using the following equation:

$$HI = (0.145)(IV)_{NumberofAccidents} + (0.199)(IV)_{AccidentRate} + (0.169)(IV)_{AccidentSeverity}$$
$$+ (0.073)(IV)_{V/C} + (0.066)(IV)_{SightDistance} + (0.053)(IV)_{TrafficConflicts}$$
$$+ (0.061)(IV)_{ErraticManeuvers} + (0.132)(IV)_{DriverExpectancy} + (0.102)(IV)_{InformationSystemDeficiencies}$$

where:

HI is the Hazardousness Index for the site
$IV_{\text{Number of Accidents}}$ is the indicator value for annual collision frequency
$IV_{\text{Accident Rate}}$ is the indicator value for the collision rate
$IV_{\text{Accident Severity}}$ is the indicator value for the accident severity
$IV_{V/C}$ is the indicator value for the volume-to-capacity ratio [v/c]
$IV_{\text{Sight Distance}}$ is the indicator value for the sight distance at the site
$IV_{\text{Traffic Conflicts}}$ is the indicator value for the number of conflicts per hour
$IV_{\text{Erratic Maneuvers}}$ is the indicator value for the number of erratic maneuvers per hour
$IV_{\text{Driver Expectancy}}$ is the indicator value for the driver expectancy at the site
$IV_{\text{Information System Deficiencies}}$ is the indicator value for problems in the Information System at the site

All of the indicator values are scored from 0 to 100 with more hazardous conditions earning higher scores. The rating system was based on feedback from 16 traffic engineers and safety experts who attended a workshop hosted by the authors. If information about one or more of the variables in the model is missing, the authors propose the following Hazardousness Rating Formula to evaluate the hazardousness of a site based on available data:

$$HI = \frac{\sum_i W_i (IV)_i}{\sum_i W_i}$$

where

HI is the weighted Hazardousness Index
W_i is the weighting factor for indicator i
$(IV)_i$ is the indicator value (0-100) for indicator i
ΣW_i is the sum of the weighting factors for all indicators used at the study site

Although this method is logical, it was not used for this study for two reasons. First, the model requires collision data, and second, typical inventory data files do not contain information about the number of conflicts per hour, the number of erratic maneuvers per hour, the driver expectancy or the deficiencies in the information system. All of these data have to be collected manually at each site to apply this method.

Tarko, Sinha and Farooq[16] developed a methodology for identifying hazardous areas of a roadway network, but not individual sites. The method used collision data to single out counties in Indiana with an excessive number of alcohol-related collisions. The authors used different confidence levels to detect counties with higher than expected alcohol-related collision frequencies. This methodology was not applicable to this work because the objective was to identify specific hazardous sites, not general hazardous areas.

Spring and Hummer[17] attempted to merge a Geographic Information System (GIS) and North Carolina's Accident Records System (ARS) to identify hazardous sites in Guilford County, North Carolina. The application of a GIS to the ARS is logical because all collisions have a specific location, and both systems have spatial dimensions. For the case study, 753 bridge sites in Guilford County, NC were examined to identify the most hazardous bridge sites. The research was limited by incomplete collision location information and difficulty with the interface between the GIS and ARS files. In fact, Spring and Hummer[17] found that 26,603 (70 %) of the 38,157 reported collisions in Guilford County were excluded from the study because of incomplete collision location information. This method may be more feasible in the near future, but was not used in this study primarily because it was based on collision data.

2.3. 'Sites with promise' method

The theoretical foundation of the methodology presented in this research was Hauer's 'sites with promise' method.[18] This technique attempts to locate hazardous sites that also have one or more cost-effective countermeasures. Hauer developed this method because identifying hazardous sites is not necessarily productive. In his paper, Hauer states:

> A site does not need to be unduly hazardous for there to be an opportunity to reduce accidents cheaply. Nor is it necessary to have accidents in a cluster (making it a black spot) for there to be a genuine need for remedial action. For the chosen term not to limit or misdirect discussion, the more neutral phrase: "sites with promise" is used.[18]

In other words, some hazardous sites require costly countermeasures to significantly reduce the number of collisions. In most jurisdictions, the highway safety budget is limited, and spending the money on inexpensive countermeasures at several 'sites with promise' may prevent more collisions than one expensive countermeasure at a single hazardous site.

Hauer[18] proposed ranking sites by five criteria: collision frequency, scaled deviation in collision frequency, jump in collision frequency, collision rate and scaled deviation in collision rate. The scaled deviation in collision frequency (or rate) is expressed as the jump in collision frequency (or rate) divided by the standard deviation of collision frequency (or rate) for similar sites. Hauer[18] argued that the jump in collision frequency and rate at a site is the most direct indication of a safety deficiency because an estimation of what is normal is used for comparison.

The 'sites with promise' method was not directly adopted for this work because it is a collision-based identification method. However, the concept of a 'promising' site is profound, and this research pursues that objective as opposed to settling for just identifying hazardous sites.

2.4. Collision prediction models for bridges

Eleven models for predicting collision frequencies or rates on rural highway sites emerged from the literature review. The models can be separated into bridge, horizontal curve and general highway segment collision prediction models. The first group of models predicts the collision rate in the vicinity of a bridge. A bridge-related collision prediction model developed by Turner[19] has the following governing equation:

$$Y = 0.4949 - 0.0612(RW) + 0.0022(RW)^2$$

where

Y is the predicted number of collisions per million vehicles
RW is the bridge width minus the approach roadway width, in feet.

The model is based on 2,849 bridge-related collisions that occurred in a four-year period on rural, two-lane roads in Texas. The model has an $R^2 = 0.81$ for the entire range of the RW variable. This model was selected for use in this project because the independent variables are found in a typical roadway inventory, and it has the highest R^2 of the bridge-related collision models that were studied.

Ivey et al.[20] formulated a bridge safety index that is the sum of ten weighted factors. Each bridge site is evaluated on a scale from 0 to 95 points, with 0 corresponding to the most hazardous condition, and 95 to the safest. The three most important factors are clear bridge width, the ratio of bridge lane width to approach lane width and the quality of the guardrail. Each of these factors is scored from 0 to 20 points, and the remaining seven factors are scored from 0 to 5 points. The other seven factors evaluate the recovery time for the driver, the recovery distance to stop the vehicle, the vertical curvature on both approaches to the bridge, the percentage shoulder reduction on the bridge, the volume to capacity ratio, the percentage of heavy truck traffic and the roadside distractions.

This bridge safety index is well known, but it was too cumbersome to use for this project. Factors such as quality of the guardrail, recovery time, recovery distance and volume to capacity ratio are not included in typical inventory data files. Subsequent studies by Ghandi et al.[21] and Murthy and Sinha[22] have attempted to simplify this model without much success.

Abed-Al-Rahim and Johnston[23] based a bridge-related collision model on a sample of more than 2,000 bridge-related collisions in North Carolina. The model had terms for average daily traffic (ADT), bridge length and bridge width relative to an acceptable width. When applied to all types of bridges, the model has an $R^2 = 0.33$, so the authors mentioned the need to develop separate models for different classes of bridges. Another reason not to use this model is the collision frequency was assumed to be Normally-distributed instead of Poisson-distributed.

2.5. Collision prediction models for horizontal and vertical curves

The second group of models includes the effect of roadway alignment on the collision frequency. Zegeer et al.[24] developed a model to predict collision frequency on horizontal curves on rural highway segments:

$$A = [1.55(L)(V) + 0.014(D)(V) - 0.012(S)(V)](0.978)^{(W-30)}$$

where

A is the number of total collisions on the curve in a 5-year period
L is the length of the curve, in miles
V is the millions of vehicles per 5-year period in both directions
D is the degree of horizontal curvature
S accounts for the presence of spiral transitions on both ends of the curve (S = 0 if no spiral exists, and S = 1 if spirals do exist)
W is the width of the roadway on the curve, in feet.

This model has a Pseudo $R^2 = 0.35$. One minor flaw with this model is that collisions are not assumed to be Poisson-distributed. However, the model was selected for this study because all of the variables are found in a typical roadway inventory, and the model has a relatively high coefficient of correlation.

Glennon et al.[25] developed a model to account for horizontal alignment of the roadway. The equation for the expected annual number of collisions, A, is:

$$A = (AR_s)(L)(V) + (0.0336)(D)(V)$$

where

AR_s is the average collision rate on comparable straight segments
L is the length of the segment
V is the ADT
D is the degree of horizontal curvature

This model is logical and simple, but sensitive to the AR_s variable, which is subjective and requires further study.

Neuman[26] developed the following equation for predicting the annual collision frequency, N, on rural, two-lane highway segments with vertical curves. Note that the form of the model is very similar to the model by Glennon et al.[25] for horizontal curves:

$$N = (AR_h)(L)(V) + (AR_h)(L_r)(V)(Far)$$

where

AR_h is the average collision rate for similar segments
L is the length of the segment, in miles
V is the ADT
L_r is the length of the sight distance restriction
Far is the collision rate factor that applies to the segment in question

The glaring weakness of this model is it relies too heavily on the *Far* factor, so the model has an unknown R^2 value. The author indicates the need to generate appropriate values for this variable for different classes of roads before the model can see practical application.

2.6. Collision prediction models for general highway segments

The third group of collision prediction models applies to all highway segments with an ADT of 5,000 or less. Bared and Vogt[27] formulated a model with an $R^2 = 0.65$. The governing equation predicts the expected number of collisions on the segment, AC_s, in a five-year period:

$$AC_s = (L)\exp[-5.2513 + 1.0794\log(ADT) - 0.0774(TW) - 0.0809(SW) + 0.0457(RHR) + 0.0061(DD) + 0.0355(H) + 0.0275(V)]$$

where

L is the segment length, in miles
ADT is the average daily traffic on the segment
TW is the travel lane width, in feet
SW is the shoulder width, in feet
RHR is the roadside hazard rating
DD is the driveway density, in driveways per mile
H is the horizontal curve index
V is the vertical curve index

The RHR variable for the segment is evaluated on an ordinal scale of 1 to 7. The low end of the scale is for sites with relatively wide, flat clear zones, and the high end is for sites with a roadside that includes several fixed objects or other hazardous features. The horizontal and vertical curve indexes are weighted measures of the roadway alignment along the entire segment. These factors are calculated using the following equations:

$$H = \sum (L)(D)^{1.5}$$

where

H is the horizontal curve index
L is the length of each horizontal curve, in hundreds of feet
D is the degree of curvature

$$V = \sum \frac{|g_1 - g_2|}{L}$$

where

V is the vertical curve index
L is the length of each vertical curve, in hundreds of feet
g_1 and g_2 are the absolute grades of each crest or sag

Segments with long or sharp horizontal curves have a high horizontal curve index, and segments with long or steep grades will have relatively high vertical curve indexes. This model was chosen for this study because it fit the data very well ($R^2 = 0.65$) and it includes seven explanatory variables that are commonly found in inventory data or easily collected.

Another collision prediction model for general highway segments was developed by Zegeer et al.[28], and uses a multiple log-linear regression equation with an $R^2 = 0.46$. The model equation is:

$$AO/M/Y = (0.0019)(ADT)^{0.8824}(0.8786)^{W}(0.9192)^{PA}(0.9316)^{UP}(1.2365)^{H}$$
$$(0.8822)^{TER1}(1.3221)^{TER2}$$

where

AO/M/Y is the number of single vehicle, head-on and sideswipe collisions per mile per year
ADT is the average daily traffic on the segment
W is lane width, in feet
PA is the average paved shoulder width, in feet
UP is the average unpaved shoulder width, in feet
H is the median roadside rating
TER1 = 1 if flat, 0 otherwise
TER2 = 1 if mountainous, 0 otherwise

Although the independent variables are reasonable, the model has been criticized in the literature because it is based on collision data from seven diverse states and the researchers assumed that collision frequency is Normally-distributed.

A model developed by Hadi et al.[29] was also considered for use in this project. Hadi et al.[29] attempted to model total, injury and fatal collision rates for different traffic levels based on four years of collision data in Florida. The final equation for total crash frequency, N, in a four-year period on two-lane, rural mid-block segments is:

$$N = \exp[-10.26 + 0.8249(Llen) + 0.8783(Ladt) - 0.0857(Lw) - 0.0130(Sp)$$
$$+ 0.0589(Is) - 0.0150(Ts)]$$

where

Llen = log(1,000 x section length in miles)
Ladt = log(ADT)
Lw is the lane width, in feet
Sp is the posted speed limit, in mph
Is is the number of intersections
Ts is the total shoulder width, in feet

The model development was sound because it assumed a Poisson distribution of collision frequency, and the Negative Binomial regression was used. However, the authors do not report an R^2 value for their equations, and the primary focus of the paper was to discuss the reduction in collision frequency when one or more variables was changed. Although this was a valid approach, it did not match the objective of this research as well as the model developed by Zegeer et al.[24]

2.7. Summary

The literature review uncovered many different hazardous site identification methods that have been published in recent years. However, all of the methods are based on collision data, which are reactive. Therefore, the method presented in this work is based on inventory data, which is not subject to the errors and inconsistencies associated with collision data. The foundation of the new method was laid out by selecting collision prediction models for bridges, horizontal curves and general highway segments on rural, two-lane highways.

Chapter 3 - Inventory Method

To identify 'promising' sites on rural, two-lane highways, a seven-step method was developed. The key characteristic of the algorithm is that it requires only roadway inventory data as input. The seven steps of the algorithm, hereafter referred to as the Inventory Method, are:

Step 1) Select population of highway sites
Step 2) Divide highway sites into bridges, horizontal curves and general highway segments
Step 3) Predict annual collision frequency at each site
Step 4) Calculate approximate cost of installing each possible countermeasure at each site
Step 5) Apply collision reduction factors for each possible countermeasure to predicted annual collision frequencies at each site
Step 6) Calculate the cost-effectiveness of each possible countermeasure at each site
Step 7) Identify the most 'promising' sites in the study area

Steps 1 through 3 estimate which sites are the most hazardous sites in a study area. Steps 4 through 7 are used to identify the most 'promising' sites. Following is a brief description of each step of the Inventory Method, and an example with actual data to demonstrate the algorithm is presented at the end of this chapter.

3.1. Step 1 – Select population of highway sites

The first step of the Inventory Method is to identify the highway network on which the analysis will be performed. To apply this method in this project, the site population was limited to rural, two-lane highways. The collision prediction models for bridges, horizontal curves and general highway segments are only valid for two-lane highways with AADT of 5,000 vehicles or less. Therefore, portions of the two-lane highway segments in the study area with ADT greater than 5,000 vehicles are discarded.

3.2. Step 2 – Divide sites into bridges, horizontal curves and general highway segments

In the second step of the Inventory Method, the highway sites are separated into bridges, horizontal curves and general highway segments. Note that other site types can be used if valid collision prediction models and high-quality inventory data are available. This organization is important because each site type has distinct collision patterns and contributing factors.

In most roadway inventories, the bridges and horizontal curves can be easily located with mileposts. Some bridge- and curve-related collisions occur on the bridge or curve itself, but many bridge- and curve-related collisions occur in the influence area on each approach. For example, a vehicle that encroaches the centerline on a narrow bridge may be involved in a sideswipe collision with an oncoming vehicle some distance past the bridge, but the collision was bridge-related. To account for the influence area, the milepost ranges for the bridge and horizontal curve sites can also include 0.1 miles along each approach.

The definition of a general highway segments is more complex. As shown in Section 2.6, the collision prediction model for general highway segments includes terms for the length of the segment, AADT, lane width, shoulder width, roadside hazard rating, driveway density, horizontal curve index and vertical curve index. For this study, the general highway segments were defined to be as homogeneous as possible. For each segment, the AADT, lane width and shoulder widths should be constant. If any of these three roadway features changes, the study segment ends at that milepost and the next segment begins. After the beginning and end mileposts for the segments are determined, the length, roadside hazard rating, driveway density, horizontal curve index and vertical curve index variables are calculated for each segment.

3.3. Step 3 – Predict annual collision frequency at each site

The collision prediction models chosen for the Inventory Method were discussed in Chapter 2. After dividing the study sites into three groups, the collision prediction model for each group is used to calculate the annual collision frequency at all of the sites in the group. The Turner[19] model for bridge sites, the Zegeer et al.[24] model for horizontal curves and the Bared and Vogt[27] model for general highway segments are applied to the appropriate group of sites.

These models were selected because they correlated well with the collision data the model was based on and they had variables that were found in a typical roadway inventory.

To compare all sites with each other, the predicted annual collision frequency is calculated. The Turner[19] model predicts the collision rate in terms of collisions per million vehicles, so the annual collision frequency is found using the AADT for the bridge. Once the collision rate is calculated in collisions per million vehicles, it is multiplied by the total number of vehicles per year that cross the bridge, in millions.

The Zegeer et al.[24] model for horizontal curves predicts the number of collisions at the site in a five-year period. Therefore, the predicted annual collision frequency is found by dividing the model prediction by five. The Bared and Vogt[27] model for general highway segments also predicts the five-year collision frequency for the segment, but the length of the segments may vary.

To compare the three site types fairly, the annual collision frequency for general highway segments is expressed in terms of annual collisions per mile. The collision frequency is expressed on a per-mile basis for the general highway segment sites because they are highway sections. The bridge and curve sites are considered spots, and the lengths of these sites will be similar. On the other hand, general highway segment sites can be several miles long. Therefore, calculating the collision frequency per mile per year is an attempt to normalize the length of the segments so they can be compared to the bridge and horizontal curve sites.

Note that the Inventory Method might be affected if other collision prediction models were chosen for Step 3 of the algorithm. Different collision prediction models for one site type (i.e., bridges) might predict different collision frequencies or rates, depending on the model chosen. For this study, the three prediction models were chosen based on criteria, which were discussed in Sections 2.4, 2.5 and 2.6. If the decision can be justified, other collision prediction models may be substituted into Step 3 of the Inventory Method.

3.4. Step 4 – Calculate approximate cost of installing each possible countermeasure at each site

In Step 4, the estimated cost of installing each candidate countermeasure is calculated at each site. Accurate unit costs of common countermeasures are required. Each site is unique, so having unit countermeasure costs on hand allows the engineer to calculate total cost at each site individually. For example, Curve A might be twice as long as Curve B, so the cost of widening the shoulder on Curve A should be twice that of Curve B, although the collision reduction factor is the same for both curves. The countermeasure unit costs can be obtained from a state DOT. For this project, the approximate countermeasure costs were obtained from North Carolina DOT.

3.5. Step 5 – Apply collision reduction factors for each possible countermeasure to predicted annual collision frequencies at each site

To perform Step 5 of the Inventory Method, a list of collision reduction factors for common countermeasures is needed. These factors can be obtained from different sources, including the Federal Highway Administration (FHWA) or a state DOT. The collision reduction factors published by FHWA and the California DOT are widely accepted. These lists are comprehensive and include dozens of common countermeasures. A sample of the collision reduction factors is shown in Table 3.1, and the complete list is included in Appendix A. Unless specified otherwise, the collision reduction factors apply to total collisions at a site. For example, some countermeasures, such as 'add asphalt seal coat', are more specific and only apply to wet-weather collisions.

Table 3.1. Sample collision reduction factors from the FHWA and the California DOT

Countermeasure	FHWA	California DOT	Mean
Widen shoulders	13 %	5 %	9 %
Install new traffic signal	23 %	29 %	26 %
Add asphalt seal coat (wet crashes only)	---	42 %	42 %
Install safety lighting	17 %	25 %	21 %
Upgrade guardrail	9 %	---	9 %

Note that for some countermeasures, the FHWA and California DOT report different collision reduction factors, and in some cases, the difference is significant. To apply the Inventory Method, the mean of the collision reduction factors for a particular countermeasure can be used in Step 5.

An alternate approach to using available lists of countermeasure collision reduction factors is to use the collision prediction models to generate these factors. For example, the horizontal curve model developed by Zegeer et al.[24] includes a term, W, for roadway width. If the other variables are held constant, the roadway width can be systematically varied to determine how it affects the predicted annual collision frequency. If widening the shoulder by 3 feet on each side is selected as a countermeasure for a horizontal curve site, the associated collision reduction factor can be calculated directly from the model.

After the list of countermeasures is complete, the collision reduction factor for each possible countermeasure is applied to the predicted annual collision frequency at each site. The reduced predicted annual collision frequency and the number of annual collisions saved are recorded for each site with each countermeasure. These data are needed to complete Step 6 of the Inventory Method algorithm.

3.6. Step 6 – Calculate the cost-effectiveness of each possible countermeasure at each site

Step 6 combines the results of Steps 4 and 5 to compute the cost-effectiveness of each possible countermeasure at each site. Cost-effectiveness is expressed in terms of dollars spent on the countermeasure per annual collision saved. The goal is to find countermeasures that are relatively inexpensive, but prevent a relatively high percentage of collisions. Countermeasures that are costly with low collision reduction factors are not cost-effective. The countermeasure cost-effectiveness measures how efficiently safety dollars can be spent, which is a logical measure of effectiveness (MOE) for this project. At the end of Step 6, each site in the study area is listed with its most cost-effective countermeasure, in terms of dollars spent per annual collision saved.

3.7. Step 7 – Identify the most 'promising' sites in the study area

Finally, the most 'promising' sites in the study area are identified in Step 7 by ranking the sites in ascending order of cost-effectiveness. The sites that have countermeasures with the fewest dollars spent per annual collision saved will rise to the top of the list. Remember that these are not necessarily the most hazardous sites in the study area. A very hazardous site might not have a cost-effective countermeasure, so it would not be high on the list of 'promising' sites. Conversely, a site that is not considered particularly hazardous might place high on the list of 'promising' sites because there is an inexpensive, yet effective, countermeasure available to the relatively few collisions that do occur.

Once the list of 'promising' sites is generated, the highway safety agency can decide which sites to investigate further. For instance, an agency might want to correct the ten most 'promising' sites, or the three most 'promising' bridge sites, or any other subset of the list. The goal here is to generate the list, then decide which sites to investigate and correct.

3.8. Example problem

The following example is provided to demonstrate how to apply the Inventory Method. Assume the study site is a 20° horizontal curve in Sumner County, Tennessee, that is 0.04 miles long, has an AADT of 3,500 vehicles (V = 6.3875 million vehicles in five years), no spiral transitions and the roadway is 26 feet wide. The example, summarized in Table 3.2, calculates the cost-effectiveness of widening the shoulder by 4 feet on the curve and 0.1 miles along both approaches.

Table 3.2. Inventory Method example

	Select site population	Sumner County, Tennessee
Step 2	Type of site	Horizontal curve
Step 3	Predicted annual collision frequency (using Zegeer et al.[24] model)	0.48
	Selected countermeasure: Widen shoulder by 4'	Cost = $75,000 per mile Collision Reduction Factor = 17%
Step 4	Cost of installing countermeasure	$18,000
Step 5	Predicted reduced number of annual collisions	0.40
	Predicted number of annual collisions saved	0.08
Step 6	Dollars spent per annual collision saved	$225,000
Step 7	Compare with all other sites	

This process is repeated for each possible countermeasure at each site to generate the list of 'promising' sites.

3.9. Summary

The Inventory Method is a seven-step process that can be used to identify 'promising' sites on rural, two-lane highways. A typical roadway inventory will have all of the necessary information needed to run the collision prediction models and evaluate the cost-effectiveness of possible countermeasures at each site. The Inventory Method is an alternative to collision-based methods, which also require large amounts of collision data. However, collision data are subject to many errors and are often out-of-date. On the other hand, roadway inventory data are becoming more accurate and recent data are available in many areas. The inventory method can also be used synergistically with the collision-based method.

Chapter 4 – Application of the Inventory Method

This chapter describes how the Inventory Method developed in Chapter 3 was used to identify the ten most 'promising' sites in two Tennessee counties. The objective of this chapter is to demonstrate how to apply the Inventory Method to identify 'promising' sites on a real highway network. The factors that affected the decision process at each of the seven steps are discussed in detail.

4.1. Step 1 – Select population of highway sites

The first step in the algorithm was to define the highway network to study. This step was critical to the entire process because the highway network must be defined accurately and correctly to insure the validity of the results. Tennessee was selected as the study state because the Tennessee DOT maintains one of the most accurate and up-to-date roadway inventory databases in the country. After a careful screening process, two of the 95 counties in Tennessee were chosen based on six criteria: sample size of collisions, location, terrain, quality of collision data, percentage of single-vehicle collisions and age of the roadway inventory data.

The sample-size criteria were used to find counties with significant numbers of annual collisions. Location of the counties was very important because if the counties were close to each other, the analysis may be biased by local collision reporting practices. It was also important to choose two counties with different terrain. If both counties had flat, rolling or mountainous terrain, the results may be biased, so the counties were required to have different terrain.

Quality of the collision data was also a key consideration because researchers at UNC-CH conducted a parallel hazardous site identification study based on the collision data. The quality of the collision data was evaluated by the percentage of reported collisions in the database that were missing location information. Counties with relatively low percentages of collisions without milepost information were favored in the selection process.

The percentage of single-vehicle collisions was used as a surrogate variable to evaluate the 'ruralness' of a county. It was assumed that counties with a high percentage of urban highway mileage also had a high percentage of multi-vehicle collisions. Therefore, counties with a high percentage of rural highway mileage were assumed to have a high percentage of single-vehicle collisions, such as run-off-the-road collisions. Counties with relatively high percentages of single-vehicle collisions were desirable for this study.

Finally, the age of the inventory data was obtained from the Tennessee DOT, and this was used as one of the screening criteria. The Tennessee DOT is continuously updating their roadway inventory files, and some counties have more recent data than other counties. There were counties with inventory data that were ten years old, so counties with more recent inventory data were favored.

After carefully reviewing these six criteria, Roane and Sumner Counties were selected for analysis. In 1995, there were 714 and 1,823 reported collisions in Roane and Sumner Counties, respectively. Out of the 95 counties in Tennessee, only 29 counties had more collisions than Roane County, and only eight counties had more collisions than Sumner County in 1995, so the sample size requirement was met. These counties are approximately 120 miles apart, Roane County has rolling terrain, and Sumner County has level terrain, so they have an acceptable mix of location and terrain. Both counties had relatively good collision data and a high percentage of single-vehicle collisions. According to the Tennessee DOT, the inventory data for both counties was two or three years old, which was considered as recent as possible. Table 4.1 summarizes the relevant data used to evaluate the six criteria.

Table 4.1. County selection evaluative criteria data

		County	
Criteria		Roane	Sumner
1	Sample size of reported collisions (1995)	714	1,823
2	Location	W of Knoxville, TN	NE of Nashville, TN
3	Terrain	Rolling	Level
4	% unmileposted collisions	30.67 %	30.72 %
5	% single-vehicle collisions	45.10 %	44.98 %
6	Age of inventory data	3-4 years	2 years

Note: In 1995, the average '% unmileposted collisions' and '% single-vehicle collisions' for the 95 counties were 32.13 %, and 44.05 %, respectively.

After Roane and Sumner Counties were selected, the next step was to define the two-lane highway segments in these counties that met the research requirements. Portions of the roadway network in these counties were systematically eliminated based on the available inventory data, the AADT and the presence of intersections.

This study was limited to state routes because these are the lowest functional class of roads for which the Tennessee DOT maintains horizontal and vertical curvature inventory data. These data were unavailable for minor roads in the two counties, so these roads could not be included in the 'promising' site identification process.

Next, the AADT files for both counties were consulted to identify the portions of the two-lane state roads with AADT of 5,000 vehicles or less in 1997. The AADT files report a beginning milepost, an end milepost and the AADT on that interval of the highway. For this study, highway segments with 5,000 or more vehicles per day were discarded. This reduced the eligible highway mileage from 127.00 miles to 70.99 miles in Roane County and from 225.78 miles to 103.5 miles in Sumner County.

Finally, the highway mileage in the vicinity of intersections was eliminated because intersections have different collision patterns than mid-block highway segments and the collision prediction models only apply to mid-block sites. During a data collection trip to Roane and Sumner Counties, the intersections where the highway traffic had to stop at either a signal or a stop sign were recorded. Intersections were assumed to have an influence area of 0.1 mile on each approach, and these milepost intervals were also discarded.

4.2. Step 2 – Divide sites into bridges, horizontal curves and general highway segments

In this step, the highway mileage was split into the three site groups. First, the beginning mileposts of the bridges were located in the roadway structure inventory files. Bridges that were on the eligible portions of the highway network were retained for the analysis. The only inventory data needed to run Turner's[19] bridge collision model is the bridge width and the approach roadway width. The only variable in the model is RW, which is the approach roadway width minus the bridge width, in feet. Turner[19] reports the range of the RW variable includes bridges that were more than 6 feet narrower to over 14 feet wider than the approach roadway. However, the maximum and minimum RW values were not reported, so all bridges in the study area were assumed to be in the model range.

Approach roadway width was available for all of the bridges, but bridge width data was missing for 20 (42 %) of the eligible bridges, so they were not included in the study. If a highway safety agency were to use the Inventory Method, some data, like bridge width, may have to be collected manually if the existing inventory data are incomplete.

The beginning and ending mileposts of the horizontal curves were listed in the curve inventory files. Some of the curves had one milepost in the eligible network and the other on a portion of the highway that was discarded. In these cases, the curve was not studied because it was not entirely on the study network. The other variables in the collision prediction model by Zegeer et al.[24] were traffic volume, degree of curve, presence of spiral transitions and roadway width. The traffic volume and roadway widths were found in the inventory data, and degree of curve is listed for each curve with the beginning and ending mileposts in the curve inventory files. For this study, it was assumed that the horizontal curves on the rural, two-lane highways in the study area did not have spiral transitions, so S = 0 in the model.

The general highway segments were defined as described in Section 3.2. Beginning at one end of an eligible highway, the beginning and ending mileposts of the general highway segments were defined when either AADT, lane width or shoulder width changed. The general highway segments were also terminated by the bridge sites. Therefore, the horizontal curves were included in the general highway segments, but the bridges were not because they were considered to be significantly different from the general highway segments. The shortest and longest segments in the study were 0.44 and 5.08 miles long, respectively. Bared and Vogt[27] report the ranges for all of the variables in their collision prediction model for general highway segments. All of the general highway segments in the study area fell within the given ranges. Table 4.2 describes the site population in the study area.

Table 4.2. Site population in Roane and Sumner Counties, Tennessee

	County		
Item	**Roane**	**Sumner**	**Total**
Two-lane highway mileage	127.90 mi.	225.78 mi.	353.68 mi.
Two-lane highway mileage, ADT < 5,000	70.99 mi.	103.47 mi.	174.46 mi.
Number of bridge sites	5	23	28
Number of horizontal curve sites	140	203	343
Number of general segment sites	14	43	57
Total number of sites	159	269	428

Note that 343 (80 %) of the 428 sites were horizontal curves, 57 (13 %) were general highway segments and only 28 (7 %) were bridges.

4.3. Step 3 – Predict annual collision frequency at each site

The collision prediction models developed by Turner[19], Zegeer et al.[24] and Bared and Vogt[27] were applied to the bridges, horizontal curves and general highway segment sites, respectively. The predicted annual collision frequencies at all bridge, horizontal curve and general highway segment sites are included in Appendices B, C and D, respectively.

The bridge collision prediction model by Turner[19] predicts a collision rate in terms of collisions per million vehicles. The collision rate at each bridge site was easily converted to an annual frequency using the AADT data. The horizontal curve model developed by Zegeer et al.[24] predicts the total number of collisions in a five-year period. The five-year collision totals were converted to annual collision frequencies at each site.

The collision prediction model for general highway segments by and Bared and Vogt[27] also predicts the total number of collisions on the segment in a five-year period. However, the general highway segments vary in length from 0.44 to 5.08 miles, so to compare them fairly with each other and with the bridges and horizontal curves, the prediction was converted into an annual collision frequency per mile.

4.4. Step 4 – Calculate approximate cost of installing each possible countermeasure at each site

To begin Step 4, a complete list of common countermeasures for sites on rural, two-lane highways was needed. The North Carolina DOT was contacted, and that agency uses a list of countermeasures compiled by the FHWA and the California DOT. The entire list of countermeasures, and collision reduction factors from the FHWA and the California DOT is in Appendix A. Table 4.3 lists 13 common countermeasures that were selected for this project.

Unit countermeasure costs were obtained from the North Carolina DOT, and are shown in the 'Unit Cost' column of Table 4.3. The unit costs were used to estimate the cost of installing a particular countermeasure at a specific site. Note from Table 4.3 that some countermeasures were only applicable to bridges and horizontal curves, while other countermeasures could be applied to any site category.

Table 4.3. Estimated unit costs and collision reduction factors for common countermeasures

	#	Countermeasure	Unit	Unit Cost	CRF
Bridges	1	Widen existing bridge	sq. ft.	$75	0.38
	2	Replace bridge	sq. ft.	$65 (+$200K detour)	0.66
	3	Retro-fit bridge rail	linear foot	$125	0.19
Curves	4	Install spiral transitions	linear foot	$125	0.09
	5	Increase curve radius	linear foot	$150	0.42
	6	Superelevate curve	linear foot	$60	0.65
All sites	7	Do nothing	--	$0	0.00
	8	Widen paved shoulder	4' per mile	$75,000	0.17
	9	Widen travel lane	2' per mile	$220,000	0.28
	10	Install illumination	light pole	$2,400	0.21
	11	Upgrade guardrail	linear foot	$12	0.09
	12	Remove roadside trees	sq. ft.	$0.40	0.22
	13	Install warning sign	sign	$250	0.16

To calculate the cost of the possible countermeasures at each site, assumptions were made that limited the list of possible countermeasures that could be applied. In the cost-effectiveness analysis, only countermeasures that could be reasonably assumed to be eligible were considered. For example, the 'widen paved shoulder' countermeasure was applicable to the horizontal curve sites because the width of the existing shoulder was known. If a horizontal curve site was identified as one of the most 'promising' sites in the study area based on the cost-effectiveness of relocating utility poles, but there are no poles at the site, then the Inventory Method is flawed. The objective in Step 4 was to calculate the cost of installing possible countermeasures when it was reasonable to assume that the countermeasure was not already in place at the site. Table 4.4 indicates which countermeasures were evaluated at each type of site.

Table 4.4. Possible countermeasures that were considered at each site type

	#	Countermeasure	Bridges	Curves	Segments
Bridges	1	Widen existing bridge	X		
	2	Replace bridge	X		
	3	Retro-fit bridge rail	X		
Curves	4	Install spiral transitions		X	
	5	Increase curve radius		X	
	6	Superelevate curve		X	
All Sites	7	Do nothing	X	X	X
	8	Widen paved shoulder		X	X
	9	Widen travel lane		X	X
	10	Install illumination	X	X	X
	11	Upgrade guardrail		X	X
	12	Remove roadside trees		X	X
	13	Install warning sign	X	X	X

Note: An 'X' indicates the countermeasure was applied to the site type

Reasonable assumptions were made in the cost calculations for each countermeasure at each type of site. The cost of some countermeasures was a function of the length of the sites. For example, the cost of widening the shoulder on a horizontal curve depends directly on the length of the curve. Following is a brief discussion of the considerations and assumptions made for each countermeasure at each type of site.

The first three countermeasures in Table 4.4 apply only to bridge sites. For the 'widen existing bridge' countermeasure, a widening of two feet on each side of the bridge was assumed. This amount of widening was considered to be a reasonable bridge-widening project. To calculate the cost of widening an entire bridge, the bridge length was found in the inventory data, multiplied by four feet of widening, then by $75 per square foot. The cost of the 'replace existing bridge' countermeasure was a similar calculation. The cost was $65 per square foot of new bridge deck area, but a detour cost of $200,000 was added to the total cost of the project. The cost of retrofitting a bridge rail was $125 multiplied by twice the length of the bridge, in feet.

The countermeasures in the second section of Table 4.4 apply only to horizontal curve sites. The cost of installing spiral transitions on both ends of a horizontal curve was calculated assuming the spirals would be 50 feet long on each approach. The cost of 'increase curve radius' and 'superelevate curve' were the unit cost multiplied by the length of the curve in feet, including 0.1 mile on each approach.

The remaining countermeasures were applicable to all three site types. The cost of 'widen paved shoulder' on horizontal curves was $75,000 per mile, multiplied by the length of the curve in miles, including 0.1 mile on each approach. For general highway segments, the unit cost was multiplied by the length of the segment. For the 'widen travel lane' countermeasure, the cost was $220,000 per mile, multiplied by the length of the site.

The 'install illumination' option was applied to all three site categories. For bridges, the cost of installing one light pole at each end of the bridge was calculated because that would provide adequate lighting for most bridges on rural, two-lane highways. For horizontal curves and general highway segments, the cost was based on a pole separation of 200 feet.

The 'upgrade guardrail' option was applied to horizontal curve and general highway segment sites. The cost was $12 per foot, multiplied by the length of the site, in feet. The length of the curve sites included 0.1 mile on both approaches.

The cost of 'remove roadside trees' was calculated for horizontal curve and general highway segment sites. The unit cost is expressed in terms of square feet, and it was assumed that the roadside would be cleared of trees up to 15 feet from the roadway. To calculate the total cost, the unit cost was multiplied by 30 feet of total clearing, then by the length of the site, in feet.

For the 'install warning signs' option, the cost of installing four warning signs (two per approach) was calculated. This countermeasure was also applied to all sites.

4.5. Step 5 – Apply collision reduction factors for each possible countermeasure to predicted annual collision frequencies at each site

For Step 5 of the Inventory Method, a list of collision reduction factors for common countermeasures was obtained from the North Carolina DOT, and that agency uses a list of factors compiled by the FHWA and the California DOT. In Table 4.3, the column titled 'CRF', for Collision Reduction Factor, is the percentage of total collisions that are prevented by the countermeasure, according to the FHWA and California DOT. For example, widening a paved shoulder by four feet at a particular site reduces the total number of collisions at that site by 17 %.

If published collision reduction factors are unavailable, a list of factors could be developed from the collision prediction models. For example, the collision reduction factor associated with widening the shoulder by 4' could be calculated by holding the other variables in the Bared and Vogt[27] constant and comparing the predicted collision frequency with the existing shoulder width and the widened shoulder. The percentage reduction in collision frequency could be used to estimate the collision reductions at other general highway segment sites.

Table 4.5 contains collision reduction factors that were calculated for the 'widen existing bridge' countermeasure using the collision prediction model developed by Turner[19].

Table 4.5. Calculated collision reduction factors for 'widen existing bridge' countermeasure

		Widen bridge by x feet		
RW [ft]	**Collisions per Million Vehicles**	**4**	**6**	**8**
-14	1.783	--	--	--
-12	1.546	24.1 %	--	--
-10	1.327	25.6 %	34.9 %	--
-8	1.125	27.2 %	36.9 %	44.8 %
-6	0.941	29.1 %	39.1 %	47.2 %
-4	0.775	31.1 %	41.6 %	49.9 %
-2	0.626	33.5 %	44.4 %	52.8 %
0	0.495	36.1 %	47.4 %	56.0 %

To find the collision reduction factor at a specific bridge site, start at the 'RW' column and find the RW value for the bridge. Then, read across Table 4.5 to the chosen widening, and the collision reduction factor is expressed as a percentage. Similar tables could be constructed for any of the variables in the collision prediction models to generate a list of collision reduction factors. Note that the collision reduction factors calculated in Table 4.5 agree with the collision reduction factor for 'widen existing bridge' reported by the FHWA and the California DOT (38 %), especially for a widening of 6 feet.

After the appropriate countermeasures were chosen, the number of predicted annual collisions saved was calculated for each candidate countermeasure at each site. The predicted number of annual collisions was multiplied by the collision reduction factor to find the number of predicted annual collisions saved by installing the given countermeasure.

In this project, the installation of a single countermeasure was considered at each site. Highway safety agencies often recommend installing two or more countermeasures at a hazardous site to prevent collisions. If multiple countermeasures are installed simultaneously, a composite collision reduction factor is calculated because it is not possible to reduce collisions by more than 100 %, no matter how many countermeasures are applied. Parker et al.[8] propose the following equation to account for the installation of more than one countermeasure at a site:

$$AR_M = AR_1 + (1 - AR_1)AR_2 + (1 - AR_1)(1 - AR_2)AR_3 + \ldots + (1 - AR_1)(1 - AR_{i-1})AR_i$$

where

AR_M is the overall accident reduction factor for multiple countermeasures installed at a single location
AR_i is the accident reduction factor for a specific countermeasure
i is the number of improvements at a single location

Note that AR_1 should correspond to the countermeasure with the highest collision reduction factor, AR_2 should correspond to the next most effective countermeasure, and so on.[8] For this project, the installation of multiple countermeasures was not considered because of the sheer number of combinations that could be applied. The assumption was a highway safety agency would apply the Inventory Method to find the single most cost-effective countermeasure at each site.

4.6. Step 6 – Calculate the cost-effectiveness of each possible countermeasure at each site

Cost-effectiveness was the most appropriate MOE for the Inventory Method. The main goal of highway safety engineering is to prevent collisions. The Inventory Method attempted to do this by identifying 'promising' sites, where a relatively inexpensive countermeasure could prevent a significant number of collisions. At each site, the cost-effectiveness of each candidate countermeasure was calculated using the cost calculated in Step 4, and dividing by the predicted number of annual collisions saved, which was found in Step 5. The result is the cost-effectiveness of the countermeasure at each site in terms of dollars spent per annual collision saved.

The following tables show the most 'promising' sites in the study area. Tables 4.6, 4.7 and 4.8 contain the five most 'promising' bridge sites, horizontal curve sites and general highway segment sites, respectively.

Table 4.6. The five most 'promising' bridge sites in the study area

#	Bridge	Length	Estimated Annual Collision Frequency	Countermeasure	Cost-effectiveness ($/collision saved)
1	S 324	37'	1.220	Widen bridge 4'	$29,176
2	S 323	43'	0.976	Widen bridge 4'	$39,958
3	S 314	86'	2.037	Widen bridge 4'	$49,533
4	S 309	154'	2.362	Widen bridge 4'	$76,355
5	R 142	170'	2.269	Widen bridge 4'	$82,879

Note that the cost-effectiveness of widening the bridges was directly related to the length of the bridge. The three most cost-effective bridges to widen were also the three shortest bridges in the study area. These bridges minimize the new bridge deck area, while achieving the same reduction in collisions from widening the bridge. Longer bridges were not as cost-effective to widen because they require more new bridge deck area for the same reduction in collisions.

Table 4.7 shows the five most 'promising' horizontal curve sites in the study area.

Table 4.7. The five most 'promising' horizontal curve sites in the study area

#	Curve	Length	Estimated Annual Collision Frequency	Countermeasure	Cost-effectiveness ($/collision saved)
1	A	0.03 mi.	0.893	Remove roadside trees	$74,177
2	B	0.03 mi.	0.640	Remove roadside trees	$103,500
3	C	0.03 mi.	0.550	Remove roadside trees	$120,438
4	F	0.03 mi.	0.483	Remove roadside trees	$137,481
5	D	0.11 mi.	0.518	Remove roadside trees	$229,809

Note that the 'remove roadside trees' countermeasure was the most cost-effective at the top five curves, and the top four are the same length, so the cost was also the same. Curve D was not as cost-effective as Curve F because it is much longer, and would require more roadside clearing.

Table 4.8 contains the results of the five most cost-effective general highway segments. Note that the most cost-effective countermeasure on these general highway segments was also 'remove roadside trees'.

Table 4.8. The five most 'promising' general highway segment sites in the study area

#	Segment	Length	Estimated Annual Collision Frequency	Countermeasure	Cost-effectiveness ($/collision saved)
1	A	1.66 mi.	4.034	Remove roadside trees	$118,513
2	B	1.78 mi.	4.290	Remove roadside trees	$119,497
3	C	0.81 mi.	1.912	Remove roadside trees	$122,008
4	D	2.91 mi.	6.548	Remove roadside trees	$127,990
5	E	1.92 mi.	4.172	Remove roadside trees	$132,541

To identify the ten most 'promising' sites in the study, the results of the cost-effectiveness for the three site categories were combined. All of the sites were listed together with the most cost-effective countermeasure for each site.

4.7. Step 7 – Identify the most 'promising' sites in the study area

In Step 7, the sites were ranked in ascending order of dollars spent per annual collision saved. The most 'promising' sites rose to the top of this list because the countermeasures applied to these sites were the most cost-effective. The ten most 'promising' sites were identified by ranking all sites in ascending order of cost-effectiveness, and they are shown in Table 4.9.

Table 4.9. The ten most 'promising' sites in the study area

#	Site	Length	Annual Frequency	Countermeasure	Cost-effectiveness ($/collision saved)
1	Bridge 324	37'	1.220	Widen bridge 4'	$29,176
2	Bridge 323	43'	0.976	Widen bridge 4'	$39,958
3	Bridge 314	86'	2.037	Widen bridge 4'	$49,533
4	Curve A	0.03 mi.	0.893	Remove roadside trees	$74,177
5	Bridge 309	154'	2.362	Widen bridge 4'	$76,355
6	Bridge 142	170'	2.269	Widen bridge 4'	$82,879
7	Bridge 322	154'	1.744	Widen bridge 4'	$91,270
8	Bridge 325	113'	1.020	Widen bridge 4'	$99,210
9	Curve B	0.03 mi.	0.640	Remove roadside trees	$103,500
10	Segment A	1.66 mi.	4.034	Remove roadside trees	$118,513

Note that the top ten most 'promising' sites include seven bridges, two horizontal curves and one general highway segment. However, only 28 (7 %) of the 428 sites in the study area are bridges, while 343 (80 %) of the sites are horizontal curves. This means that, in general, this application of the Inventory Method identified bridges as very 'promising' sites for improvement on rural, two-lane highways.

4.8. Summary

This chapter discusses the application of the Inventory Method to rural, two-lane highways in Roane and Sumner Counties, Tennessee. The methodology presented in Chapter 3 was followed, and all seven steps of the Inventory Method were explained in more detail. The Inventory Method was used to identify the ten most 'promising' sites out of the population of 428 sites.

Chapter 5 - Hazardous Site Identification Method

The collision-based identification method was incorporated to contrast the results of the inventory identification method with the process currently followed by TDOT. Eight most hazardous sites in the two counties were identified using a collision-based method that replicates TDOT's current hazardous site identification method. The sites identified by the collision-based method are evaluated against the sites identified by the inventory method. This chapter describes the process of applying the collision-based method to Roane and Sumner crash data and presents the results of this analysis.

5.1 Step 1 – Determining Relevant Crashes

The first step in applying the collision inventory method is to determine crashes that are relevant for analysis. Determination of the relevant crashes for analysis involved several components. The relevant crashes must take place on roadway segments subject to the same criteria as used in the inventory method. As mentioned in section 3.1, selected road segments were restricted to rural, two-lane roads with annual traffic volumes below 5,000 ADT within Roane and Sumner counties. Identification was based upon Tennessee's roadway inventory database and these roadways were verified through physical inspection. Selected roadways were also restricted to those that did not involve any major design changes, between the first year of data collection and present time. The study team also identified the bridge, curve and segment components of these roadways based upon the same definitions as used for the inventory data analysis (see section 3.2).

The Tennessee Department of Transportation provided police crash reports data on crashes in Sumner and Roane counties for three years, 1995, 1996, 1997. Each accident report was coded by the number of vehicles involved, the severity of the crash injuries, the milepost location of the crash site, the nature of the crash, major road features, and several other relevant crash characteristics. A Geographic Information System (GIS) representation of the two county study areas was developed based upon U.S. Census Tiger road network files linked to TDOT roadway inventory data. Milepost and other site information contained in the crash file enabled the study team to match particular crash locations with road segments. The accuracy of the network and location of crashes was confirmed by analysis of County road inventory maps provided by TDOT, and physical inspection. Intersection crashes were not included in this analysis. All crashes occurring within .1 mile of a major intersection were removed. The GIS was also used to produced a database of eligible road segments, curves and bridges, containing data on total crashes, injury and fatal crashes, segment lengths, and AADT for each site in both counties in all three years. Appendix E provides summary tables of crash data by study region sites.

5.2. Step 2 – Accident Rate Calculations

The procedures for determining particular hazardous locations follow the TDOT Safety Manual[30], with little modification. This method is a variant of the Quality Rate method described in Chapter 2[30]. The first step in this method is to calculate an accident rate for each site. The accident rate is a standardized measure and permits a rough comparison of hazardousness both within and across site types. The accident rate for any particular location is calculated as:

Sections: $R_s = A*10^6 / T*V*L$

Spots (bridges and curves): $R_p = A*10^6 / T*V$

where

R_s = Accident rate expressed as accidents per million vehicle-miles for highway sections longer than 0.1 mile;

R_p = Accident rate expressed as accidents per million entering vehicles for a "spot" location where a cluster of accidents occurs within a distance of 0.1 mile, or a point location such as a bridge;

A = Number of accidents recorded at a location;

L	=	Length of the section in miles, to the nearest hundredth;
T	=	Time period, in days, for the number of accidents, T = 1,095 for three years;
V	=	Vehicle volume in average annual daily traffic (AADT) on a section or spot;
10^6	=	A constant to convert accidents per vehicle or vehicle-mile to million vehicles or million vehicle-miles.

Appendix E lists the accident rate calculations for all sights by segment type.

5.2. Step 3 - Statistical Considerations

By their nature, vehicular crashes are random events, which can occur independently of road design or other site characteristics. In addition, few crashes occur within a finite time period at any particular location. Therefore, it is necessary to develop a statistical procedure to determine the locations that experienced a large number of accidents beyond that occurring by chance. The TDOT method meets these statistical considerations by determining an average crash rate by segment type, and developing a statistical confidence interval around this average rate. If a particular site has more crashes than the upper limit of the chosen confidence interval, it is reasonable to assume that the hazardousness of this site is beyond that possible through chance alone.

The TDOT safety manual suggests calculating separate average hazard ratings by type of road location (sections, curves, and bridges), types of highways (two-lane, multi-lane), and types of environment (rural, and urban). Due to the limit scope of our analysis, the later two classifications are irrelevant. To calculate the average rates all accidents and vehicle miles for the eligible locations in the two counties were summed for the specific class. These sums were used in the following equations to calculate the average accident rates:

Sections: $R_s^{bar} = \Sigma A*10^6 / \Sigma (T*V*L)$

Spots (bridges & curves): $R_p^{bar} = \Sigma A*10^6 / \Sigma (T*V)$

Where:

R_s^{bar} and R_p^{bar} = the average value for R_s and R_p, respectively.

Upper and lower confidence limits were established for the average accident rates. The upper limit is also referred to as the "critical rate" because any rate larger than this value is unlikely to entirely attributable to chance. The upper control limit is determined by the following formula:

$$Rc = R^{bar} + K\sqrt{R^{bar}/m} + (1/2)*m$$

where:

Rc	=	Critical Accident Rate;
R^{bar}	=	Average accident rate for the appropriate location type
m	=	Vehicular travel, in millions of vehicle-miles or millions of vehicles; and
K	=	2.327 (corresponding to a confidence level of 99% along a standard normal curve.

The TDOT safety manual recommends the use of a K value of 2.327, reflecting a 99% confidence interval around the average crash rate, assuming a normal distribution. In practice, TDOT recommends only selecting site that have a hazard rating equal to or greater than four times the critical rate to keep the list of hazardous sites to a manageable number. A hazard rating was produced for each site by dividing the crash rate the appropriate critical rate. A hazard rate greater than or equal four indicates sites with crash rates beyond four times the critical rate. The hazard rating for each site by type also appear in Appendix E.

5.4. Step 4 - Final selection criteria

The final list of hazardous sites only included sites where there were at least four crashes in the past three years. The TDOT safety manual recommends using sites with at least 6 crashes in the past three years, but we found it necessary to lower this cut-off to four to ensure enough sites for analysis. Furthermore, the TDOT safety manual suggests the creation of a severity index for each location, to aid in selecting from among locations that meet all the other evaluation criteria. The index is calculated as:

$$SI = F + I \ / \ F{+}I{+}PDO$$

where:

SI	=	Severity Index
F	=	Number of Fatality Accidents
I	=	Number of Injury Accidents
PDO	=	Number of Property Damage Only Accidents

Although this index was calculated and is included in Appendix E, there were not enough sites meeting the other evaluation criteria to warrant its use in this analysis.

5.5. Eight most hazardous sites

Table 5.1 shows the eight most hazardous sites as determined by the TDOT method. These sites met all of the criteria described previously in this chapter. Two additional sites met the qualification criteria, but were eliminated due to recent reconstruction.

Table 5.1. The eight most hazardous sites in the study area (in random order)

Site Type	Route	County	Crashes	Accident Rate	Hazard Rate	Severity Index
Bridge	SR174	Sumner	4	7.025	10.428	Severity 0.75
Curve	SR025	Sumner	7	2.089	8.560	0.43
Segment	SR025	Sumner	33	12.959	5.0608	0.283
Curve	SR029	Roane	17	3.901	15.982	0.35
Curve	SR174	Sumner	5	2.020	8.278	0.201
Bridge	SR025	Sumner	10	2.984	10.428	0.50
Curve	SR174	Sumner	4	1.616	6.623	0.75
Curve	SR001	Roane	4	1.522	6.236	0.50

Note that five of the eight sites were horizontal curve sites, one was a general highway segment and two were bridges. This distribution was similar to the overall distribution of site types in the study area (80 % curves, 13 % general highway segments and 7 % bridges). Furthermore, the majority of selected sites were in Sumner County. This is to be expected given the larger pool of possible sites in Sumner, and not indicative of any county specific characteristics.

It is interesting to note that none of the sites were identified with both methods. The TDOT method identified two bridge sites among the eight most hazardous sites, but these bridges were not among the seven most 'promising' bridges from the Inventory Method. One possible explanation for this trend is that the Inventory Method tended to identify short bridges as more 'promising' than long bridges because they would be relatively inexpensive to widen. Note that one of the bridges identified as hazardous by the TDOT method is 140' long, so this bridge would not be identified as 'promising' by the Inventory Method. The same trend was true for the horizontal curve sites and the general highway segment sites. In general, the Inventory Method identified spot sites, such as short bridges and curves, as more 'promising' to correct than section sites, such as long bridges and horizontal curves, because installing a countermeasure at a spot site is less expensive than at a section site, while the collision reduction is the same.

5.6. Summary

The eight most hazardous sites were identified with the TDOT collision method. These sites included two bridges, seven horizontal curves and one general highway segment. There were no common sites to both the inventory method and the collision-based method. A panel of experts reviewed information about the 18 sites, and participated in a questionnaire that is described in Chapter 6.

Chapter 6 – Expert Opinion

An important part of this research effort was to gather feedback about the Inventory Method from an expert panel of highway safety professionals. Questionnaires containing information about the 18 most hazardous and 'promising' sites in the study area were mailed to a panel of highway safety experts across the southeastern United States. The questionnaires also contained color photographs of each site. Ten of the sites were identified as 'promising' with the Inventory Method, and eight sites were identified by researchers at UNC-CH as the most hazardous sites in the study area. The objective of the questionnaire was to determine if the experts thought that one method identified sites that were more cost-effective to correct than the other method.

6.1. Selection of the expert panel

A panel of highway safety experts was chosen to review the 18 sites selected by the Inventory Method and the TDOT Method. The goal of the questionnaire was to obtain the opinions of highway safety professionals who are underrepresented in academic literature. The panelists were selected because they deal directly with highway safety issues every day.

Highway safety experts from eight southeastern states (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee) were contacted by phone, were given a brief description of the project, were asked to review the questionnaire and were asked to confirm their mailing address. The panel consisted of State DOT Design Engineers, State DOT Traffic Engineers, State Highway Patrol Commanders and FHWA Division Traffic Engineers in each of the eight states. At least four officials in each state were contacted, and a total of 35 experts agreed to participate in the study, including at least three from each state in the southeast.

The list of experts contacted for this study was based on a list of highway safety experts who were asked to respond to a questionnaire during Phase I of this project. The previous list included a State DOT Design Engineer, a State DOT Traffic Engineer, a Highway Patrol Officer and a representative from the Governor's Highway Safety Program in all eight states. However, only two out of the eight representatives from the Governor's Highway Safety Program responded to that questionnaire, so they were replaced on this list by FHWA Division Traffic Engineers.

6.2. Questionnaire format

A 20-page packet of information was assembled for review by each expert panelist. The cover letter was followed by a response sheet to be filled out and returned. The response sheet had a list of 18 possible countermeasures that could be installed at the sites. The remainder of the packet was information describing the 18 sites, one site per page. Each page had the arbitrary site number at the top and two color digital camera photographs of the site. One photograph was taken on the centerline of one approach to the site, and the other image was from the shoulder of the same approach. At the bottom of each page was a table including the type of site (bridge, curve or segment), AADT, lane width, shoulder width, degree of horizontal curvature and bridge width (if appropriate). A sample copy of the cover letter, survey response sheet and the 18 site pages is included in Appendix F. Sample photographs from five randomly selected sites (two curves, two bridges and one curve) are displayed in Appendix G. The packets were identical, and the sites and countermeasures were presented in random order. To avoid bias in the responses, the experts were not told which method identified each site.

The respondents were asked two questions regarding each site. The first question asked the respondent to objectively evaluate the hazardousness of the site on a scale of 1 (collisions very infrequent) to 7 (collisions very frequent). On this scale, a score of 4 would correspond to average collision frequency in the opinion of the panelists.

The second question asked the respondent to consider typical highway safety budget constraints and recommend a single countermeasure for each site from a list of 18 common countermeasures. This question addressed the concept of a 'promising' site because if a site was identified as hazardous, but a cost-effective countermeasure could not be recommended, safety dollars were best spent on other sites.

As shown in Table 6.1, at least three experts in each state agreed on the phone to participate in the study, and at least two experts actually responded from each state, except Florida. Out of the 35 experts that were asked to participate, 24 (69%) responded, including all six of the North Carolina experts, and five out of seven experts in Tennessee.

Table 6.1. Questionnaire response rates by state

State	Packets Mailed	Responses
Alabama	3	3
Florida	3	1
Georgia	4	2
Kentucky	4	3
Mississippi	4	2
North Carolina	6	6
South Carolina	4	2
Tennessee	7	5
Total	35	24

Table 6.2 shows the distribution of responses by expert office. Note that out of the 24 responses, each position was represented at least four times. Also, the response rate for the FHWA Division Traffic Engineers (71 %) was much higher than the response rate of the Governor's Highway Safety Program representatives who participated in the previous study.

Table 6.2. Questionnaire response rates by expert office

Office	Packets Mailed	Responses
State Design Engineer	8	5
State Traffic Engineer	13	10
Highway Patrol	7	4
FHWA Division	7	5
Total	35	24

This questionnaire was considered successful because a wide cross-section of professional opinion was obtained. Each state and each expert office was well represented in this study.

6.3. Summary

Questionnaires containing data about 18 sites were mailed to 35 experts across the southeastern United States. The Inventory Method was used to identify the ten most 'promising' sites and the TDOT method was used to identify the eight most hazardous sites in the study area. Out of the 35 experts who agreed to participate, 24 (69%) responded to the questionnaire. The goal of Chapter 7 was to analyze the responses to determine how well the Inventory Method identified 'promising' sites compared to the TDOT Method.

Chapter 7 – Analysis and Results

This chapter summarizes the questionnaire responses of the 24 highway safety professionals who participated in the study. The first part of this chapter discusses the hazard ratings of the sites, but most of the chapter focuses on the question of cost-effectiveness of the countermeasure recommendations made by the expert panelists. The goal was to determine if, in the opinion of the expert panel, the Inventory Method identified sites that were more 'promising' than the sites identified with the TDOT method, or vice versa.

7.1. Question #1 – Hazard ratings of the sites

The first question asked the respondents to evaluate the "hazardousness" of the 18 sites on a scale of 1 (collisions very infrequent) to 7 (collisions very infrequent). The hazard rating given to each site by each expert was potentially influenced by many factors, including the method that selected the site, the type of site and the job title of the expert. The relationships between the hazard ratings and the influencing factors were explored using basic statistics. Table 7.1 summarizes the mean hazard ratings of different site groups. The hazard rating responses for all of the sites are shown in Table 7.2.

Table 7.1. Mean hazard rating by the experts of major site groups

Site group	Number of sites	Mean Hazard Rating
TDOT Method	8	3.73
Inventory Method	10	3.35
Horizontal curves	7	3.92
Bridges	9	3.27
Segments	2	3.27
All	18	3.52

Table 7.2. Hazard ratings by respondent for all 18 sites

		Alabama	Alabama	Alabama	Florida	Georgia	Georgia	Kentucky	Kentucky	Kentucky	Mississippi	Mississippi	North Carolina	North Carolina	North Carolina	North Carolina	North Carolina	North Carolina	South Carolina	South Carolina	Tennessee	Tennessee	Tennessee	Tennessee	Tennessee	Mean	Median	Mode
#	Site Type	1	2	4	6	9	10	13	15	16	18	19	21	22	23	24	25	26	28	30	31	32	33	34	35			
1	Bridge	5	1	5	1	3	5	1	4	4	3	5	6	1	3	4	1	2	2	2	3	4	2	5	3	3.13	3	5
2	Bridge	1	1	2	1	5	1	4	5	5	2	3	1	2	1	1	1	1	3	2	5	1	7	3	1	2.46	2	1
3	Bridge	2	1	7	4	6	1	7	5	5	2	6	4	4	2	5	1	5	3	3	5	2	7	3	4	3.92	4	5
4	Bridge	6	3	6	3	6	4	3	4	7	2	4	3	3	2	4	1	2	3	3	5	3	4	4	4	3.71	4	3
5	Curve	7	1	6	3	4	4	6	3	5	3	5	1	3	3	3	3	6	3	4	6	4	4	4	5	4.00	4	3
6	Segment	3	2	5	3	5	2	3	3	4	2	5	1	3	4	4	4	5	3	2	5	2	4	3	4	3.38	3	3
7	Bridge	6	1	4	3	6	6	5	6	6	2	3	1	3	3	3	2	3	3	4	6	3	5	5	5	3.92	4	3
8	Curve	4	1	5	3	6	6	5	6	7	4	4	1	4	4	2	2	4	3	4	6	6	4	3	4	4.08	4	4
9	Bridge	3	1	3	2	4	1	3	3	4	1	3	1	2	1	6	1	1	3	2	2	2	4	2		2.39	2	1
10	Curve	1	3	3	2	3	4	4	2	4	2	5	2	2	4	2	5	2	3	3	2	3	4	4	4	3.04	3	2
11	Curve	6	3	4	4	1	4	4	3	5	2	5	3	5	4	5	4	5	3	4	4	6	4	5	6	4.13	4	4
12	Bridge	7	1	2	5	5	4	3	4	6	2	6	3	4	2	5	2	4	4	4	6	3	4	5	4	3.96	4	4
13	Segment	5	1	6	3	1	5	4	2	3	2	4	2	3	3	2	2	5	3	2	2	3	7	2	4	3.17	3	2
14	Bridge	3	2	5	2	3	2	3	2	4	2	6	3	1	1	5	3	2	3	2	2	3	7	3	3	3.00	3	3
15	Bridge	4	1	5	2	3	2	4	2	4	3	4	2	2	2	5	3	3	3	2	2	2	5	3	2	2.92	3	2
16	Curve	7	3	6	4	6	6	6	6	7	3	6	2	3	5	4	4	6	6	4	2	3	4	6	5	4.75	5	6
17	Curve	6	2	6	4	6	4	7	3	6	3	7	2	5	5	2	4	5	5	4	3	3	4	5	5	4.42	5	5
18	Curve	3	1	4	2	1	3	4	2	4	1	5	2	4	3	5	3		3	2	3	2		4	3	2.91	3	3
	Mean	4.4	1.6	4.7	2.8	4.1	3.6	4.2	3.6	5.0	2.3	4.8	2.2	3.0	2.9	3.7	2.6	3.6	3.3	2.9	3.8	3.1	4.7	3.8	3.9			
	Median	4.5	1.0	5.0	3.0	4.5	4.0	4.0	3.0	5.0	2.0	5.0	2.0	3.0	3.0	4.0	2.5	4.0	3.0	3.0	3.5	3.0	4.0	4.0	4.0			
	Mode	6	1	5	3	6	4	4	3	4	2	5	1	3	3	5	1	5	3	2	2	3	4	3	4			

Overall, based on the mean hazard ratings, the experts considered the TDOT Method sites to be more hazardous than the Inventory Method sites. Also, the horizontal curve sites were considered more hazardous than the bridges and general highway segment sites. Note that the groups of bridges and general highway segment sites had similar mean hazard ratings.

To test if one method identified sites that were more hazardous than the other method, the Mann-Whitney Rank Test was applied.[31] This statistical test was used to determine if one group of sites ranked higher on a list than the other group sites. First, the sites were ranked in descending order of mean hazard rating, as shown in Table 7.3.

Table 7.3. Sites ranked by mean hazard rating

Rank	Site #	Method	Site Type	Mean Hazard Rating
1	16	Inventory	Curve	4.75
2	17	TDOT	Curve	4.42
3	11	TDOT	Curve	4.13
4	8	TDOT	Curve	4.08
5	5	TDOT	Curve	4.00
6	12	Inventory	Bridge	3.96
7.5	3	Inventory	Bridge	3.92
7.5	7	Inventory	Bridge	3.92
9	4	TDOT	Bridge	3.71
10	6	TDOT	Segment	3.38
11	13	Inventory	Segment	3.17
12	1	TDOT	Bridge	3.13
13	10	TDOT	Curve	3.04
14	14	Inventory	Bridge	3.00
15	15	Inventory	Bridge	2.92
16	18	Inventory	Curve	2.91
17	9	Inventory	Bridge	2.39
18	2	Inventory	Bridge	2.46
Overall				3.52

To apply the Mann-Whitney test, the sum of the ranks for the TDOT Method sites, R_1, was found. Then, the Mann-Whitney statistic, U, was calculated as follows:

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

where:

n_1 is the number of TDOT Method sites
n_2 is the number of Inventory Method sites
R_1 is the sum of the ranks for the TDOT Method sites

For this study, the test was to determine if one method identified sites that were more hazardous than the other method. This is a two-tailed test, so the second Mann-Whitney statistic, U', is needed, and it was calculated as follows:

$$U' = n_1 n_2 - U$$

where:

U' is the second Mann-Whitney statistic
n_1 is the number of TDOT Method sites
n_2 is the number of Inventory Method sites
U is the first Mann-Whitney statistic

The Mann-Whitney statistics were compared to critical values found in statistical tables to test the null hypothesis:

H_O: The mean hazard rating of the TDOT Method sites was equal to the mean hazard rating of the Inventory Method sites

H_A: The mean hazard rating of the TDOT Method sites was not equal to the mean hazard rating of the Inventory Method sites

TDOT Method	**Inventory Method**
$n_1 = 8$ sites	$n_2 = 10$ sites
$R_1 = 58$	$R_2 = 113$

$$U = (8)(10) + \frac{8(8+1)}{2} - 58 = 58$$

$$U' = (8)(10) - 58 = 22$$

The critical statistic found in the textbook by Zar[31], at 5 % significance, is 63. The Mann-Whitney statistics, U and U', were both less than 63, so the null hypothesis could not be rejected. Note that at 20 % significance, the critical statistic is 56, so the null hypothesis would be rejected at that level of significance.

A one-tailed t-test was performed on the mean hazard ratings to test if the mean hazard rating for the TDOT Method sites was significantly higher than the mean hazard rating for the Inventory Method sites. The null and alternative hypotheses were:

H_O: The mean hazard rating for the TDOT sites was not greater than the mean hazard rating for the Inventory Method sites.

H_A: The mean hazard rating for the TDOT sites was greater than the mean hazard rating for the Inventory Method sites.

TDOT Method	Inventory Method
$n_1 = 192$	$n_2 = 237$
$v_1 = 191$	$v_2 = 236$
$X_1 = 3.73$	$X_2 = 3.35$
$SS_1 = 407.453$	$SS_2 = 689.215$

$$S_p^2 = 2.568$$
$$S_X = 0.156$$
$$t = 2.442$$
$$t_{critical} = t_{0.05(1),\,427} = 1.648$$

The t-statistic was greater than the critical t-statistic, therefore the null hypothesis was rejected. At 5 % significance, the mean hazard rating of the TDOT Method sites was significantly greater than the mean hazard rating of the Inventory Method sites.

A two-tailed t-test was performed for the bridge sites to determine if one method identified bridges that the experts considered more hazardous than the other method. For this test, the null and alternative hypotheses were:

H_O: The mean hazard rating of the bridge sites identified with the TDOT Method was equal to the mean hazard rating of the bridge sites identified with the Inventory Method.

H_A: The mean hazard rating for the bridge sites identified with the TDOT Method was not equal to the mean hazard rating for the bridge sites identified with the Inventory Method.

TDOT Method	Inventory Method
$n_1 = 48$	$n_2 = 167$
$v_1 = 47$	$v_2 = 166$
$X_1 = 3.42$	$X_2 = 3.23$
$SS_1 = 109.660$	$SS_2 = 47.770$

$$S_p^2 = 0.739$$
$$S_X = 0.141$$
$$t = 1.349$$
$$t_{critical} = t_{0.05(2),\,213} = 1.971$$

The calculated t-statistic was less than the critical t-statistic, so the null hypothesis could not be rejected. Therefore we conclude that neither method produced a list of bridges that were more hazardous than the other.

A two-tailed t-test was performed on the horizontal curve sites to determine if the experts thought one method identified horizontal curve sites that were more hazardous than the other method. The null and alternative hypotheses were:

H_O: The mean hazard rating of the curve sites identified with the TDOT Method was equal to the mean hazard rating of the curve sites identified with the Inventory Method.

H_A: The mean hazard rating of the curve sites identified with the TDOT Method was not equal to the mean hazard rating of the curve sites identified with the Inventory Method.

TDOT Method	Inventory Method
$n_1 = 120$	$n_2 = 46$
$v_1 = 119$	$v_2 = 45$
$X_1 = 3.93$	$X_2 = 3.87$
$SS_1 = 253.467$	$SS_2 = 153.164$

$$S_p^2 = 2.479$$
$$S_X = 0.273$$
$$t = 0.220$$
$$t_{critical} = t_{0.05(2),\,164} = 1.975$$

The calculated t-statistic was less than the critical t-statistic of 1.975, therefore the null hypothesis could not be rejected. In other words, neither method appears to produce a list of more hazardous curves.

To elaborate upon the paired comparison analysis, a linear regression model was estimated. The linear regression model allows for the statistical testing of several variables as explanatory factors in a model, essentially quantifying the effect of one explanatory variable while simultaneously controlling for the influence of other explanatory variables. The dependent variable for this model was the hazard rating for a given site as determined by each expert witness. The explanatory variables were dummy variable representations of whether the site was identified by inventory method or collision method, whether the site was a bridge, segment, or curve, the job title of the respondent (DOT design engineer, DOT traffic engineer, etc.), and the state of origin of the respondent.

The final regression model results are included in Table 7.4. This model has a relatively weak R^2 of .0408, indicating that the explanatory variables only explain 4% of the variation in the dependent variable. This might be due to the limited number of explanatory variables in the model. What is more revealing for our purposes is the coefficient estimates of the explanatory variables and the statistical significance of these variables. As mentioned before, all of the independent variables are dummy variables, taking on a value of 1 if the observation has the characteristic in question, and zero otherwise. A regression model cannot be estimated if it includes all of the categories for a particular explanatory variable. Therefore one category from the set must be withheld for estimation. The coefficient for the included variable(s) represent the change in the dependent variable attributable to that variable compared against the withheld variable (referred to as the base). In our analysis, the inventory method dummy variable is included, and the collision method dummy variable is withheld (not included). The coefficient estimate for the inventory variable is -.1414, indicating that on a scale of 1 to 7 the inventory method selected sites are perceived .1414 less hazardous than the collision based method sites, controlling for the type of site (bridge, segment or curve). The Pr. < [t] value, on the other hand, for the method variable indicates that this difference is statistically insignificant at the 95% confidence level

Furthermore, the coefficient estimates for bridges and segments are both negative and statistically significant at a 95% level of confidence. This indicates that on a scale of 1 to 7 the experts rate bridges as .575 less hazardous than curves, and segments as .613 less hazardous than curves, controlling for the method of selection. The intercept indicates that experts perceive the sites to be in the middle of the hazardousness scale. Regression models were also estimated that included the job title and state of expert variables, but none of them were statistically significant and therefore withheld from the final model specification.

Table 7.4. OLS Regression model for Site/Expert Specific Hazard Ratings

Dependent Variable: Reported Hazard Rating (On a 1-7 Scale)

Model Summary:

	N: 428	d.f.: 425
	F value: 6.03	Pr > F: .0005
	R^2: .0408	Adj. R^2: .0341

Parameter Estimates:

Variable	Parameter Estimate	Standard Error	t-value	Pr > $\|t_C\|$
Intercept	3.95485	.13014	30.39	.0001
Inventory Method	-.14141	.17177	-.82	.4108
Bridge	-.57524	.18266	-3.15	.0018
Segment	-.61331	.25860	-2.37	.0182

These results suggest that in the experts' opinion collision sites are more hazardous than inventory sites. This is partly because the collision method selects more curves than the inventory method. Once the type of site is controlled for, the experts' opinion of the difference between the hazard ratings of two methods evaporates, as indicated by the lack of significant differences between the mean hazard ratings of the inventory method and the collision method. This result is also supported by another, unreported, regression model that estimated the inventory method dummy variable as the sole independent variable. When site type is not controlled for, the collision method sites are perceived significantly more hazardous than the inventory sites at the 5% confidence level.

7.2. Question #2 – Countermeasure recommendations

Table 7.5 contains all of the countermeasure recommendations made by each expert at each site. The recommendations were coded according to the response sheet found in Appendix E. The codes are also listed below for easier reference:

1. Do nothing
2. Widen travel lane
3. Superelevate curve
4. Install or improve warning signs
5. Install spiral transitions on curve
6. Add turn lane
7. Upgrade guardrail
8. Widen existing bridge
9. Lengthen vertical curve
10. Lengthen horizontal curve radius
11. Install illumination
12. Widen shoulder
13. Replace bridge with wider bridge
14. Install or improve bridge rail
15. Remove roadside trees
16. Flatten side slopes
17. Relocate utility poles
18. Install or improve pavement markings
19. Other

There was a notable trend among the countermeasure recommendations. The most obvious was that three of the 18 possible countermeasures, 'superelevate curve', 'install spiral transitions on curve', and 'install illumination' were not recommended by any expert at any site. This indicates that, in the opinion of the highway safety experts, these countermeasures were not as cost-effective as the other countermeasures on the list, based on the given information.

Overall, five countermeasures accounted for 275 (75 %) of the 366 total recommendations that were made. The five most commonly recommended countermeasures were 'do nothing' (24 %), 'install or improve warning signs' (22 %), 'upgrade guardrail' (14 %), 'lengthen horizontal curve radius' (9 %) and 'install or improve pavement markings' (5 %). These countermeasures were among the least expensive to install. This indicates that the experts took into account that most highway safety agencies have relatively small budgets. The 'lengthen

Table 7.5. Number of countermeasure recommendations made by experts at each site

#	Site Type	Method	1 Do nothing	2 Widen travel lane	3 Superelevate curve	4 Install or improve warning signs	5 Install spiral transitions on curve	6 Add turn lane	7 Upgrade guardrail	8 Widen existing bridge	9 Lengthen vertical curve	10 Lengthen horizontal curve radius	11 Install illumination	12 Widen shoulder	13 Replace bridge with wider bridge	14 Install or improve bridge rail	15 Remove roadside trees	16 Flatten side slopes	17 Relocate poles	18 Install or improve pavement markings
1	Bridge	TDOT	2			1			9						4	3	2			
2	Bridge	Inventory	10			1			2						3					6
3	Bridge	Inventory	4			2			4	1					3	2	1			4
4	Bridge	TDOT	2			1			10						2	5				
5	Curve	TDOT	3			6		2				3		1			1		2	1
6	Segment	TDOT	5			5		2											3	
7	Bridge	Inventory	4			9		1	1	1					1	1				1
8	Curve	TDOT	5			4			2			4								1
9	Bridge	Inventory	11	1		2			3					1		3				
10	Curve	TDOT	4			5		2	1		1			1				7		1
11	Curve	TDOT	1			6		3				8							2	1
12	Bridge	Inventory	1						11	3					2	4				
13	Segment	Inventory	9			8								3						
14	Bridge	Inventory	5	2		9		1	4	1										
15	Bridge	Inventory	9	1		4		1	4	1							1			1
16	Curve	Inventory	4			5			1			8					2			1
17	Curve	TDOT	3			8		1				6					2			1
18	Curve	Inventory	6			5						5		1			2		1	2
		Total	88	4	0	81	0	13	52	7	1	34	0	7	15	18	11	7	8	20

Note: There were 14 'other' responses, and they were included with the most similar countermeasure on the list, or ignored horizontal curve radius' countermeasure was fairly expensive, but the experts considered it to be one of the most cost-effective countermeasures for horizontal curves.

Table 7.6 shows the results of a chi-square test that was performed on the most common countermeasure recommendations for the sites identified by each method.[31] The goal of the two-tailed chi-square test was to determine if there was a significant relationship between the identification method and the countermeasure recommendations.

Table 7.6. Actual (expected) number of countermeasure recommendations for each method

Method	Do nothing	Install/ improve warning signs	Add turn lane	Upgrade guardrail	Lengthen horizontal curve	Replace bridge with wider bridge	Install/ improve bridge rail	Remove roadside trees	Install/ improve pavement markings	Total
Collision	25 (37)	36 (34)	10 (5)	22 (22)	21 (14)	6 (6)	8 (7)	5 (5)	5 (8)	138
Inventory	63 (51)	45 (47)	3 (8)	30 (30)	13 (20)	9 (9)	10 (11)	6 (6)	15 (12)	194
Total	88	81	13	52	34	15	18	11	20	332

H_O: The countermeasure recommendations are independent of identification method.

H_A: The countermeasure recommendations are not independent of identification method.

$$\chi^2 = 21.367$$

$$\chi^2_{critical} = \chi^2_{0.05,8} = 15.507$$

At 5 % significance, the χ^2 statistic was greater than the critical χ^2 statistic, so the null hypothesis of independence was rejected. This implies a significant relationship between the countermeasure recommendations and the identification method.

The significant differences between the actual and expected number of recommendations were found by comparing the values in each cell of Tables 7.6. The three countermeasure recommendations with the largest differences were 'do nothing', 'add turn lane' and 'lengthen horizontal curve radius'. The Inventory Method sites had more 'do nothing' recommendations and fewer 'add turn lane' and 'lengthen horizontal curve radius' recommendations than expected. This indicates that many of the experts were more likely to recommend installing countermeasures at the TDOT Method sites than the Inventory Method sites. Two possible explanations for this are: 1) the experts thought the Inventory Method sites were not as hazardous as the collision sites, and therefore did not need a countermeasure, or 2) the Inventory Method sites were hazardous, but a cost-effective countermeasure does not exist. To expand on this point, the 'do nothing' responses are discussed in more detail later in this chapter.

A chi-square analysis was also performed on the countermeasure recommendations by site type, and the results are shown in Table 7.7. The general highway segment sites were ignored because there were not enough countermeasure recommendations relative to the bridge sites and the horizontal curve sites. Also, the countermeasures that could only be applied to one type of site (i.e. 'widen existing bridge') were excluded for this chi-square analysis because those recommendations would bias the test.

Table 7.7. Actual (expected) number of countermeasure recommendations for each site type

Site Type	Do nothing	Install/ improve warning signs	Upgrade guardrail	Install/ improve pavement markings	Total
Bridges	48 (47)	29 (44)	48 (33)	12 (13)	137
Horizontal curves	26 (27)	39 (24)	4 (19)	8 (7)	77
Total	74	68	52	20	214

H_O: The countermeasure recommendations are independent of site type.

H_A: The countermeasure recommendations are not independent of site type.

$$\chi^2 = 31.712$$

$$\chi^2_{critical} = \chi^2_{0.05,3} = 7.815$$

Again, the χ^2 statistic was greater than the critical χ^2 statistic, so the null hypothesis was rejected, implying a significant relationship between the countermeasure recommendations and the site type. In this case, the largest differences between the actual and expected number of recommendations were for the 'install or improve warning signs' and 'upgrade guardrail' options. The experts recommended 'install or improve warning signs' more often than expected for curve sites, and made fewer than expected recommendations for 'upgrade guardrail' at the curve sites. This indicates that the experts thought that installing warning signs at hazardous horizontal curves, and upgrading the guardrail at hazardous bridge sites would be cost-effective.

7.3. Cost-effectiveness evaluation

The goal of the questionnaire was to determine if, in the opinion of the expert panel, one method identified sites that were more 'promising' than the other method. To compare the two groups of sites, a fair measure of effectiveness (MOE) was needed. A 'promising' site has one or more cost-effective countermeasures, so the chosen MOE had to relate the cost of installing the countermeasure to the collision reduction associated with the countermeasure.

Table 7.8 shows the predicted and actual annual collision frequencies at all 18 sites. The predicted frequencies were calculated using the Turner[19], Zegeer et al.[24] and Bared and Vogt[27] collision prediction models for bridges, horizontal curves and general highway segments, respectively. The actual collision frequencies were obtained from the Tennessee DOT by the UNC-CH research team. The predicted and actual collision frequencies were used to evaluate the cost-effectiveness of the countermeasure recommendations made by the experts.

Table 7.8. Predicted and actual annual collision frequencies for each site

Site #	Site Type	Method	Predicted Annual Collision Frequency	Actual Annual Collision Frequency
1	Bridge	TDOT	0.179	1.333
2	Bridge	Inventory	2.037	0
3	Bridge	Inventory	2.362	0
4	Bridge	TDOT	1.022	3.333
5	Curve	TDOT	0.259	2.333
6	Segment	TDOT	1.554	11
7	Bridge	Inventory	2.269	2
8	Curve	TDOT	0.390	5.667
9	Bridge	Inventory	1.020	0.333
10	Curve	TDOT	0.164	1.667
11	Curve	TDOT	0.284	1.333
12	Bridge	Inventory	1.744	0
13	Segment	Inventory	4.034	3
14	Bridge	Inventory	0.976	0.667
15	Bridge	Inventory	1.220	1
16	Curve	Inventory	0.893	0
17	Curve	TDOT	0.323	1.333
18	Curve	Inventory	0.640	0

In the first attempt to find a fair MOE, the cost-effectiveness was expressed in terms of dollars spent on the countermeasure per actual annual collision saved. Based on the countermeasure recommendations at each site made by all of the experts, the total dollars spent on countermeasure installation was divided by the total number of actual annual collisions that would be saved by the countermeasure. In the case of a 'do nothing' recommendation, the total cost is $0 and the collision savings is zero, so these responses had no effect on the MOE. Therefore, the 'do nothing' responses were not included in the degrees of freedom of the statistical tests. The results of this analysis are presented in Table 7.9.

Table 7.9. Cost-effectiveness of sites based on actual number of collisions saved

Rank	Site #	Site Type	Method	$ Spent per annual Actual Collision Saved
1	6	Segment	TDOT	$4,511
2	8	Curve	TDOT	$71,096
3	7	Bridge	Inventory	$73,040
4	5	Curve	TDOT	$77,326
5	4	Bridge	TDOT	$89,112
6	15	Bridge	Inventory	$90,815
7	14	Bridge	Inventory	$120,159
8	10	Curve	TDOT	$125,389
9	13	Segment	Inventory	$140,596
10	1	Bridge	TDOT	$179,422
11	17	Curve	TDOT	$244,735
12	11	Curve	TDOT	$285,866
13	9	Bridge	Inventory	$466,436
14	2	Bridge	Inventory	--
15	3	Bridge	Inventory	--
16	12	Bridge	Inventory	--
17	16	Curve	Inventory	--
18	18	Curve	Inventory	--

Note: The '--' entries indicate that there were no actual collisions at that particular site, so the denominator of the cost-effectiveness term was zero

As described in Section 7.1, the Mann-Whitney Rank Test was applied to the ranked list of sites based on the dollars spent per actual annual collision saved. The parameters were calculated:

H_O: The mean cost-effectiveness of the TDOT Method sites is equal to the mean cost-effectiveness of the Inventory Method sites

H_A: The mean cost-effectiveness of the TDOT Method sites is not equal to the mean cost-effectiveness of the Inventory Method sites

TDOT Method	Inventory Method
$n_1 = 8$ sites	$n_2 = 10$ sites
$R_1 = 53$	$R_2 = 118$

$$U = (8)(10) + \frac{8(8+1)}{2} - 53 = 63$$

$$U' = (8)(10) - 63 = 17$$

The critical Mann-Whitney statistic is 63 for a two-tailed test at 5 % significance, so the null hypothesis was rejected. Therefore, the TDOT Method sites, as a group, were considered by the experts to be more cost-effective to correct than the Inventory Method sites.

However, expressing the cost-effectiveness MOE in terms of actual number of collisions saved was clearly biased in favor of the TDOT Method sites because five of the Inventory Method sites did not have any actual reported collisions during the study period. This means there was not an opportunity to save any collisions at these sites. On the other hand, the sites identified by the TDOT Method by definition had high annual collision frequencies. These sites were selected because it was known that there were relatively high collision rates and severity indices at the sites.

In an effort to find a fairer MOE, the cost-effectiveness was recalculated in terms of dollars spent per predicted annual collision saved by the countermeasure. Again, the 'do nothing' recommendations are accounted for in the MOE, but have no effect on the cost-effectiveness calculation. The ranked list of sites by this method is shown in Table 7.10.

Table 7.10. Cost-effectiveness of sites based on predicted number of collisions saved

Rank	Site #	Type	Method	$ Spent per annual Predicted Collision Saved
1	6	Segment	TDOT	$31,931
2	7	Bridge	Inventory	$64,151
3	15	Bridge	Inventory	$72,334
4	14	Bridge	Inventory	$79,622
5	13	Segment	Inventory	$104,558
6	3	Bridge	Inventory	$119,169
7	2	Bridge	Inventory	$142,497
8	9	Bridge	Inventory	$152,422
9	12	Bridge	Inventory	$161,998
10	4	Bridge	TDOT	$290,615
11	16	Curve	Inventory	$358,713
12	18	Curve	Inventory	$380,623
13	5	Curve	TDOT	$696,531
14	17	Curve	TDOT	$1,010,005
15	8	Curve	TDOT	$1,033,085
16	10	Curve	TDOT	$1,274,534
17	1	Bridge	TDOT	$1,336,139
18	11	Curve	TDOT	$1,341,759

Again, the Mann-Whitney Rank Test was performed for this list, and the necessary parameters were calculated:

H_O: The mean cost-effectiveness of the TDOT Method sites is equal to the mean cost-effectiveness of the Inventory Method sites

H_A: The mean cost-effectiveness of the TDOT Method sites is not equal to the mean cost-effectiveness of the Inventory Method sites

TDOT Method	Inventory Method
$n_1 = 8$ sites	$n_2 = 10$ sites
$R_1 = 104$	$R_2 = 67$

$$U = (8)(10) + \frac{8(8+1)}{2} - 104 = 12$$

$$U' = (8)(10) - 12 = 68$$

The critical Mann-Whitney statistic for a two-tailed comparison at 5 % significance is 63, and U was greater than this critical value. Therefore, the null hypothesis was rejected. The Inventory Method sites, as a group, were considered more cost-effective to correct than the TDOT Method sites, when the cost-effectiveness was expressed in terms of predicted number of collisions saved. Note that this MOE was clearly biased in favor of the Inventory Method sites because it was based on the predicted annual collision frequency for each site. This favors the Inventory Method sites because five of the Inventory Method sites did not have any actual collisions, and some of the TDOT Method sites had many more collisions than the model predicted. This means all of the Inventory Method sites had collisions to save, but some of the TDOT Method sites had only a fraction of the actual collisions to save.

Finally, the cost-effectiveness was computed in terms of dollars spent per one-percent collision reduction by the countermeasure. This MOE was considered to be fair because a percentage reduction in the collision frequency is a normalized measure, which does not depend on a collision total or a prediction model. In this case, the cost-effectiveness was found by dividing the total dollars spent for all countermeasure recommendations at a site, divided by the sum of the collision reduction factors, in percent. The 'do nothing' recommendations also had no effect on this MOE. The results of this analysis are shown in Table 7.11.

Table 7.11. Cost-effectiveness of sites based on the percentage collision reduction

Rank	Site #	Site Type	Method	$ Spent per 1% Collision Reduction
1	6	Segment	TDOT	$365
2	7	Bridge	Inventory	$868
3	14	Bridge	Inventory	$979
4	15	Bridge	Inventory	$1,176
5	5	Curve	TDOT	$1,250
6	2	Bridge	Inventory	$1,500
7	18	Curve	Inventory	$1,620
8	10	Curve	TDOT	$1,738
9	9	Bridge	Inventory	$1,748
10	3	Bridge	Inventory	$1,905
11	17	Curve	TDOT	$2,051
12	1	Bridge	TDOT	$2,127
13	16	Curve	Inventory	$2,338
14	4	Bridge	TDOT	$2,730
15	11	Curve	TDOT	$2,790
16	12	Bridge	Inventory	$2,862
17	8	Curve	TDOT	$2,863
18	13	Segment	Inventory	$4,040

The Mann-Whitney Rank Test was performed for this list, and the parameters were:

TDOT Method	**Inventory Method**
$n_1 = 8$ sites	$n_2 = 10$ sites
$R_1 = 83$	$R_2 = 88$

$$U = (8)(10) + \frac{8(8+1)}{2} - 83 = 33$$

$$U' = (8)(10) - 33 = 47$$

Again, the critical Mann-Whitney statistic is 63 at 5 % significance, so there was no statistical difference between the methods at that level of significance. When the MOE was expressed in terms of dollars spent per one-percent collision reduction, the mean cost-effectiveness of the sites were equal for both methods at 5 % significance.

Table 7.12 contains the cost-effectiveness, in terms of dollars spent per one-percent collision reduction, for the major site groups.

Table 7.12. Cost-effectiveness of different site groups

Site group	Number of sites	$ Spent per 1% Collision Reduction
Inventory Method	10	$1,893
TDOT Method	8	$2,067
Bridges	9	$1,841
Horizontal curves	7	$2,079
Segments	2	$2,290
All	18	$1,974

There were two interesting trends in Table 7.12. First, according to the countermeasure recommendations made by the experts, the Inventory Method sites were more cost-effective to fix than the collision sites. As a group, the Inventory Method sites required $1,893 per one-percent collision reduction compared to $2,067 per one-percent collision reduction for the group of TDOT Method sites. Second, the bridges were the most cost-effective group of sites to fix, followed by the horizontal curves and the general highway segments, with $1,841, $2,079 and $2,290 per one-percent collision reduction, respectively.

A two-tailed t-test was performed to determine if one method identified sites that were significantly more cost-effective to fix than the other method. The null and alternative hypotheses were:

H_O: The mean cost-effectiveness of the TDOT Method sites is equal to the mean cost-effectiveness of the Inventory Method sites.

H_A: The mean cost-effectiveness of the TDOT Method sites is not equal to the mean cost-effectiveness of the Inventory Method sites.

TDOT Method	Inventory Method
$n_1 = 130$	$n_2 = 148$
$v_1 = 129$	$v_2 = 147$
$X_1 = \$2,067$ per 1 % reduction	$X_2 = \$1,893$ per 1 % reduction
$SS_1 = 591,574,910$	$SS_2 = 873,237,327$

$$S_p^2 = 5,307,290.7$$
$$S_X = 276.921$$
$$t = 0.628$$
$$t_{critical} = t_{0.05(2),276} = 1.968$$

The t-statistic was less than the critical t-statistic, therefore the null hypothesis could not be rejected. At 5 % significance, the mean cost-effectiveness of the sites were equal for both methods.

The countermeasure recommendations were studied to determine if there was a significant difference in the mean cost-effectiveness of the bridge sites and the horizontal curve sites. The general highway segment sites were excluded from the analysis because each method only identified one of these sites. For the bridge sites, the null and alternative hypotheses were:

H_O: The mean cost-effectiveness of the bridge sites identified with TDOT Method was equal to the mean cost-effectiveness of the bridge sites identified with the Inventory Method.

H_A: The mean cost-effectiveness of the bridge sites identified with TDOT Method was not equal to the mean cost-effectiveness of the bridge sites identified with the Inventory Method.

TDOT Method	Inventory Method
$n_1 = 37$	$n_2 = 104$
$v_1 = 36$	$v_2 = 103$
X_1 = \$2,420 per 1 % reduction	X_2 = \$1,623 per 1 % reduction
$SS_1 = 48{,}292{,}165$	$SS_2 = 219{,}057{,}184$

$$S_p^2 = 1{,}923{,}376.6$$
$$S_X = 265.475$$
$$t = 3.002$$
$$t_{critical} = t_{0.05(2),\,139} = 1.977$$

The calculated t-statistic was greater than the critical t-statistic, so the null hypothesis was rejected. At 5 % significance, the test indicated that the bridge sites identified with the Inventory Method were significantly more cost-effective to correct than the bridges identified with the TDOT Method.

The analysis was repeated for the horizontal curve sites, and the null and alternative hypotheses were:

H_O: The mean cost-effectiveness of the curve sites identified with TDOT Method was equal to the mean cost-effectiveness of the curve sites identified with the Inventory Method

H_A: The mean cost-effectiveness of the curve sites identified with TDOT Method was not equal to the mean cost-effectiveness of the curve sites identified with the Inventory Method

TDOT Method	Inventory Method
$n_1 = 83$	$n_2 = 33$
$v_1 = 82$	$v_2 = 32$
$X_1 = \$2,108$ per 1 % reduction	$X_2 = \$1,980$ per 1 % reduction
$SS_1 = 508,616,805$	$SS_2 = 131,600,864$

$$S_p^2 = 5,615,944.5$$
$$S_X = 487.691$$
$$t = 0.262$$
$$t_{critical} = t_{0.05(2),\,114} = 1.981$$

The calculated t-statistic was less than the critical t-statistic, so the null hypothesis could not be rejected. At 5 % significance, the mean cost-effectiveness of the horizontal curve sites was equal for both methods.

To confirm the difference of means analysis, a linear regression model was estimated with cost-effectiveness rating for each site by each respondent as the dependent variable. Cost-effectiveness could only be calculated for sites where respondents recommended a treatment. There are 277 observations in the data set. The explanatory variables were dummy variable representations of whether the site was an inventory method or a collision method site, whether the site was a bridge, segment, or curve.

The regression results are included in Table 7.13. Again, this model has a relatively weak R^2 of .0043, indicating that the explanatory variables only explain less than 1% of the variation in the dependent variable. Also the low F statistic indicates that the model as a whole is not statistically significant.

Like the hazardous rating regression, all of the independent variables are dummy variables. Again, the coefficient for the included variable(s) represent the change in the dependent variable attributable to that variable compared against the withheld variable (referred to as the base). In our analysis the inventory method dummy variable is included, and the collision method dummy variable is withheld (not included). The coefficient estimates for all independent variables considered together are not statistically significant, therefore implying that no conclusions can be drawn from the model.

Table 7.13. OLS Regression model for Site/Expert Specific Cost-Effectiveness

Dependent Variable: Reported Cost Effectiveness ($)

Model Summary:

	N: 277	d.f.: 274
	F value: 0.40	Pr > F: 0.7550
	R^2: 0.0043	Adj. R^2: -0.0066

Parameter Estimates:

Variable	Parameter Estimate	Standard Error	t-value	Pr > $\|t_C\|$
Intercept	2104.73807	231.01428	9.11	<.0001
Inventory Method	-91.32293	307.36291	-0.30	0.7666
Bridge	-196.13967	320.51944	-0.61	0.5411
Segment	233.06584	551.08286	0.42	0.6727

The countermeasure recommendations were also analyzed for all four expert groups: DOT Design Engineers, DOT Traffic Engineers, Highway Patrol representatives and FHWA District Traffic Engineers. The cost-effectiveness, in dollars spent per one-percent reduction, of the countermeasure recommendations for each group are shown in Table 7.13.

Table 7.14. Cost-effectiveness by method and expert group

Method	DOT Design	DOT Traffic	Highway Patrol	FHWA	Total
Inventory	$3,206	$1,471	$811	$1,970	$1,893
TDOT	$3,428	$1,346	$879	$2,312	$2,067
Total	$3,310	$1,411	$841	$2,139	$1,974

Note that, as a group, the Highway Patrol representatives made the most cost-effective countermeasure recommendations, followed by the DOT Traffic Engineers, the FHWA District Traffic Engineers and the DOT Design Engineers. Only two Highway Patrol representatives made countermeasure recommendations, and they both recommended 'install warning sign' frequently. The 'install warning sign' option was the most cost-effective countermeasure on the list of countermeasures that accompanied the questionnaire.

In general, the DOT Traffic Engineers and FHWA District Traffic Engineers recommended countermeasures that were close to the mean cost-effectiveness of all sites. However, the DOT Design Engineers recommended countermeasures such as 'lengthen horizontal curve radius', which were expensive. As a result, their recommendations tended to be the least cost-effective in this study.

Two-tailed t-tests were performed on the data in Table 7.13 to determine if there was a significant difference between the cost-effectiveness of the sites identified with both methods. For all four expert groups, the difference in the mean cost-effectiveness between the two methods was not significant at 5 %.

7.4. 'Do nothing' recommendations

The 'do nothing' responses were analyzed in more detail because this response could have different meanings at different sites. There were three possible reasons to recommend 'do nothing' as a countermeasure at a site:

1) The site was not hazardous, so a countermeasure was not needed
2) The site was hazardous, but cannot be corrected with a cost-effective countermeasure
3) The photographs in the questionnaire did not adequately portray the site

The first two cases were undesirable because the goal of the Inventory Method was to identify sites that had cost-effective countermeasures. If a site was identified that was either not hazardous or not cost-effective to correct, then the method failed. The third case was also undesirable, but does not indicate a failure in the identification method. It is difficult to determine how often the third case occurred. One way to study this case would be to edit the questionnaire to allow the experts to indicate that they could not make a decision because the photographs or other information that was provided was inadequate.

The 'do nothing' responses were studied further to determine if either of the first two cases was evident. Table 7.14 shows the actual and expected number of 'do nothing' countermeasure recommendations, and the total number of all other countermeasure recommendations, for each hazard rating category. A chi-square test was performed on the data in Table 7.14 to determine if the distribution of 'do nothing' recommendations was related to the hazard rating given to each site.

Table 7.15. Actual (expected) number of countermeasure recommendations in each hazard rating category

	Hazard Rating							
Countermeasure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
'Do nothing'	27 (10)	36 (15)	20 (21)	3 (18)	2 (12)	0 (9)	0 (2)	88
All others	16 (33)	28 (49)	67 (66)	70 (55)	49 (39)	39 (30)	9 (7)	278
Total	43	64	87	73	51	39	9	366

H_O: The 'do nothing' recommendations were independent of hazard rating.

H_A: The 'do nothing' recommendations were not independent of hazard rating.

$$\chi^2 = 114.137$$

$$\chi^2_{critical} = \chi^2_{0.05,6} = 12.592$$

The computed χ^2 exceeded the critical χ^2, therefore there was a significant relationship between the 'do nothing' recommendations and the hazard rating of the site at 5 % significance. The actual number of 'do nothing' responses for sites with hazard ratings of 1 and 2 were much greater than the expected number of responses. The actual number of 'do nothing' responses for a site with a hazard rating of 3 was close to the expected value, and the actual number of 'do nothing' responses for the hazard ratings above 3 were all less than the expected number.

Table 7.15 shows the results of a chi-square test performed on the countermeasure recommendations to determine if there was a relationship between the 'do nothing' recommendations and the identification method.

Table 7.16. Actual (expected) number of countermeasure recommendations for each method

Countermeasure	Inventory	TDOT	Total
'Do nothing'	63 (51)	25 (37)	88
All others	148 (160)	130 (118)	278
Total	211	155	366

H_O: The 'do nothing' recommendations were independent of method.

H_A: The 'do nothing' recommendations were not independent of method.

$$\chi^2 = 9.222$$

$$\chi^2_{critical} = \chi^2_{0.05,1} = 3.841$$

Again, the computed χ^2 was greater than the critical χ^2, therefore there was a significant relationship at 5 % significance. The Inventory Method sites had more 'do nothing' recommendations than expected, and the TDOT Method sites had fewer 'do nothing' recommendations than expected.

Table 7.16 shows the actual and expected numbers of 'Do nothing' recommendations by site type.

Table 7.17. Actual (expected) number of countermeasure recommendations for each site type

Countermeasure	Bridges	Curves	Segments	Total
'Do nothing'	48 (45)	26 (34)	14 (8)	88
All others	141 (144)	116 (108)	21 (27)	278
Total	189	142	35	366

H_O: The 'do nothing' recommendations were independent of site type.

H_A: The 'do nothing' recommendations were not independent of site type.

$$\chi^2 = 7.625$$

$$\chi^2_{critical} = \chi^2_{0.05,2} = 5.991$$

The computed χ^2 was greater than the critical χ^2, therefore there was a significant relationship between the 'do nothing' responses and the site type. The bridge sites and the general highway segment sites had more 'do nothing' responses than expected, and the horizontal curve sites had fewer 'do nothing' recommendations than expected.

7.5. Comments and suggestions from the experts about the questionnaire

Eleven (46 %) of the 24 experts who responded to the survey offered various comments and suggestions regarding the questionnaire. The experts responded to the questionnaire based on the given information about each site, but many of the comments referred to other information that would have been helpful in evaluating the hazardousness of each site and recommending an appropriate countermeasure. The four categories of information or data most often referred to in the comments were the speed limit, collision history, a site visit and turning volumes.

The speed limit was not included in the data table for each site because for most rural, two-lane highway segments, the speed limit is 50 or 55 miles per hour. There was a field for speed limit in the TDOT roadway inventory files, but it was unpopulated. Other roadway inventories may have speed limit data available.

Collision data and collision diagrams were not included with the site data for two reasons. First, this information might have biased the responses. As shown earlier in Table 7.8, five of the Inventory Method sites did not have any actual collisions in the three-year study period. If this information had been included, the experts might have given these sites very low hazard ratings without looking at the other data objectively. The second reason was including this data would have burdened the experts with a lot of extra data. The objective of the questionnaire was to be as brief as possible to insure a relatively high response rate.

Many experts mentioned that a hazardous site evaluation usually includes a site visit. The goal of the two digital photographs was to give the experts a good look at the site, but two photographs cannot substitute for actually walking or driving through the site. The turning movements were not included in the questionnaire data for two reasons. First, it was not available in the inventory data files, and second, it would have increased the burden on the experts during their evaluation. The AADT data were in the inventory data, and were provided in the data table for each site.

7.6. Summary

The feedback from the 24 experts who responded to the questionnaire was carefully studied. First, the question regarding the hazard rating of each site was analyzed to find any significant trends and relationships. According to the experts, the TDOT Method sites had a higher mean hazard rating than the Inventory Method sites, and the difference was found to be significant at 5 % confidence level. The horizontal curve sites had a higher mean hazard rating than the bridge sites and general highway segment sites. However, regression model results show that the method effect becomes insignificant after we control for location type (bridge, curve or segment).

The countermeasure recommendations were studied to draw conclusions about the cost-effectiveness of installing countermeasures at the sites. After studying the responses, the fairest

MOE for evaluating the cost-effectiveness of the recommendations was in terms of dollars spent per one-percent collision reduction. The main conclusions were that, as a group, the Inventory Method sites performed similarly to the Collision Method sites, once the type of site (bridge, curve, or segment) was controlled. In addition, the Inventory Method sites were slightly more cost-effective to correct than the collision sites, but the difference was not significant at 5 % confidence level. Also, the bridge sites were the most cost-effective group of sites to fix, followed by the horizontal curve and general highway segment sites.

The 'do nothing' recommendations were studied to determine if the experts gave these recommendations to sites that were not hazardous or sites that were hazardous but not correctable. Using a chi-square test, it was shown that the 'do nothing' responses are not independent of sites given low hazard ratings as opposed to high hazard ratings.

Chapter 8 – Conclusions and Recommendations

This work describes the development and application of a 'promising' site identification method that only requires inventory data instead of collision data. Twenty-four highway safety experts responded to a questionnaire regarding the performance of the sites identified by Inventory Method and Collision method on low volume rural, two-lane highways. This chapter summarizes the important conclusions that were drawn from the research.

8.1. Conclusions

The main conclusions that were drawn from this research were based on the Inventory Method as it was developed and applied for this project. The results of the Inventory Method were specific to one highway network and three collision prediction models. The conclusions were drawn from the responses of 24 individual highway safety professionals from the southeastern United States. The main conclusions are listed below:

1. The Inventory Method could be applied efficiently in areas that have high-quality roadway inventory data, and it would be especially helpful in areas with poor collision data.
2. The Inventory Method was applied to a highway network in two Tennessee counties in a reasonable amount of time.
3. The TDOT Collision Method identified five horizontal curves, two bridges and one general highway segment among the eight most hazardous sites in the study area.
4. The Inventory Method identified seven bridges, two horizontal curves and one general highway segment among the ten most 'promising' sites in the study area.
5. According to the expert panel, the Inventory Method performed about as well as the TDOT Method in identifying 'promising' sites on rural, two-lane highways.
6. At 5 % significance level, the mean hazard rating for the TDOT Method sites (3.73) was significantly higher than the mean hazard rating given to the Inventory Method sites (3.35), but this effect disappeared when the type of site (bridge, curve, or segment) was controlled.
7. The mean hazard rating for the horizontal curve sites (3.92) was higher than the mean hazard rating given to the bridge sites (3.27) and highway segments (3.27).

8. At 5 % significance, the mean hazard ratings of the bridge and horizontal curve sites were equal for both methods.

9. The three most common countermeasure recommendations were 'do nothing' (24 %), 'install or improve warning signs' (22 %) and 'upgrade guardrail' (14 %).

10. The fairest measure of cost-effectiveness for each countermeasure at each site was dollars spent on the countermeasure per one-percent collision reduction.

11. The mean cost-effectiveness of the Inventory Method sites ($1,893 per one-percent reduction) was not statistically different to the mean cost-effectiveness of the TDOT Collision Method sites ($2,067 per one-percent reduction) at 5 % significance.

12. At 5 % significance, the mean cost-effectiveness of the bridge sites identified with the Inventory Method ($1,623 per one-percent reduction) was better than the mean cost-effectiveness of the bridge sites identified with the TDOT Collision Method ($2,420 per one-percent reduction).

13. At 5 % significance, the mean cost-effectiveness of the curve sites identified with the Inventory Method ($1,980 per one-percent reduction) was not statistically different from the mean cost-effectiveness of the curve sites identified with the TDOT Method ($2,108 per one-percent reduction).

14. As a group, the Highway Patrol representatives made the most cost-effective countermeasure recommendations, followed by the DOT Traffic Engineers, the FHWA District Traffic Engineers and the DOT Design Engineers, with $841, $1,411, $2,139 and $3,310 per one-percent reduction, respectively.

15. At 5 % significance, the mean cost-effectiveness of the sites identified with both methods were equal for all four of the experts groups.

16. The 'do nothing' recommendations were strongly related to the lowest hazard ratings given to the sites by the experts.

17. At 5 % significance, the Inventory Method sites had more 'do nothing' recommendations than the TDOT Collision Method sites.

18. At 5 % significance, the bridge and highway segment sites had more 'do nothing' recommendations than expected, while the curve sites had fewer 'do nothing' recommendations than expected.

8.2. Recommendations for future research

Based on the feedback from 24 highway safety professionals, the Inventory Method was roughly as successful as the TDOT Method in identifying 'promising' sites on rural, two-lane highways. Therefore, the Inventory Method could be expanded to identify 'promising' sites among other site populations. For example, the Inventory Method could be modified to identify 'promising' sites on urban highways, freeways or unsignalized intersections. Inventory data are available for these and other classes of roadway in many states, and collision prediction models for many different roadway sites have been published over the years. The seven-step process of the Inventory Method can be applied to any site population, if high-quality inventory data and collision prediction models of interest are available. The inventory method can also be used in conjunction with the collision method.

There are improvements that could be made to the Inventory Method developed in this work. For example, this study was limited to installing a single countermeasure at each site. One possible extension of the research would be to investigate the application of multiple countermeasures at each site because countermeasures are often installed in combination.

The Inventory Method could be extended to account for collision severity in the 'promising' site identification algorithm. The Collision Method identified the most hazardous sites in the network based, in part, on the severity of the collisions that occurred at the site. The Inventory Method could be modified to rank the 'promising' sites by a predicted collision severity distribution. An additional step could be included in the algorithm to study the predicted collision severity at a site with published models. For example, Hadi et al.[29] present a model to predict the fatal crash frequency in a 4-year period for rural, two-lane mid-block highway segments:

$$N = \exp[-15.47 + 1.025(Llen) + 0.9624(Ladt) - 0.1428(Lw)]$$

where

Llen = log(1,000 x section length in miles)
Ladt = log(ADT)
Lw is the lane width, in feet

Other models could be found in the literature to predict injury and fatal collision frequencies at different types of sites. The model predictions could then be incorporated into the Inventory Method to identify 'promising' sites that have particular collision severity problems.

One limitation of the Inventory Method was the reliance on the collision prediction models. The results of the Inventory Method might be influenced in some way by the specific collision prediction models that were chosen. For example, if another collision prediction model for horizontal curves was chosen, that particular model might predict a higher annual collision frequency at all curves, compared to the Zegeer et al.[24] model. In that case, the ten most 'promising' sites in the study area might have included more than two horizontal curves. Future studies could be conducted with different collision prediction models for the three site types to determine the sensitivity of the Inventory Method to the chosen collision prediction models.

8.3. Recommendations for the questionnaire

The questionnaire used in this study allowed the expert panelists to make any countermeasure recommendation at any site without a fixed budget. One way to alter the questionnaire to make it more realistic would be to give the experts a fixed budget to spend on countermeasures at all of the sites. The experts would be given a fixed budget and the relative costs of each countermeasure at each site, and instructed to make countermeasure recommendations at all 18 sites without exceeding the budget. This approach would force the experts to make recommendations that are more cost-effective than the responses made for this project. However, this would also increase the time burden on the panelists, and the response rate might decrease.

Another extension of this research would be to design a questionnaire to determine if an expert panel can correctly identify the truly 'promising' sites out of a group of sites that includes sites that were not considered 'promising'. For example, pictures and data could be given regarding 10 sites, five of which were identified as the most 'promising' in the highway network.

The other five sites would be lower on the ranked list of 'promising' sites. The questionnaire could include information similar to the information provided in the questionnaire for this work. An analysis of the responses would test if the experts could tell which sites were the most 'promising' and which sites were not considered 'promising'.

A third possibility for future research would be to test the Inventory Method against the actual countermeasures that have been installed in a site population. This approach would compare the Inventory Method to a 'ground truth' scenario. For example, the Inventory Method could be used to identify the most 'promising' sites in a network with roadway inventory data that are 5 years old. The Inventory Method would be applied, the most 'promising' sites identified, then these most 'promising' sites would be visited. The results of the Inventory Method could be compared to which countermeasures, if any, were installed at the sites, and how well those countermeasures prevented collisions.

8.4. Summary

The main conclusions from the research effort were discussed in this chapter. The Collision Method tested in this study is reactive, whereas the Inventory Method is proactive. Based on the feedback from the 24 highway safety professionals, the Inventory Method performed adequately compared to the TDOT Collision Method in the identification of 'promising' sites on rural, two-lane highways. Based on this successful application, we recommend that highway safety agencies apply the Inventory Method to identify 'promising' sites in conjunction with collision-based hazardous site identification methods. If the Inventory Method works as well as the TDOT Collision Method in identifying 'promising' sites, then it should be tested as a complement to traditional methods. While we expect both methods to improve in their predictive accuracy as data collection efforts continue to improve, we anticipate the inventory data to improve relatively more rapidly than collision data.

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Appendix A:

List of collision reduction factors for common countermeasures

Note: The 'FHWA' column contains the collision reduction factors suggested by the Federal Highway Administration, and the 'CDOT' column contains the factors suggested by the California Department of Transportation. The collision reduction factors are expressed in percentage (%) reduction in collisions.

	FHWA	CDOT
Channelization		
Install Median Barrier (Non Freeway)	13	36
Install Painted or Raised Median	32	8
Install Reflectorized Traffic Buttons		25
Pavement Markings and Delineators	6	
Add Turn Lane and Signal		36
Add Turn Lane	27	25
Channelization	27	30
Access Control		
Modify Entrance Ramp		30
Modify Exit Ramp		20
Add Acceleration/Deceleration Lanes		10
Construction or Reconstruction		
Widen Shoulders	13	5
Widen Travelway		28
Construct New Frontage Roads		40
Improve Horizontal and/or Vertical Alignment	44	40
Modernize Travelway to Design Standards		15
Improve Median and/or Shoulders on Divided Highways		42
Reconstruct Curve		42
Reconstruct Curve for Superelevation		65
Construct Pedestrian Walkway		60
Widen Existing Bridge	31	44
Replace Narrow Bridge	70	62
Widen Small Structures	21	40
Modernize Bridge Rail to Design Standards	33	5
Construct Pedestrian Crossover (pedestrian Crashes Only)		95
Construct Pedestrian Crossover (All Crashes)		5
Install Grade Separation		55
Construct Interchange		55
Reconstruct Intersection		40
Construct Turn-Around		40
Construct Emergency Truck Deceleration Beds (All Crashes)		20
Construct Emergency Truck Deceleration Beds (Truck Crashes)		60
Groove Pavement to Prevent Hydroplaning	15	21
Groove Pavement to Prevent Hydroplaning (Wet Crashes Only)		42
Add Asphalt Seal Coat		21
Add Asphalt Seal Coat (Wet Crashes Only)		42
Install ACP Overlay	19	21
Deslick		20
Install Rumble Strips		27
Lighting		
Install Safety Lighting	17	25

	FHWA	CDOT
Regulations		
Eliminate Parking		32
Curtail Turning Move		40
Signalization		
Install Railroad Warning Device		50
Install/Improve Warning Signal	42	56
Add Pedestrian Signal		13
Improve or Modernize Signals	22	25
Add Turn Signal (No Lane)		22
Install New Traffic Signal	23	29
Upgrade Flashing Lights (Railroad)	48	
Install New Flashing Lights (Railroad)	81	
New Flashing Lights and Gates (Railroad)	86	
New Gates (Railroad)	80	
Signs		
Install/Improve Warning Signs		35
Install Stop Ahead Sign		47
Install Yield Sign		59
Install Minor Leg Stop Control		48
Install/Improve Stop Signs		68
Traffic Signs (general)		16
Roadside		
Relocated/Breakaway Utility Poles	44	
Upgrade Guardrail	9	
Upgrade Median Barrier	23	
Impact Attenuators	34	
Flatten Side Slopes	25	46
Remove Obstacles	22	

Appendix B:

Predicted annual collision frequencies at the 28 bridge sites in the study area

Turner's[19] bridge-related collision model:

$$Y = 0.4949 - 0.0612(RW) + 0.0022(RW)^2$$

where,

Y is the predicted number of collisions per million vehicles
RW is the bridge width minus the approach roadway width, in feet.

Table B.1. Predicted annual collision frequencies at the 28 bridge sites in the study area

#	County	#	Route	Milepost	bridge width [ft]	roadway width [ft]	RW [ft]	Collisions per million vehicles	AADT	Collisions per Year
1	Roane	131	1	2.46	28	34	-6	0.9413	2,760	0.9483
2	Roane	142	29	13.91	28	40	-12	1.5461	4,020	2.2686
3	Roane	163	72	1.87	36	35	1	0.4359	1,410	0.2243
4	Roane	179	322	2.98	24	26	-2	0.6261	840	0.1920
5	Roane	184	327	1.37	36	36	0	0.4949	3,180	0.5744
6	Sumner	289	25	0.88	40.7	22	18.7	0.119778	1,970	0.0861
7	Sumner	290	25	1.6	20.5	22	-1.5	0.59165	1,970	0.4254
8	Sumner	293	25	7.86	40	40	0	0.4949	3,020	0.5455
9	Sumner	295	25	10.88	28.5	22	6.5	0.19005	3,020	0.2095
10	Sumner	296	25	12.42	40	40	0	0.4949	3,060	0.5528
11	Sumner	297	25	13.57	28.3	34	-5.7	0.915218	3,060	1.0222
12	Sumner	302	25	3.8	22	24	-2	0.6261	2,510	0.5736
13	Sumner	309	41	14.54	26	40	-14	1.7829	3,630	2.3623
14	Sumner	311	41	17.73	28	40	-12	1.5461	2,540	1.4334
15	Sumner	312	41	19.1	42	40	2	0.3813	2,540	0.3535
16	Sumner	314	41	21.81	26	40	-14	1.7829	3,130	2.0369
17	Sumner	315	52	7.72	34	40	-6	0.9413	5,000	1.7179
18	Sumner	316	52	9.95	34	40	-6	0.9413	4,020	1.3812
19	Sumner	322	76	0.92	20	30	-10	1.3269	3,600	1.7435
20	Sumner	323	76	4.05	24	30	-6	0.9413	2,840	0.9758
21	Sumner	324	76	7.28	22	30	-8	1.1253	2,970	1.2199
22	Sumner	325	76	7.59	24	30	-6	0.9413	2,970	1.0204
23	Sumner	342	174	39.4	20	26	-6	0.9413	520	0.1787
24	Sumner	343	174	39.5	20	26	-6	0.9413	520	0.1787
25	Sumner	352	174	14.08	32	36	-4	0.7749	4,360	1.2332
26	Sumner	354	174	28.2	28	28	0	0.4949	1,350	0.2439
27	Sumner	367	259	2.96	25.5	26	-0.5	0.52605	740	0.1421
28	Sumner	368	259	4.32	24	26	-2	0.6261	550	0.1257

Appendix C:

Predicted annual collision frequencies at the 343 horizontal curve sites in the study area

Zegeer et al.[24] model for predicting collision frequency on horizontal curves:

$$A = [1.55(L)(V) + 0.014(D)(V) - 0.012(S)(V)](0.978)^{(W-30)}$$

where,

A is the number of total collisions on the curve in a 5-year period
L is the length of the curve, in miles
V is the millions of vehicles per 5-year period in both directions
D is the degree of horizontal curvature
S accounts for the presence of spiral transitions on both ends of the curve (S = 0 if no spiral exists, and S = 1 if spirals do exist)
W is the width of the roadway on the curve, in feet.

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
1	Roane	SR1	0.20	0.25	7	1	0.05	2,760	5.04	30	0	0.884	0.177
2	Roane	SR1	0.37	0.42	7	2	0.05	2,760	5.04	30	0	0.884	0.177
3	Roane	SR1	0.55	0.62	9	2	0.07	2,760	5.04	30	0	1.181	0.236
4	Roane	SR1	0.83	0.99	4	2	0.16	2,760	5.04	30	0	1.531	0.306
5	Roane	SR1	1.32	1.36	6	1	0.04	2,760	5.04	30	0	0.735	0.147
6	Roane	SR1	1.40	1.48	13	1	0.08	2,760	5.04	30	0	1.541	0.308
7	Roane	SR1	1.52	1.60	12	2	0.08	2,760	5.04	30	0	1.471	0.294
8	Roane	SR1	1.63	1.69	15	1	0.06	2,760	5.04	30	0	1.526	0.305
9	Roane	SR1	1.70	1.76	17	1	0.06	2,760	5.04	30	0	1.667	0.333
10	Roane	SR1	1.79	1.88	7	2	0.09	2,760	5.04	30	0	1.196	0.239
11	Roane	SR1	1.88	1.93	10	1	0.05	2,760	5.04	30	0	1.096	0.219
12	Roane	SR1	2.04	2.08	8	1	0.04	2,760	5.04	30	0	0.876	0.175
13	Roane	SR1	2.10	2.15	8	2	0.05	2,760	5.04	30	0	0.955	0.191
14	Roane	SR1	2.33	2.37	5	2	0.04	2,760	5.04	30	0	0.665	0.133
15	Roane	SR1	2.40	2.53	4	2	0.13	2,760	5.04	30	0	1.297	0.259
16	Roane	SR1	5.58	5.66	5	1	0.08	4,230	7.72	31	0	1.465	0.293
17	Roane	SR1	17.47	17.50	38	1	0.03	4,230	7.72	30	0	4.466	0.893
18	Roane	SR1	17.81	17.85	4	2	0.04	4,230	7.72	30	0	0.911	0.182
19	Roane	SR1	18.70	18.82	7	2	0.12	4,230	7.72	30	0	2.192	0.438
20	Roane	SR1	19.40	19.49	8	1	0.09	4,230	7.72	30	0	1.942	0.388
21	Roane	SR1	19.67	19.74	10	2	0.07	4,230	7.72	30	0	1.918	0.384
22	Roane	SR1	20.25	20.35	8	1	0.10	3,315	6.05	30	0	1.615	0.323
23	Roane	SR1	20.45	20.51	6	2	0.06	2,400	4.38	30	0	0.775	0.155
24	Roane	SR1	20.68	20.72	11	2	0.04	2,400	4.38	30	0	0.946	0.189
25	Roane	SR1	20.73	20.88	15	2	0.15	2,400	4.38	30	0	1.938	0.388

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
26	Roane	SR1	20.90	20.98	13	1	0.08	2,400	4.38	30	0	1.340	0.268
27	Roane	SR1	21.04	21.10	11	1	0.06	2,400	4.38	30	0	1.082	0.216
28	Roane	SR1	21.11	21.16	9	2	0.05	2,400	4.38	30	0	0.891	0.178
29	Roane	SR1	21.72	21.74	6	1	0.02	2,010	3.67	30	0	0.422	0.084
30	Roane	SR1	21.96	22.02	10	2	0.06	2,010	3.67	30	0	0.855	0.171
31	Roane	SR1	22.14	22.22	9	1	0.08	2,010	3.67	30	0	0.917	0.183
32	Roane	SR1	22.52	22.55	59	2	0.03	2,010	3.67	30	0	3.201	0.640
33	Roane	SR1	22.60	22.65	12	1	0.05	2,010	3.67	30	0	0.901	0.180
34	Roane	SR1	22.68	22.74	8	2	0.06	2,010	3.67	30	0	0.752	0.150
35	Roane	SR1	22.97	23.11	14	2	0.14	2,010	3.67	30	0	1.515	0.303
36	Roane	SR1	23.37	23.42	4	1	0.05	2,010	3.67	30	0	0.490	0.098
37	Roane	SR1	23.50	23.58	19	1	0.08	2,010	3.67	30	0	1.431	0.286
38	Roane	SR1	23.59	23.62	17	1	0.03	2,010	3.67	30	0	1.044	0.209
39	Roane	SR1	23.65	23.69	15	2	0.04	2,010	3.67	30	0	0.998	0.200
40	Roane	SR1	23.70	23.75	16	2	0.05	2,010	3.67	30	0	1.106	0.221
41	Roane	SR1	23.88	23.96	14	2	0.08	2,010	3.67	30	0	1.174	0.235
42	Roane	SR1	24.00	24.09	10	1	0.09	2,010	3.67	30	0	1.025	0.205
43	Roane	SR1	24.17	24.24	11	2	0.07	2,010	3.67	30	0	0.963	0.193
44	Roane	SR1	24.27	24.33	10	1	0.06	2,010	3.67	30	0	0.855	0.171
45	Roane	SR1	24.41	24.46	10	2	0.05	2,010	3.67	30	0	0.798	0.160
46	Roane	SR1	24.71	24.76	10	2	0.05	2,010	3.67	30	0	0.798	0.160
47	Roane	SR1	24.83	24.92	17	2	0.09	2,010	3.67	30	0	1.385	0.277
48	Roane	SR1	24.95	25.01	14	1	0.06	2,010	3.67	30	0	1.060	0.212
49	Roane	SR1	25.25	25.29	6	1	0.04	2,010	3.67	30	0	0.536	0.107
50	Roane	SR1	25.36	25.43	8	2	0.07	2,010	3.67	30	0	0.809	0.162

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
51	Roane	SR1	25.49	25.58	8	1	0.09	2,010	3.67	30	0	0.923	0.185
52	Roane	SR1	25.64	25.70	16	2	0.06	2,010	3.67	30	0	1.163	0.233
53	Roane	SR1	25.85	26.02	8	1	0.17	2,325	4.24	30	0	1.593	0.319
54	Roane	SR1	26.17	26.21	8	2	0.04	2,640	4.82	30	0	0.838	0.168
55	Roane	SR1	26.23	26.33	10	2	0.10	2,640	4.82	30	0	1.421	0.284
56	Roane	SR1	26.42	26.48	6	1	0.06	2,640	4.82	30	0	0.853	0.171
57	Roane	SR1	26.55	26.57	4	1	0.02	2,640	4.82	30	0	0.419	0.084
58	Roane	SR1	26.62	26.65	4	1	0.03	2,640	4.82	30	0	0.494	0.099
59	Roane	SR1	26.85	26.91	6	2	0.06	2,640	4.82	30	0	0.853	0.171
60	Roane	SR1	27.07	27.11	6	2	0.04	2,640	4.82	30	0	0.703	0.141
61	Roane	SR1	27.22	27.27	4	1	0.05	2,640	4.82	30	0	0.643	0.129
62	Roane	SR29	4.90	4.98	5	2	0.08	3,980	7.26	30	0	1.409	0.282
63	Roane	SR29	5.05	5.12	9	1	0.07	3,980	7.26	30	0	1.703	0.341
64	Roane	SR29	5.17	5.23	8	1	0.06	3,980	7.26	30	0	1.489	0.298
65	Roane	SR29	5.35	5.42	5	1	0.07	3,980	7.26	30	0	1.297	0.259
66	Roane	SR29	5.77	5.86	7	2	0.09	3,980	7.26	30	0	1.725	0.345
67	Roane	SR29	5.94	6.01	9	1	0.07	3,980	7.26	30	0	1.703	0.341
68	Roane	SR29	6.15	6.25	10	2	0.10	3,980	7.26	30	0	2.143	0.429
69	Roane	SR29	6.35	6.39	6	2	0.04	3,980	7.26	30	0	1.060	0.212
70	Roane	SR29	6.51	6.56	8	1	0.05	3,980	7.26	30	0	1.376	0.275
71	Roane	SR29	6.67	6.72	10	1	0.05	3,980	7.26	30	0	1.580	0.316
72	Roane	SR29	6.73	6.83	8	2	0.10	4,000	7.30	30	0	1.949	0.390
73	Roane	SR29	12.79	12.85	4	2	0.06	4,020	7.34	36	0	0.957	0.191
74	Roane	SR29	13.90	14.12	5	2	0.22	4,020	7.34	40	0	2.414	0.483
75	Roane	SR58	0.12	0.37	4	1	0.25	1,210	2.21	28	0	1.024	0.205

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
76	Roane	SR58	0.50	0.53	4	1	0.03	1,210	2.21	28	0	0.237	0.047
77	Roane	SR58	0.55	0.60	4	1	0.05	1,210	2.21	28	0	0.308	0.062
78	Roane	SR58	1.75	1.85	3	1	0.10	1,210	2.21	28	0	0.455	0.091
79	Roane	SR58	4.96	5.01	7	2	0.05	2,420	4.42	28	0	0.810	0.162
80	Roane	SR58	5.09	5.12	3	1	0.03	2,420	4.42	28	0	0.409	0.082
81	Roane	SR58	7.59	7.62	5	2	0.03	4,060	7.41	44	0	0.632	0.126
82	Roane	SR58	7.74	7.77	4	1	0.03	4,060	7.41	44	0	0.556	0.111
83	Roane	SR58	8.10	8.14	5	1	0.04	4,060	7.41	44	0	0.716	0.143
84	Roane	SR58	8.17	8.27	5	2	0.10	4,060	7.41	44	0	1.221	0.244
85	Roane	SR58	8.30	8.34	7	1	0.04	4,060	7.41	44	0	0.868	0.174
86	Roane	SR58	8.37	8.41	5	2	0.04	4,060	7.41	44	0	0.716	0.143
87	Roane	SR58	8.56	8.61	7	2	0.05	4,060	7.41	44	0	0.952	0.190
88	Roane	SR72	0.11	0.15	19	1	0.04	1,320	2.41	24	0	0.903	0.181
89	Roane	SR72	0.21	0.24	6	2	0.03	1,320	2.41	24	0	0.359	0.072
90	Roane	SR72	0.25	0.32	17	2	0.07	1,320	2.41	24	0	0.954	0.191
91	Roane	SR72	0.33	0.38	4	1	0.05	1,320	2.41	24	0	0.368	0.074
92	Roane	SR72	0.45	0.50	5	2	0.05	1,410	2.57	23	0	0.444	0.089
93	Roane	SR72	0.56	0.63	16	1	0.07	1,410	2.57	23	0	1.000	0.200
94	Roane	SR72	0.63	0.76	9	1	0.13	1,410	2.57	23	0	0.985	0.197
95	Roane	SR72	0.77	0.88	9	2	0.11	1,410	2.57	23	0	0.892	0.178
96	Roane	SR72	1.70	1.73	5	2	0.03	1,410	2.57	23	0	0.350	0.070
97	Roane	SR72	2.03	2.05	5	1	0.02	1,410	2.57	23	0	0.304	0.061
98	Roane	SR72	2.20	2.23	62	2	0.03	1,410	2.57	23	0	2.750	0.550
99	Roane	SR72	2.24	2.29	33	1	0.05	2,000	3.65	24	0	2.250	0.450
100	Roane	SR72	2.39	2.44	17	2	0.05	2,000	3.65	24	0	1.316	0.263

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
101	Roane	SR72	2.68	2.71	5	1	0.03	2,000	3.65	24	0	0.486	0.097
102	Roane	SR72	2.93	2.99	7	1	0.06	2,000	3.65	24	0	0.797	0.159
103	Roane	SR72	3.00	3.05	12	2	0.05	2,000	3.65	24	0	1.024	0.205
104	Roane	SR72	3.10	3.13	15	2	0.03	2,000	3.65	24	0	1.070	0.214
105	Roane	SR72	3.25	3.29	5	1	0.04	2,000	3.65	24	0	0.551	0.110
106	Roane	SR72	3.30	3.33	9	2	0.03	2,000	3.65	24	0	0.720	0.144
107	Roane	SR72	3.40	3.45	8	1	0.05	2,000	3.65	24	0	0.790	0.158
108	Roane	SR72	3.48	3.51	4	1	0.03	2,000	3.65	24	0	0.428	0.086
109	Roane	SR72	3.57	3.60	4	2	0.03	2,000	3.65	24	0	0.428	0.086
110	Roane	SR72	3.72	3.75	11	1	0.03	2,000	3.65	24	0	0.836	0.167
111	Roane	SR72	3.87	3.90	4	2	0.03	2,000	3.65	24	0	0.428	0.086
112	Roane	SR72	3.94	3.97	5	2	0.03	2,000	3.65	24	0	0.486	0.097
113	Roane	SR72	4.05	4.09	4	2	0.04	2,000	3.65	24	0	0.492	0.098
114	Roane	SR72	4.11	4.15	17	1	0.04	2,000	3.65	24	0	1.251	0.250
115	Roane	SR72	4.19	4.25	21	2	0.06	2,000	3.65	24	0	1.614	0.323
116	Roane	SR72	4.26	4.29	38	1	0.03	2,000	3.65	24	0	2.413	0.483
117	Roane	SR72	4.38	4.43	11	1	0.05	2,000	3.65	24	0	0.966	0.193
118	Roane	SR72	4.69	4.73	11	1	0.04	2,000	3.65	24	0	0.901	0.180
119	Roane	SR72	4.77	4.83	14	2	0.06	2,000	3.65	24	0	1.205	0.241
120	Roane	SR72	5.32	5.38	9	1	0.06	2,000	3.65	24	0	0.913	0.183
121	Roane	SR72	5.43	5.50	4	1	0.07	2,000	3.65	24	0	0.686	0.137
122	Roane	SR72	5.80	5.89	8	2	0.09	1,930	3.52	24	0	1.012	0.202
123	Roane	SR72	5.98	6.04	7	1	0.06	1,930	3.52	24	0	0.769	0.154
124	Roane	SR72	6.05	6.11	7	2	0.06	1,930	3.52	24	0	0.769	0.154
125	Roane	SR72	6.29	6.37	9	1	0.08	1,930	3.52	24	0	1.006	0.201

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
126	Roane	SR72	6.39	6.42	4	2	0.03	1,930	3.52	24	0	0.413	0.083
127	Roane	SR72	6.46	6.51	18	2	0.05	1,930	3.52	24	0	1.326	0.265
128	Roane	SR72	6.66	6.72	7	1	0.06	1,930	3.52	24	0	0.769	0.154
129	Roane	SR72	6.75	6.79	4	2	0.04	1,930	3.52	24	0	0.475	0.095
130	Roane	SR72	6.86	6.89	9	1	0.03	1,930	3.52	24	0	0.694	0.139
131	Roane	SR72	7.14	7.18	10	2	0.04	1,930	3.52	24	0	0.813	0.163
132	Roane	SR72	7.23	7.32	16	2	0.09	1,930	3.52	24	0	1.463	0.293
133	Roane	SR72	7.33	7.37	11	1	0.04	1,930	3.52	24	0	0.869	0.174
134	Roane	SR72	7.41	7.45	15	1	0.04	1,930	3.52	24	0	1.095	0.219
135	Roane	SR72	7.46	7.49	20	1	0.03	1,930	3.52	24	0	1.314	0.263
136	Roane	SR327			15	2	0.10	2,390	4.36	26	0	1.740	0.348
137	Roane	SR327			15	2	0.06	1,990	3.63	26	0	1.203	0.241
138	Roane	SR327			32	1	0.07	1,990	3.63	26	0	2.209	0.442
139	Roane	SR327			17	2	0.11	3,180	5.80	26	0	2.591	0.518
140	Roane	SR327			12	1	0.11	3,180	5.80	26	0	2.147	0.429
141	Sumner	SR6	36.78	36.81	2.1	1	0.03	4,570	8.34	44	0	0.464	0.093
142	Sumner	SR25	0.09	0.13	3.2	1	0.04	1,970	3.60	26	0	0.420	0.084
143	Sumner	SR25	0.89	0.98	6.0	2	0.09	1,970	3.60	26	0	0.878	0.176
144	Sumner	SR25	1.20	1.31	3.1	1	0.11	1,970	3.60	26	0	0.841	0.168
145	Sumner	SR25	1.43	1.53	3.4	2	0.10	1,970	3.60	26	0	0.796	0.159
146	Sumner	SR25	1.69	1.79	5.7	1	0.10	1,970	3.60	26	0	0.923	0.185
147	Sumner	SR25	1.90	2.05	3.9	2	0.15	1,970	3.60	26	0	1.128	0.226
148	Sumner	SR25	2.57	2.66	6.0	1	0.09	1,970	3.60	26	0	0.878	0.176
149	Sumner	SR25	3.35	3.41	5.1	1	0.06	1,970	3.60	26	0	0.646	0.129
150	Sumner	SR25	3.86	3.92	6.3	2	0.06	2,510	4.58	26	0	0.907	0.181

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
151	Sumner	SR25	4.06	4.14	6.2	1	0.08	2,510	4.58	26	0	1.055	0.211
152	Sumner	SR25	4.19	4.24	4.9	2	0.05	2,510	4.58	26	0	0.732	0.146
153	Sumner	SR25	4.84	4.88	2.4	1	0.04	2,510	4.58	26	0	0.479	0.096
154	Sumner	SR25	5.21	5.32	3.9	1	0.11	2,510	4.58	26	0	1.127	0.225
155	Sumner	SR25	5.34	5.39	10.5	2	0.05	2,510	4.58	26	0	1.124	0.225
156	Sumner	SR25	5.43	5.46	21.0	2	0.03	2,510	4.58	26	0	1.705	0.341
157	Sumner	SR25	5.58	5.65	7.3	1	0.07	2,510	4.58	26	0	1.055	0.211
158	Sumner	SR25	5.67	5.71	3.2	1	0.04	2,510	4.58	26	0	0.535	0.107
159	Sumner	SR25	5.93	5.96	7.8	1	0.03	2,510	4.58	26	0	0.780	0.156
160	Sumner	SR25	6.24	6.27	8.6	2	0.03	2,510	4.58	26	0	0.836	0.167
161	Sumner	SR25	6.96	7.00	5.5	1	0.04	2,510	4.58	26	0	0.696	0.139
162	Sumner	SR25	7.16	7.19	3.4	2	0.03	2,510	4.58	26	0	0.471	0.094
163	Sumner	SR25	7.25	7.29	3.2	2	0.04	2,510	4.58	26	0	0.535	0.107
164	Sumner	SR25	7.56	7.62	6.5	1	0.06	2,510	4.58	42	0	0.645	0.129
165	Sumner	SR25	7.67	7.74	7.1	2	0.07	2,510	4.58	42	0	0.729	0.146
166	Sumner	SR25	8.07	8.19	3.9	2	0.12	3,020	5.51	24	0	1.515	0.303
167	Sumner	SR25	8.53	8.62	5.0	1	0.09	3,020	5.51	24	0	1.320	0.264
168	Sumner	SR25	8.63	8.67	6.7	2	0.04	3,020	5.51	24	0	0.981	0.196
169	Sumner	SR25	9.05	9.09	5.6	2	0.04	3,020	5.51	24	0	0.884	0.177
170	Sumner	SR25	9.11	9.16	8.3	1	0.05	3,020	5.51	24	0	1.220	0.244
171	Sumner	SR25	9.25	9.29	9.6	2	0.04	3,020	5.51	24	0	1.237	0.247
172	Sumner	SR25	10.31	10.35	4.0	1	0.04	3,020	5.51	38	0	0.544	0.109
173	Sumner	SR25	10.48	10.53	5.1	1	0.05	3,020	5.51	24	0	0.938	0.188
174	Sumner	SR25	11.20	11.26	6.0	2	0.06	3,060	5.58	24	0	1.130	0.226
175	Sumner	SR25	11.58	11.62	2.6	1	0.04	3,060	5.58	24	0	0.628	0.126

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
176	Sumner	SR25	13.62	13.67	4.3	1	0.05	3,060	5.58	26	0	0.841	0.168
177	Sumner	SR25	13.83	13.89	8.5	2	0.06	3,060	5.58	26	0	1.294	0.259
178	Sumner	SR25	14.24	14.28	10.5	1	0.04	3,060	5.58	24	0	1.334	0.267
179	Sumner	SR25	24.76	24.82	2.7	1	0.06	4,730	8.63	40	0	0.904	0.181
180	Sumner	SR25	24.85	24.89	2.7	1	0.04	4,730	8.63	40	0	0.690	0.138
181	Sumner	SR25	24.93	25.03	2.6	1	0.10	4,730	8.63	40	0	1.323	0.265
182	Sumner	SR52	6.94	7.00	4.4	2	0.06	5,000	9.13	24	0	1.612	0.322
183	Sumner	SR52	8.50	8.58	3.8	1	0.08	5,000	9.13	44	0	1.184	0.237
184	Sumner	SR52	12.05	12.20	5.2	2	0.15	4,020	7.34	44	0	1.640	0.328
185	Sumner	SR52	12.36	12.43	13.3	1	0.07	3,320	6.06	26	0	1.952	0.390
186	Sumner	SR52	12.73	12.78	5.7	1	0.05	3,320	6.06	26	0	1.042	0.208
187	Sumner	SR52	12.90	13.02	8.5	2	0.12	3,320	6.06	26	0	2.020	0.404
188	Sumner	SR52	13.10	13.16	17.4	1	0.06	3,320	6.06	26	0	2.229	0.446
189	Sumner	SR52	13.75	13.84	6.9	2	0.09	3,320	6.06	26	0	1.564	0.313
190	Sumner	SR52	13.86	14.00	7.0	1	0.14	3,320	6.06	26	0	2.086	0.417
191	Sumner	SR52	14.12	14.17	10.4	1	0.05	3,320	6.06	26	0	1.478	0.296
192	Sumner	SR52	14.22	14.27	4.3	1	0.05	3,320	6.06	26	0	0.912	0.182
193	Sumner	SR52	14.30	14.42	5.6	2	0.12	3,320	6.06	26	0	1.751	0.350
194	Sumner	SR52	14.44	14.51	8.2	2	0.07	3,320	6.06	26	0	1.479	0.296
195	Sumner	SR52	14.67	14.74	3.6	2	0.07	3,320	6.06	48	0	0.645	0.129
196	Sumner	SR52	14.87	14.93	3.4	1	0.06	3,320	6.06	48	0	0.571	0.114
197	Sumner	SR52	15.44	15.62	2.9	1	0.18	3,320	6.06	48	0	1.297	0.259
198	Sumner	SR52	16.53	16.63	3.0	2	0.10	3,320	6.06	48	0	0.800	0.160
199	Sumner	SR52	18.09	18.21	3.9	2	0.12	3,670	6.70	48	0	1.080	0.216
200	Sumner	SR52	20.72	20.75	2.3	1	0.03	3,670	6.70	58	0	0.283	0.057

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
201	Sumner	SR76	0.15	0.20	15.6	1	0.05	3,100	5.66	24	0	1.913	0.383
202	Sumner	SR76	0.65	0.72	4.5	1	0.07	3,600	6.57	24	0	1.288	0.258
203	Sumner	SR76	0.99	1.08	7.3	2	0.09	3,600	6.57	26	0	1.736	0.347
204	Sumner	SR76	1.21	1.36	5.9	2	0.15	3,600	6.57	26	0	2.263	0.453
205	Sumner	SR76	1.39	1.48	6.0	1	0.09	3,600	6.57	26	0	1.605	0.321
206	Sumner	SR76	1.75	1.81	3.4	1	0.06	3,600	6.57	26	0	1.010	0.202
207	Sumner	SR76	2.03	2.12	7.2	1	0.09	3,600	6.57	26	0	1.726	0.345
208	Sumner	SR76	2.22	2.28	6.2	2	0.06	3,600	6.57	26	0	1.291	0.258
209	Sumner	SR76	2.36	2.46	5.3	2	0.10	3,600	6.57	26	0	1.646	0.329
210	Sumner	SR76	2.63	2.71	6.3	1	0.08	2,840	5.18	26	0	1.202	0.240
211	Sumner	SR76	2.97	3.02	4.2	1	0.05	2,840	5.18	26	0	0.772	0.154
212	Sumner	SR76	3.84	3.89	3.5	1	0.05	2,840	5.18	26	0	0.717	0.143
213	Sumner	SR76	4.37	4.42	6.5	1	0.05	2,840	5.18	26	0	0.955	0.191
214	Sumner	SR76	4.58	4.64	5.1	2	0.06	2,840	5.18	26	0	0.931	0.186
215	Sumner	SR76	5.13	5.19	3.8	1	0.06	2,840	5.18	26	0	0.828	0.166
216	Sumner	SR76	5.62	5.66	2.3	2	0.04	2,840	5.18	26	0	0.534	0.107
217	Sumner	SR76	5.75	5.78	3.2	1	0.03	2,840	5.18	26	0	0.517	0.103
218	Sumner	SR76	5.91	6.01	5.4	2	0.10	2,840	5.18	26	0	1.306	0.261
219	Sumner	SR76	6.30	6.39	7.4	1	0.09	2,970	5.42	26	0	1.440	0.288
220	Sumner	SR76	6.45	6.57	7.1	2	0.12	2,970	5.42	26	0	1.691	0.338
221	Sumner	SR76	6.82	6.94	3.3	1	0.12	2,970	5.42	26	0	1.376	0.275
222	Sumner	SR76	7.07	7.12	6.9	1	0.05	2,970	5.42	26	0	1.031	0.206
223	Sumner	SR76	7.31	7.39	3.1	1	0.08	2,970	5.42	26	0	0.992	0.198
224	Sumner	SR76	7.67	7.73	3.0	2	0.06	2,970	5.42	26	0	0.800	0.160
225	Sumner	SR76	7.79	7.90	2.9	2	0.11	2,970	5.42	26	0	1.251	0.250

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
226	Sumner	SR76	8.10	8.21	5.3	1	0.11	2,970	5.42	26	0	1.450	0.290
227	Sumner	SR76	8.29	8.44	4.8	2	0.15	2,970	5.42	26	0	1.776	0.355
228	Sumner	SR76	8.56	8.61	4.5	1	0.05	2,970	5.42	26	0	0.832	0.166
229	Sumner	SR76	8.80	8.87	4.6	1	0.07	3,130	5.71	26	0	1.080	0.216
230	Sumner	SR76	8.97	9.06	3.2	1	0.09	3,130	5.71	26	0	1.151	0.230
231	Sumner	SR76	9.35	9.43	7.6	2	0.08	3,130	5.71	26	0	1.439	0.288
232	Sumner	SR76	9.52	9.58	3.8	2	0.06	3,130	5.71	26	0	0.913	0.183
233	Sumner	SR76	9.75	9.83	5.2	1	0.08	3,130	5.71	26	0	1.229	0.246
234	Sumner	SR76	9.88	9.94	5.2	1	0.06	3,130	5.71	26	0	1.035	0.207
235	Sumner	SR76	10.02	10.15	7.0	2	0.13	3,130	5.71	26	0	1.870	0.374
236	Sumner	SR174	9.97	10.02	2.4	1	0.05	4,360	7.96	36	0	0.774	0.155
237	Sumner	SR174	11.50	11.55	3.1	1	0.05	4,360	7.96	36	0	0.842	0.168
238	Sumner	SR174	12.22	12.29	3.4	1	0.07	4,360	7.96	36	0	1.087	0.217
239	Sumner	SR174	12.44	12.47	2.4	2	0.03	4,360	7.96	36	0	0.558	0.112
240	Sumner	SR174	12.81	12.90	2.7	2	0.09	4,360	7.96	36	0	1.235	0.247
241	Sumner	SR174	14.15	14.22	3.0	1	0.07	4,360	7.96	36	0	1.048	0.210
242	Sumner	SR174	17.55	17.60	2.9	2	0.05	3,030	5.53	32	0	0.625	0.125
243	Sumner	SR174	17.72	17.81	4.2	1	0.09	3,030	5.53	32	0	1.049	0.210
244	Sumner	SR174	19.31	19.40	4.5	1	0.09	3,030	5.53	32	0	1.071	0.214
245	Sumner	SR174	19.68	19.81	6.9	1	0.13	3,030	5.53	32	0	1.577	0.315
246	Sumner	SR174	19.99	20.07	5.8	2	0.08	3,030	5.53	32	0	1.085	0.217
247	Sumner	SR174	20.27	20.31	2.3	2	0.04	3,030	5.53	32	0	0.498	0.100
248	Sumner	SR174	20.49	20.53	8.9	1	0.04	2,260	4.12	32	0	0.736	0.147
249	Sumner	SR174	20.55	20.70	9.1	2	0.15	2,260	4.12	32	0	1.420	0.284
250	Sumner	SR174	20.75	20.92	9.1	1	0.17	2,260	4.12	32	0	1.542	0.308

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
251	Sumner	SR174	20.94	21.09	9.5	2	0.15	2,260	4.12	32	0	1.442	0.288
252	Sumner	SR174	21.19	21.23	3.9	1	0.04	2,260	4.12	32	0	0.460	0.092
253	Sumner	SR174	21.65	21.75	3.7	1	0.10	2,260	4.12	32	0	0.816	0.163
254	Sumner	SR174	21.80	21.85	3.5	2	0.05	2,260	4.12	32	0	0.499	0.100
255	Sumner	SR174	22.19	22.34	3.8	1	0.15	2,260	4.12	32	0	1.127	0.225
256	Sumner	SR174	22.39	22.59	4.0	2	0.20	2,260	4.12	32	0	1.444	0.289
257	Sumner	SR174	22.74	22.79	5.4	1	0.05	2,260	4.12	32	0	0.604	0.121
258	Sumner	SR174	23.28	23.36	4.1	1	0.08	2,260	4.12	32	0	0.716	0.143
259	Sumner	SR174	23.84	23.92	7.7	2	0.08	2,260	4.12	32	0	0.914	0.183
260	Sumner	SR174	23.97	24.15	4.0	1	0.18	2,260	4.12	32	0	1.322	0.264
261	Sumner	SR174	24.44	24.48	3.0	2	0.04	2,260	4.12	32	0	0.410	0.082
262	Sumner	SR174	24.61	24.77	4.0	2	0.16	2,260	4.12	32	0	1.199	0.240
263	Sumner	SR174	24.82	24.92	3.8	2	0.10	2,260	4.12	32	0	0.821	0.164
264	Sumner	SR174	25.00	25.04	2.9	1	0.04	2,260	4.12	32	0	0.405	0.081
265	Sumner	SR174	25.47	25.50	3.3	1	0.03	2,260	4.12	32	0	0.366	0.073
266	Sumner	SR174	25.78	25.87	3.9	1	0.09	1,350	2.46	32	0	0.457	0.091
267	Sumner	SR174	26.06	26.10	2.9	1	0.04	1,350	2.46	32	0	0.242	0.048
268	Sumner	SR174	26.42	26.61	4.9	2	0.19	1,350	2.46	32	0	0.856	0.171
269	Sumner	SR174	27.07	27.11	4.0	1	0.04	1,350	2.46	32	0	0.278	0.056
270	Sumner	SR174	27.71	27.81	5.0	1	0.10	1,350	2.46	32	0	0.530	0.106
271	Sumner	SR174	28.47	28.53	4.0	1	0.06	1,350	2.46	32	0	0.351	0.070
272	Sumner	SR174	29.28	29.35	2.6	2	0.07	1,350	2.46	32	0	0.341	0.068
273	Sumner	SR174	29.38	29.48	5.6	1	0.10	1,350	2.46	32	0	0.550	0.110
274	Sumner	SR174	29.70	29.89	3.8	2	0.19	1,740	3.18	28	0	1.154	0.231
275	Sumner	SR174	30.38	30.49	5.3	1	0.11	1,740	3.18	28	0	0.812	0.162

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
276	Sumner	SR174	30.69	30.83	4.1	2	0.14	1,740	3.18	28	0	0.911	0.182
277	Sumner	SR174	30.89	30.97	5.1	1	0.08	1,740	3.18	28	0	0.649	0.130
278	Sumner	SR174	31.71	31.75	2.8	2	0.04	1,200	2.19	28	0	0.232	0.046
279	Sumner	SR174	32.12	32.22	4.3	1	0.10	1,200	2.19	28	0	0.493	0.099
280	Sumner	SR174	32.63	32.68	2.8	1	0.05	1,200	2.19	28	0	0.267	0.053
281	Sumner	SR174	32.74	32.79	34.6	2	0.05	1,200	2.19	28	0	1.287	0.257
282	Sumner	SR174	32.96	33.06	8.3	2	0.10	1,200	2.19	28	0	0.621	0.124
283	Sumner	SR174	33.08	33.26	7.2	1	0.18	1,200	2.19	28	0	0.870	0.174
284	Sumner	SR174	33.78	33.90	6.8	2	0.12	690	1.26	28	0	0.370	0.074
285	Sumner	SR174	34.07	34.15	4.7	1	0.08	690	1.26	28	0	0.250	0.050
286	Sumner	SR174	34.22	34.26	2.8	2	0.04	690	1.26	28	0	0.133	0.027
287	Sumner	SR174	34.95	35.03	4.9	1	0.08	690	1.26	26	0	0.265	0.053
288	Sumner	SR174	35.05	35.19	7.5	2	0.14	690	1.26	26	0	0.443	0.089
289	Sumner	SR174	35.31	35.40	11.0	1	0.09	690	1.26	26	0	0.404	0.081
290	Sumner	SR174	35.42	35.54	3.8	2	0.12	690	1.26	26	0	0.329	0.066
291	Sumner	SR174	35.92	35.96	2.8	2	0.04	690	1.26	26	0	0.139	0.028
292	Sumner	SR174	36.20	36.35	4.5	2	0.15	690	1.26	26	0	0.407	0.081
293	Sumner	SR174	37.18	37.29	10.0	1	0.11	690	1.26	26	0	0.427	0.085
294	Sumner	SR174	37.56	37.61	3.5	2	0.05	690	1.26	26	0	0.174	0.035
295	Sumner	SR174	38.08	38.13	4.1	1	0.05	690	1.26	26	0	0.186	0.037
296	Sumner	SR257	0.12	0.22	6.7	1	0.10	3,500	6.39	28	0	1.662	0.332
297	Sumner	SR257	0.34	0.37	2.3	1	0.03	3,500	6.39	28	0	0.526	0.105
298	Sumner	SR257	0.60	0.66	6.1	2	0.06	3,500	6.39	28	0	1.191	0.238
299	Sumner	SR257	0.75	0.81	5.0	2	0.06	3,500	6.39	28	0	1.089	0.218
300	Sumner	SR259	1.08	1.13	9.4	1	0.05	940	1.72	22	0	0.429	0.086

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
301	Sumner	SR259	1.58	1.63	7.4	2	0.05	740	1.35	22	0	0.292	0.058
302	Sumner	SR259	2.12	2.17	11.2	1	0.05	740	1.35	22	0	0.378	0.076
303	Sumner	SR259	2.18	2.23	12.7	2	0.05	740	1.35	22	0	0.412	0.082
304	Sumner	SR259	2.62	2.66	6.8	1	0.04	740	1.35	22	0	0.254	0.051
305	Sumner	SR259	2.67	2.71	11.8	2	0.04	740	1.35	22	0	0.367	0.073
306	Sumner	SR259	2.85	2.94	6.3	2	0.09	740	1.35	22	0	0.367	0.073
307	Sumner	SR259	3.03	3.10	5.9	1	0.07	740	1.35	22	0	0.308	0.062
308	Sumner	SR259	3.28	3.33	9.5	2	0.05	740	1.35	22	0	0.340	0.068
309	Sumner	SR259	3.54	3.58	4.9	1	0.04	740	1.35	22	0	0.211	0.042
310	Sumner	SR259	3.61	3.64	2.4	1	0.03	740	1.35	22	0	0.129	0.026
311	Sumner	SR259	4.10	4.13	6.6	1	0.03	550	1.00	22	0	0.167	0.033
312	Sumner	SR259	4.17	4.23	5.3	2	0.06	550	1.00	22	0	0.201	0.040
313	Sumner	SR259	5.06	5.11	4.5	2	0.05	550	1.00	22	0	0.168	0.034
314	Sumner	SR259	5.84	5.94	15.8	2	0.10	550	1.00	22	0	0.451	0.090
315	Sumner	SR259	6.09	6.20	2.9	1	0.11	550	1.00	22	0	0.253	0.051
316	Sumner	SR259	6.62	6.68	8.4	2	0.06	550	1.00	22	0	0.253	0.051
317	Sumner	SR259	6.75	6.81	5.2	1	0.06	550	1.00	22	0	0.199	0.040
318	Sumner	SR259	7.52	7.56	4.1	1	0.04	550	1.00	22	0	0.143	0.029
319	Sumner	SR259	7.65	7.69	2.9	1	0.04	550	1.00	22	0	0.123	0.025
320	Sumner	SR259	7.77	7.83	7.2	1	0.06	310	0.57	22	0	0.131	0.026
321	Sumner	SR259	7.84	7.88	12.6	2	0.04	310	0.57	22	0	0.161	0.032
322	Sumner	SR259	8.11	8.16	10.0	2	0.05	310	0.57	22	0	0.147	0.029
323	Sumner	SR259	8.47	8.53	5.9	2	0.06	310	0.57	22	0	0.119	0.024
324	Sumner	SR259	8.55	8.67	7.5	1	0.12	310	0.57	22	0	0.197	0.039
325	Sumner	SR259	8.68	8.73	11.6	2	0.05	310	0.57	22	0	0.162	0.032

Table C.1. Predicted annual collision frequencies at the 343 horizontal curve sites in the study area (continued)

#	County	Route	BEGmp	ENDmp	Degree	L / R	L [mi]	AADT	Volume	Roadway Width [ft]	Spirals	Collisions per 5 years	Collisions per year
326	Sumner	SR259	8.81	8.86	14.3	1	0.05	310	0.57	22	0	0.188	0.038
327	Sumner	SR259	8.95	9.00	6.0	2	0.05	310	0.57	22	0	0.109	0.022
328	Sumner	SR259	9.02	9.11	14.6	2	0.09	310	0.57	22	0	0.232	0.046
329	Sumner	SR259	9.13	9.20	6.6	2	0.07	310	0.57	22	0	0.136	0.027
330	Sumner	SR259	9.23	9.31	8.1	1	0.08	310	0.57	22	0	0.160	0.032
331	Sumner	SR259	9.45	9.51	4.4	1	0.06	310	0.57	22	0	0.105	0.021
332	Sumner	SR259	9.92	10.00	4.5	1	0.08	310	0.57	22	0	0.126	0.025
333	Sumner	SR259	10.14	10.21	9.0	2	0.07	310	0.57	22	0	0.159	0.032
334	Sumner	SR259	10.29	10.41	8.0	1	0.12	310	0.57	22	0	0.201	0.040
335	Sumner	SR259	10.52	10.57	7.3	2	0.05	310	0.57	22	0	0.121	0.024
336	Sumner	SR259	10.70	10.80	25.3	2	0.10	335	0.61	22	0	0.372	0.074
337	Sumner	SR259	11.30	11.44	13.1	1	0.14	360	0.66	22	0	0.314	0.063
338	Sumner	SR259	11.55	11.62	8.4	2	0.07	360	0.66	22	0	0.177	0.035
339	Sumner	SR259	11.73	11.83	9.8	2	0.10	360	0.66	22	0	0.229	0.046
340	Sumner	SR259	12.09	12.15	8.3	1	0.06	360	0.66	22	0	0.164	0.033
341	Sumner	SR259	12.48	12.52	5.9	2	0.04	360	0.66	22	0	0.114	0.023
342	Sumner	SR259	12.69	12.73	4.3	1	0.04	360	0.66	22	0	0.096	0.019
343	Sumner	SR259	12.86	12.89	17.3	2	0.03	360	0.66	22	0	0.227	0.045

Appendix D:

Predicted annual collision frequencies on the 57 general highway segment sites in the study area

Bared and Vogt[27] model for predicting collision frequency on general highway segments:

$$AC_s = (L)\exp[-5.2513 + 1.0794\log(ADT) - 0.0774(TW) - 0.0809(SW)$$
$$+ 0.0457(RHR) + 0.0061(DD) + 0.0355(H) + 0.0275(V)]$$

where,

L is the segment length, in miles
ADT is the average daily traffic on the segment
TW is the travel lane width, in feet
SW is the shoulder width, in feet
RHR is the roadside hazard rating
DD is the driveway density, in driveways per mile
H is the horizontal curve index
V is the vertical curve index

Table D.1. Predicted annual collision frequencies on the 57 general highway segment sites in the study area

County	#	Route	BEGmp	ENDmp	L [mi]	AADT	TW [ft]	SW [ft]	RHR	DD	H Index	V Index	Collisions per 5 years	Collisions per mile per year
Roane	1	SR1	0.00	2.78	2.78	2,760	24	3	6.5	2.9	9.77	4.65	20.333	1.4628
Roane	2	SR1	5.57	8.80	3.23	4,230	24	9	4	10.8	0.28	6.59	16.257	1.0066
Roane	3	SR1	17.38	20.29	2.91	4,230	22	4	5.5	16.6	5.42	5.10	32.750	2.2509
Roane	4	SR1	20.29	21.33	1.04	2,400	22	4	5.5	16.6	19.08	2.67	9.644	1.8546
Roane	5	SR1	21.33	25.94	4.61	2,010	22	4	5.5	16.6	16.92	4.44	34.327	1.4893
Roane	6	SR1	25.94	27.96	2.02	2,640	22	4	5.5	16.6	5.24	4.43	13.332	1.3200
Roane	7	SR29	4.37	6.75	2.38	3,980	22	4	5	10.7	6.99	2.88	23.521	1.9765
Roane	8	SR29	12.68	14.25	1.57	4,020	24	8	4.5	3.8	1.87	1.24	7.260	0.9249
Roane	9	SR58	0.00	3.79	3.79	1,210	22	3	5	9.3	0.83	1.99	8.731	0.4608
Roane	10	SR58	3.79	7.08	3.29	2,420	22	3	5	9.3	0.33	0.81	15.232	0.9260
Roane	11	SR58	7.08	8.75	1.67	4,060	24	10	5	9.3	2.55	0.52	7.054	0.8448
Roane	12	SR72	0.00	2.24	2.24	1,395	20.8	1.2	6.5	12.4	15.97	3.03	14.683	1.3110
Roane	13	SR72	2.24	5.55	3.31	2,000	20	2	6.5	12.4	14.30	0.88	28.350	1.7130
Roane	14	SR72	5.55	7.60	2.05	1,930	20	2	6.5	12.4	12.79	1.74	16.397	1.5997
Sumner	15	SR6	34.85	37.72	2.87	4,570	24	10	4	5.2	0.03	1.18	11.953	0.8330
Sumner	16	SR25	0.00	3.47	3.47	1,970	22	2	4.5	15.7	2.11	6.53	17.677	1.0188
Sumner	17	SR25	3.47	7.54	4.07	2,510	22	2	4.5	15.7	3.01	6.54	27.812	1.3667
Sumner	18	SR25	7.54	7.98	0.44	2,661	24	9	4.5	15.7	5.27	1.31	1.461	0.6641
Sumner	19	SR25	7.98	10.21	2.23	3,020	22	1	4.5	15.7	2.48	6.10	19.559	1.7542
Sumner	20	SR25	10.44	11.08	0.64	3,020	22	1.6	4.5	15.7	0.90	12.88	6.092	1.9038
Sumner	21	SR25	11.08	13.00	1.92	3,060	22	1	4.5	15.7	0.55	15.86	20.861	2.1730
Sumner	22	SR25	13.00	13.57	0.57	3,060	22	1	4.5	15.7	0.00	1.74	4.119	1.4452
Sumner	23	SR25	13.57	14.33	0.76	3,060	20.8	2	4.5	15.7	4.25	8.43	7.769	2.0444
Sumner	24	SR25	22.51	25.23	2.72	4,730	24	8	5	16.5	0.32	1.33	15.727	1.1564
Sumner	25	SR41	14.38	16.39	2.01	3,630	24	10	4	13.4	0.00	5.84	7.792	0.7753
Sumner	26	SR41	16.39	19.41	3.02	2,540	24	10	4	13.4	0.00	5.82	7.958	0.5270
Sumner	27	SR41	19.41	22.75	3.34	3,214	24	10	4	13.4	0.00	2.68	10.409	0.6233
Sumner	28	SR52	7.50	9.51	2.01	5,000	24	10	3.5	13.6	0.29	3.46	10.198	1.0148
Sumner	29	SR52	9.51	11.51	2.00	4,020	24	10	3.5	13.6	0.00	2.10	7.645	0.7645

Table D.1. Predicted annual collision frequencies on the 57 general highway segment sites in the study area (continued)

County	#	Route	BEGmp	ENDmp	L [mi]	AADT	TW [ft]	SW [ft]	RHR	DD	H Index	V Index	Collisions per 5 years	Collisions per mile per year
Sumner	30	SR52	11.51	12.21	0.70	4,020	24	11.5	3.5	13.6	2.54	1.06	2.521	0.7202
Sumner	31	SR52	12.21	14.52	2.31	3,320	20	3	3.5	13.6	9.08	3.42	24.685	2.1372
Sumner	32	SR52	14.52	16.90	2.38	3,320	24	12	3.5	13.6	0.95	3.92	6.845	0.5752
Sumner	33	SR52	16.90	20.11	3.21	3,670	24	12	3.5	13.6	0.29	4.17	10.118	0.6304
Sumner	34	SR76	0.11	0.92	0.81	3,440	20	2.7	5	25.9	4.63	5.28	9.558	2.3601
Sumner	35	SR76	0.92	2.58	1.66	3,600	20	3	5	25.9	5.73	4.02	20.169	2.4300
Sumner	36	SR76	2.58	6.24	3.66	2,840	20	3	5	25.9	1.52	2.94	28.780	1.5727
Sumner	37	SR76	6.24	8.67	2.43	2,970	20	3	5	25.9	4.28	1.88	21.483	1.7681
Sumner	38	SR76	8.67	10.34	1.67	3,130	20	3	5	25.9	4.43	6.47	17.821	2.1342
Sumner	39	SR174	9.58	14.22	4.64	4,360	24	6.1	4	18.8	0.38	2.04	28.352	1.2221
Sumner	40	SR174	18.00	20.45	2.45	3,030	22	5	5	16.1	1.83	3.32	14.483	1.1823
Sumner	41	SR174	20.45	25.53	5.08	2,260	22	5	5	16.1	4.99	3.03	24.287	0.9562
Sumner	42	SR174	25.53	29.56	4.03	1,350	22	5	5	16.1	1.61	2.50	9.657	0.4792
Sumner	43	SR174	29.56	31.68	2.12	1,740	22	3	5	16.1	2.28	7.76	9.295	0.8769
Sumner	44	SR174	31.68	33.57	1.89	1,200	22	3	5	16.1	9.18	3.63	6.328	0.6696
Sumner	45	SR174	33.57	34.76	1.19	690	22	3	5	16.1	2.63	3.82	1.747	0.2935
Sumner	46	SR174	34.76	38.28	3.52	690	20	3	5	16.1	3.91	2.41	6.072	0.3450
Sumner	47	SR174	38.28	39.67	1.39	520	20	1	5	16.1	0.00	0.48	1.714	0.2467
Sumner	48	SR257	0.00	0.84	0.84	3,500	24	2	4	36.9	4.06	4.55	7.695	1.8321
Sumner	49	SR258	8.09	11.38	3.29	3,280	20	2	5	26.6	0.00	3.19	31.386	1.9080
Sumner	50	SR258	11.38	13.16	1.78	4,110	20	2	5	26.6	0.00	2.80	21.431	2.4080
Sumner	51	SR259	0.00	1.38	1.38	940	18	2	5	12.5	1.04	5.46	4.043	0.5860
Sumner	52	SR259	1.38	3.96	2.58	740	18	2	5	12.5	4.62	13.40	8.248	0.6394
Sumner	53	SR259	3.96	5.96	2.00	550	18	2	5	12.5	4.00	11.40	4.297	0.4297
Sumner	54	SR259	5.96	7.75	1.79	550	20	1	5	12.5	1.81	2.94	2.619	0.2926
Sumner	55	SR259	7.75	10.76	3.01	310	20	1	5	12.5	13.43	11.66	4.554	0.3026
Sumner	56	SR259	10.76	12.88	2.12	360	20	1	5	12.5	13.09	3.76	2.997	0.2827
Sumner	57	SR376	0.00	3.39	3.39	3,270	22	7	5	9.4	0.00	3.59	16.782	0.9901

Appendix E
Summary Crash Information, Accident Rates, Critical Rates, and Severity Index Calculations

Table E.1. – Roane County Highway Segments

Route	Beginning Milepost	Ending Milepost	Crashes	Length	AADT	Total Injured	Total Killed	Accident Rate	Hazard Rate	Severity Index
SR001	0	2.78	34	2.78	2760	21	1	4.047	1.580	0.2444
SR001	5.57	8.8	52	3.23	4230	43	0	3.476	1.357	0.2353
SR001	17.38	20.29	13	2.91	4230	7	0	0.964	0.377	0.2778
SR001	20.29	21.33	11	1.04	2400	11	0	4.025	1.572	0.3125
SR001	21.33	25.94	14	4.61	2010	8	0	1.380	0.539	0.3000
SR001	25.94	27.96	6	2.02	2640	7	0	1.028	0.401	0.4000
SR029	4.37	6.75	46	2.38	3980	18	0	4.435	1.732	0.2698
SR029	12.68	14.25	14	1.57	4020	9	0	2.026	0.791	0.2632
SR058	0	3.79	9	3.79	1210	9	0	1.792	0.700	0.3077
SR058	3.79	7.08	18	3.29	2420	11	4	2.065	0.806	0.3571
SR058	7.08	8.75	24	1.67	4060	18	1	3.233	1.262	0.3333
SR072	0	2.24	8	2.24	1395	3	0	2.338	0.913	0.2727
SR072	2.24	5.55	17	3.31	2000	10	0	2.345	0.916	0.3462
SR072	5.55	7.6	14	2.05	1930	8	1	3.231	1.262	0.3636

Table E.2. – Sumner County Highway Segments

Route	Beginning Milepost	Ending Milepost	Crashes	Length	AADT	Total Injured	Total Killed	Accident Rate	Hazard Rate	Severity Index
SR006	34.85	37.72	11	2.87	4570	4	1	0.766	0.2991	0.267
SR025	0	3.47	26	3.47	1970	16	1	3.473	1.3565	0.333
SR025	3.47	7.54	44	4.07	2510	26	0	3.933	1.5361	0.279
SR025	7.54	7.98	4	0.44	2661	8	0	3.120	1.2184	0.429
SR025	7.98	10.21	17	2.23	3020	18	0	2.305	0.9003	0.414
SR025	10.44	11.08	5	0.64	3020	1	0	2.362	0.9226	0.167
SR025	11.08	13	27	1.92	3060	14	0	4.197	1.6390	0.270
SR025	13	13.57	5	0.57	3060	3	0	2.618	1.0224	0.286
SR025	13.57	14.33	33	0.76	3060	20	0	12.959	5.0608	0.283
SR025	22.51	25.23	21	2.72	4730	15	1	1.491	0.5821	0.344
SR041	14.38	16.39	8	2.01	3630	11	0	1.001	0.3910	0.385
SR041	16.39	19.41	16	3.02	2540	6	0	1.905	0.7439	0.200
SR041	19.41	22.75	18	3.34	3214	4	0	1.531	0.5980	0.182
SR052	7.5	9.51	6	2.01	5000	4	0	0.545	0.2129	0.400
SR052	9.51	11.51	12	2	4020	7	0	1.363	0.5323	0.250
SR052	11.51	12.21	1	0.7	4020	0	0	0.325	0.1267	0.000
SR052	12.21	14.52	31	2.31	3320	25	1	3.691	1.4416	0.326
SR052	14.52	16.9	19	2.38	3320	17	1	2.196	0.8576	0.424
SR052	16.9	20.11	9	3.21	3670	15	0	0.698	0.2725	0.438
SR076	0.11	0.92	1	0.81	3440	0	0	0.328	0.1280	0.000
SR076	0.92	2.58	9	1.66	3600	5	0	1.375	0.5371	0.357
SR076	2.58	6.24	21	3.66	2840	17	1	1.845	0.7205	0.344
SR076	6.24	8.67	28	2.43	2970	22	0	3.543	1.3837	0.349
SR076	8.67	10.34	20	1.67	3130	17	2	3.494	1.3646	0.286
SR174	9.58	14.22	20	4.64	4360	14	0	0.903	0.3526	0.310
SR174	18	20.45	19	2.45	3030	13	0	2.337	0.9128	0.345
SR174	20.45	25.53	47	5.08	2260	41	2	3.739	1.4600	0.356
SR174	25.53	29.56	17	4.03	1350	9	0	2.854	1.1144	0.292
SR174	29.56	31.68	8	2.12	1740	3	0	1.981	0.7735	0.273
SR174	31.68	33.57	8	1.89	1200	7	0	3.221	1.2580	0.333
SR174	33.57	34.76	5	1.19	690	5	1	5.561	2.1718	0.500

Table E.2. (continued) – Sumner County Highway Segments

Route	Beginning Milepost	Ending Milepost	Crashes	Length	AADT	Total Injured	Total Killed	Accident Rate	Critical Rate	Severity Index
SR174	34.76	38.28	9	3.52	690	8	2	3.384	1.3216	0.400
SR174	38.28	39.67	5	1.39	520	3	0	6.317	2.4671	0.375
SR257	0	0.84	6	0.84	3500	2	0	1.864	0.7279	0.250
SR258	8.09	11.38	33	3.29	3280	18	1	2.793	1.0906	0.313
SR258	11.38	13.16	14	1.78	4110	5	1	1.748	0.6825	0.263
SR259	0	1.38	4	1.38	940	4	1	2.816	1.0997	0.500
SR259	1.38	3.96	2	2.58	740	2	0	0.957	0.3736	0.333
SR259	3.96	5.96	11	2	550	8	1	9.132	3.5665	0.353
SR259	5.96	7.75	5	1.79	550	2	0	4.638	1.8113	0.286
SR259	7.75	10.76	7	3.01	310	7	0	6.851	2.6755	0.364
SR259	10.76	12.88	6	2.12	360	5	0	7.180	2.8038	0.333
SR376	0	3.39	7	3.39	3270	3	3	0.577	0.2252	0.364

Table E.3. – Roane County Bridges

Route	Beginning Milepost	Ending Milepost	Crashes	AADT	Total Injured	Total Killed	Accident Rate	Hazard Rate	Severity Index
SR029	13.81	14.01	6	4020	4	0	1.36	2.023	0.667
SR072	1.77	1.97	2	1410	0	0	1.30	1.923	0
SR322	2.88	3.08	1	840	0	0	1.09	1.614	0
SR304	6.1	6.3	1	900	0	0	1.01	1.506	0
SR304	10	10.2	2	2110	0	0	0.87	1.285	0
SR327	1.27	1.47	2	3180	0	0	0.57	0.853	0
SR326	1.07	1.27	2	3910	0	0	0.47	0.693	0
SR327	3.54	3.74	1	1990	0	0	0.46	0.681	0
SR072	4.45	4.65	1	2000	0	0	0.46	0.678	0
SR326	0.95	1.15	1	3910	0	0	0.23	0.347	0

Table E.4. – Sumner County Bridges

Route	Beginning Milepost	Ending Milepost	Crashes	AADT	Total Injured	Total Killed	Accident Rate	Hazard Rate	Severity Index
SR174	39.4	39.6	4	520	3	0	7.025	10.428	0.75
SR025	13.47	13.67	10	3060	5	0	2.984	4.430	0.5
SR025	12.32	12.52	6	3060	4	0	1.791	2.658	0.67
SR041	17.63	17.83	4	2540	2	0	1.438	2.135	0.5
SR174	28.1	28.3	2	1350	1	0	1.353	2.008	0.5
SR025	22.41	22.61	7	4730	1	0	1.352	2.006	0.14
SR025	10.21	10.41	4	3020	3	0	1.210	1.795	0.75
SR174	30.24	30.44	2	1740	1	0	1.050	1.558	0.5
SR025	0.78	0.98	2	1970	0	0	0.927	1.376	0
SR025	6.03	6.23	2	1970	1	0	0.927	1.376	0.5
SR076	7.18	7.38	3	2970	2	0	0.922	1.369	0.67
SR025	7.76	7.96	3	3020	2	0	0.907	1.347	0.67
SR174	12.64	12.84	4	4360	2	0	0.838	1.244	0.5
SR076	3.95	4.15	2	2840	2	0	0.643	0.955	1
SR258	9.84	10.04	2	3280	1	0	0.557	0.827	0.5
SR025	7.52	7.72	1	1970	1	0	0.464	0.688	1
SR258	12.6	12.8	2	4110	1	0	0.444	0.660	0.5
SR076	7.49	7.69	1	2970	0	0	0.307	0.456	0
SR052	9.85	10.05	1	4020	0	0	0.227	0.337	0
SR052	7.62	7.82	1	5000	0	0	0.183	0.271	0

Table E.5. – Roane County Horizontal Curves

Route	Beginning Milepost	Ending Milepost	Crashes	AADT	Total Injured	Total Killed	Accident Rate	Hazard Rate	Severity Index
SR001	0.37	0.42	1	2760	0	0	0.331	1.356	0.00
SR001	0.55	0.62	1	2760	0	0	0.331	1.356	0.00
SR001	5.58	5.66	2	4230	1	0	0.432	1.769	0.50
SR001	18.7	18.82	1	4230	1	0	0.216	0.885	1.00
SR001	20.25	20.35	4	2400	2	0	1.522	6.236	0.50
SR001	20.73	20.88	1	2400	0	0	0.381	1.559	0.00
SR001	21.04	21.1	2	2400	1	0	0.761	3.118	0.50
SR001	21.96	22.02	1	2010	1	0	0.454	1.862	1.00
SR001	22.6	22.65	1	2010	0	0	0.454	1.862	0.00
SR001	22.97	23.11	1	2010	1	0	0.454	1.862	1.00
SR001	23.37	23.42	1	2010	0	0	0.454	1.862	0.00
SR001	23.5	23.58	1	2010	1	0	0.454	1.862	1.00
SR001	24.83	24.92	1	2010	1	0	0.454	1.862	1.00
SR001	25.36	25.43	1	2010	1	0	0.454	1.862	1.00
SR001	25.49	25.58	2	2010	0	0	0.909	3.723	0.00
SR001	26.23	26.33	1	2640	1	0	0.346	1.417	1.00
SR029	4.9	4.98	2	3980	0	0	0.459	1.880	0.00
SR029	5.05	5.12	1	3980	1	0	0.229	0.940	1.00
SR029	5.17	5.23	1	3980	0	0	0.229	0.940	0.00
SR029	5.94	6.01	1	3980	0	0	0.229	0.940	0.00
SR029	6.15	6.25	1	3980	0	0	0.229	0.940	0.00
SR029	6.35	6.39	3	3980	2	0	0.688	2.820	0.67
SR029	6.51	6.56	1	3980	1	0	0.229	0.940	1.00
SR029	6.67	6.72	1	3980	1	0	0.229	0.940	1.00
SR029	6.73	6.83	17	3980	6	0	3.901	15.982	0.35
SR029	12.79	12.85	1	4020	0	0	0.227	0.931	0.00
SR029	13.9	14.12	4	4020	2	0	0.909	3.723	0.50
SR058	0.12	0.37	1	1210	1	0	0.755	3.092	1.00
SR058	8.1	8.14	1	4060	0	0	0.225	0.922	0.00
SR058	8.37	8.41	1	4060	2	0	0.225	0.922	2.00
SR072	0.45	0.5	1	1410	0	0	0.648	2.654	0.00
SR072	2.24	2.29	1	2000	1	0	0.457	1.871	1.00
SR072	3	3.05	1	2000	1	0	0.457	1.871	1.00
SR072	3.48	3.51	1	2000	0	0	0.457	1.871	0.00
SR072	3.57	3.6	1	2000	1	0	0.457	1.871	1.00
SR072	5.43	5.5	1	2000	0	0	0.457	1.871	0.00
SR072	5.8	5.89	1	1930	1	0	0.473	1.939	1.00
SR072	6.39	6.42	1	1930	0	1	0.473	1.939	1.00

Table E.6. – Sumner County Horizontal Curves

Route	Beginning Milepost	Ending Milepost	Crashes	AADT	Total Injured	Total Killed	Accident Rate	Hazard Rate	Severity Index
SR025	0.89	0.98	1	1970	0	0	0.464	1.899	0.00
SR025	1.2	1.31	1	1970	0	0	0.464	1.899	0.00
SR025	1.69	1.79	1	1970	0	0	0.464	1.899	0.00
SR025	1.9	2.05	2	1970	1	0	0.927	3.799	0.50
SR025	2.57	2.66	1	1970	1	0	0.464	1.899	1.00
SR025	4.06	4.14	1	2510	1	0	0.364	1.491	1.00
SR025	4.19	4.24	1	2510	0	0	0.364	1.491	0.00
SR025	5.21	5.32	2	2510	1	0	0.728	2.981	0.50
SR025	5.43	5.46	2	2510	1	0	0.728	2.981	0.50
SR025	5.58	5.65	1	2510	0	0	0.364	1.491	0.00
SR025	5.67	5.71	2	2510	1	0	0.728	2.981	0.50
SR025	5.93	5.96	1	2510	0	0	0.364	1.491	0.00
SR025	6.24	6.27	1	2510	0	0	0.364	1.491	0.00
SR025	6.96	7	1	2510	1	0	0.364	1.491	1.00
SR025	7.56	7.62	1	2510	1	0	0.364	1.491	1.00
SR025	8.53	8.62	1	3020	1	0	0.302	1.239	1.00
SR025	9.11	9.16	1	3020	1	0	0.302	1.239	1.00
SR025	10.31	10.35	3	3020	2	0	0.907	3.717	0.67
SR025	11.2	11.26	1	3060	0	0	0.298	1.223	0.00
SR025	13.62	13.67	2	3060	0	0	0.597	2.446	0.00
SR025	13.83	13.89	7	3060	3	0	2.089	8.560	0.43
SR052	12.73	12.78	2	3320	0	0	0.550	2.254	0.00
SR052	12.9	13.02	4	3320	2	0	1.100	4.508	0.50
SR052	14.3	14.42	2	3320	2	0	0.550	2.254	1.00
SR052	14.44	14.51	4	3320	2	0	1.100	4.508	0.50
SR052	14.67	14.74	5	3320	5	1	1.375	5.635	1.20
SR052	15.44	15.62	3	3320	2	0	0.825	3.381	0.67
SR076	0.65	0.72	1	3600	0	0	0.254	1.039	0.00
SR076	0.99	1.08	1	3600	0	0	0.254	1.039	0.00
SR076	1.39	1.48	1	3600	1	0	0.254	1.039	1.00
SR076	2.36	2.46	1	3600	0	0	0.254	1.039	0.00
SR076	2.97	3.02	1	2840	0	0	0.322	1.318	0.00
SR076	6.3	6.39	1	2970	0	0	0.307	1.260	0.00
SR076	6.82	6.94	1	2970	1	0	0.307	1.260	1.00
SR076	7.07	7.12	1	2970	1	0	0.307	1.260	1.00
SR076	7.67	7.73	1	2970	1	0	0.307	1.260	1.00
SR076	7.79	7.9	1	2970	0	0	0.307	1.260	0.00
SR076	8.29	8.44	1	2970	1	0	0.307	1.260	1.00
SR174	11.5	11.55	1	4360	1	0	0.209	0.858	1.00
SR174	12.22	12.29	1	4360	0	0	0.209	0.858	0.00
SR174	14.15	14.22	1	4360	0	0	0.209	0.858	0.00
SR174	17.55	17.6	2	3030	1	0	0.603	2.470	0.50
SR174	17.72	17.81	1	3030	0	0	0.301	1.235	0.00
SR174	19.31	19.4	2	3030	1	0	0.603	2.470	0.50
SR174	19.99	20.07	2	3030	0	0	0.603	2.470	0.00
SR174	20.55	20.7	4	2260	3	0	1.616	6.623	0.75
SR174	20.75	20.92	3	2260	3	0	1.212	4.967	1.00
SR174	21.65	21.75	1	2260	0	0	0.404	1.656	0.00
SR174	22.19	22.34	2	2260	1	0	0.808	3.311	0.50
SR174	22.39	22.59	2	2260	0	1	0.808	3.311	0.50
SR174	23.28	23.36	2	2260	1	0	0.808	3.311	0.50
SR174	23.97	24.15	1	2260	1	0	0.404	1.656	1.00
SR174	24.61	24.77	1	2260	1	0	0.404	1.656	1.00
SR174	24.82	24.92	5	2260	1	0	2.020	8.278	0.20
SR174	25.47	25.5	1	2260	0	0	0.404	1.656	0.00
SR174	29.38	29.48	1	1350	1	0	0.676	2.772	1.00
SR174	30.38	30.49	1	1740	0	0	0.525	2.150	0.00
SR174	30.69	30.83	1	1740	0	0	0.525	2.150	0.00

Table E.6. (continued) – Sumner County Horizontal Curves

Route	Beginning Milepost	Ending Milepost	Crashes	AADT	Total Injured	Total Killed	Accident Rate	Hazard Rate	Severity Index
SR174	32.12	32.22	2	1200	0	0	1.522	6.236	0.00
SR174	32.96	33.06	1	1200	0	0	0.761	3.118	0.00
SR174	33.08	33.26	1	1200	1	0	0.761	3.118	1.00
SR174	34.07	34.15	1	690	0	0	1.324	5.423	0.00
SR174	36.2	36.35	1	690	0	0	1.324	5.423	0.00
SR174	37.56	37.61	1	690	1	0	1.324	5.423	1.00
SR174	38.08	38.13	1	690	1	1	1.324	5.423	2.00
SR257	0.12	0.22	1	3500	1	0	0.261	1.069	1.00
SR257	0.6	0.66	1	3500	0	0	0.261	1.069	0.00
SR257	0.75	0.81	1	3500	0	0	0.261	1.069	0.00
SR259	2.12	2.17	1	740	1	0	1.234	5.056	1.00
SR259	4.17	4.23	1	550	0	0	1.660	6.803	0.00
SR259	5.84	5.94	1	550	0	0	1.660	6.803	0.00
SR259	7.52	7.56	1	550	1	0	1.660	6.803	1.00
SR259	7.84	7.88	1	310	0	0	2.946	12.070	0.00
SR259	8.68	8.73	1	310	0	0	2.946	12.070	0.00
SR259	9.02	9.11	1	310	1	0	2.946	12.070	1.00

Appendix F:

Questionnaire mailed to the 35 expert panelists

December 14, 1998

Dear _______________:

North Carolina State University and the University of North Carolina at Chapel Hill are conducting this survey of highway safety professionals for the Southeastern Transportation Center as part of a project on ranking hazardous sites. Experts representing eight southeastern states (AL, FL, GA, KY, MS, NC, SC and TN) are participating in this survey.

Enclosed is a packet of information that our research team has compiled about 18 sites on rural, two-lane highways. The first page of the packet is for your responses. The remainder of the packet contains one page for each of the 18 sites. Each of these pages has two photos of the site and a table with relevant information about the site.

The survey consists of only two questions. First, we would like you to evaluate the probable hazardousness of each site on a scale of 1 (collisions very infrequent) to 7 (collisions very frequent). Second, we would like to know which single countermeasure you would recommend for each site given typical safety program budget constraints. This survey should take approximately 20 minutes to complete. We will not publish your individual responses in our report.

Please mail your response sheet back to me in the enclosed envelope. Feel free to call me (919-515-7733) or e-mail me (hummer@eos.ncsu.edu) with questions or comments you may have. We appreciate your honest, professional opinions. Thank you very much for your time.

Sincerely,

Dr. Joseph Hummer, P.E.
Associate Professor
Project Principal Investigator

Enclosures

Response Sheet

Name: ______________________________ Phone #: ______________________________

Title: ______________________________ Agency: ______________________________

E-mail: ______________________________ Fax #: ______________________________

Address: ____

1. For each site, please circle the appropriate number for the probable hazardousness. The scale is from 1 (collisions very infrequent) to 7 (collisions very frequent).
2. For each site, given typical safety program budget constraints, please choose one countermeasure from the list below and enter the number or description of the countermeasure in the 'Countermeasure' column.

Site #	Hazardousness (1-7)							Countermeasure
1	1	2	3	4	5	6	7	
2	1	2	3	4	5	6	7	
3	1	2	3	4	5	6	7	
4	1	2	3	4	5	6	7	
5	1	2	3	4	5	6	7	
6	1	2	3	4	5	6	7	
7	1	2	3	4	5	6	7	
8	1	2	3	4	5	6	7	
9	1	2	3	4	5	6	7	
10	1	2	3	4	5	6	7	
11	1	2	3	4	5	6	7	
12	1	2	3	4	5	6	7	
13	1	2	3	4	5	6	7	
14	1	2	3	4	5	6	7	
15	1	2	3	4	5	6	7	
16	1	2	3	4	5	6	7	
17	1	2	3	4	5	6	7	
18	1	2	3	4	5	6	7	

List of Possible Countermeasures:

1	Do nothing	6	Add turn lane	11	Install illumination	16	Flatten side slopes
2	Widen travel lane	7	Upgrade guardrail	12	Widen shoulder	17	Relocate poles
3	Superelevate curve	8	Widen existing bridge	13	Replace bridge with a wider bridge	18	Install / improve pavement markings
4	Install / improve warning signs	9	Lengthen vertical curve	14	Improve / install bridge rail	19	Other: __________ (please specify).
5	Install spiral transitions on curve	10	Lengthen horizontal curve radius	15	Remove roadside trees		

Appendix F:

Sample Photographs from Questionnaire

Photo 1: Bridge, Centerline View

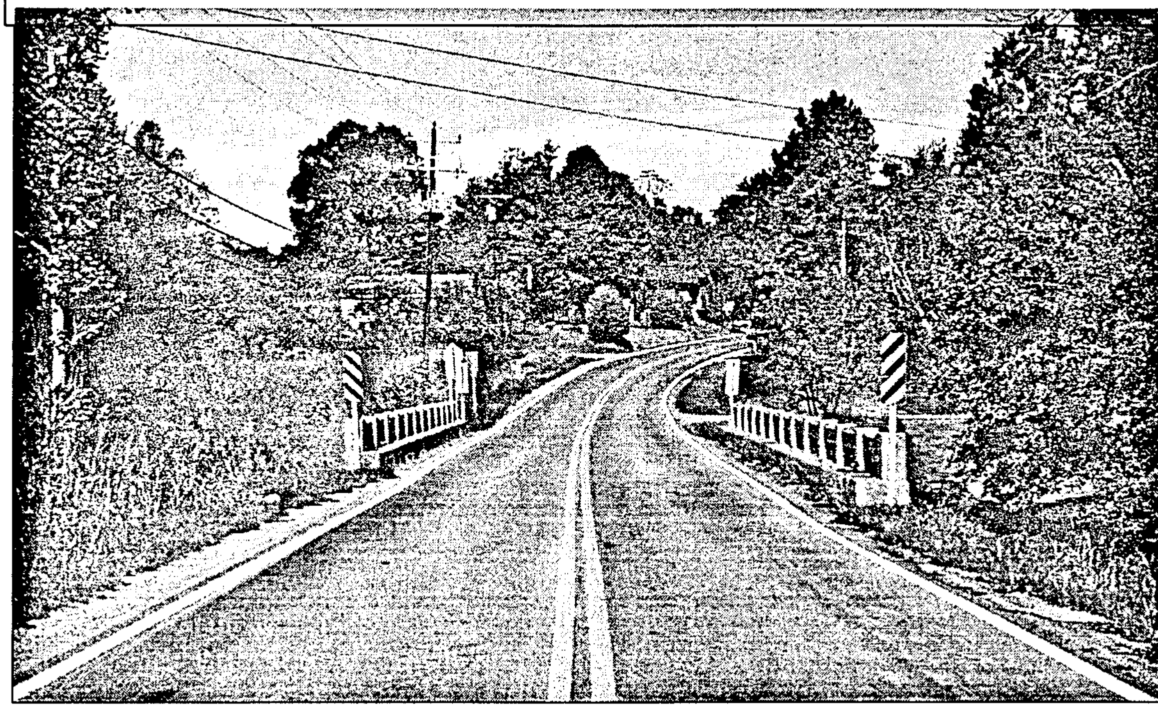

Photo 2: Curve, Left Side View

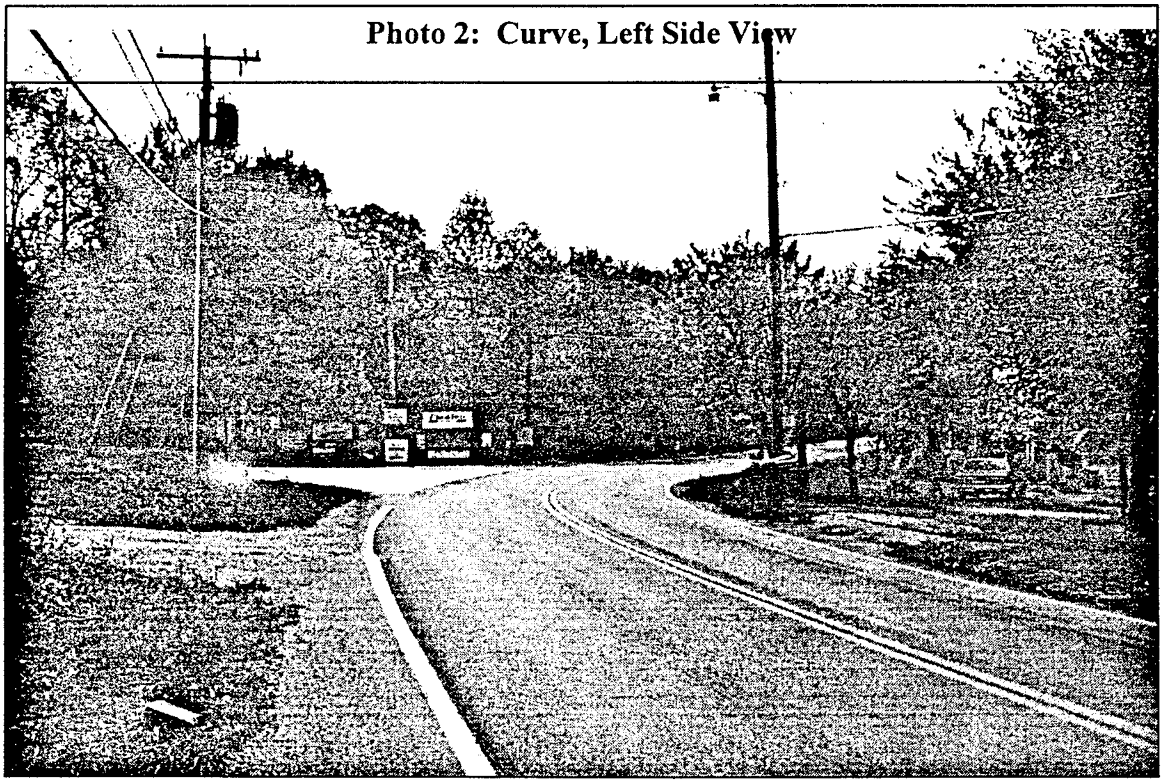

Photo 3: Segment, Right Side View

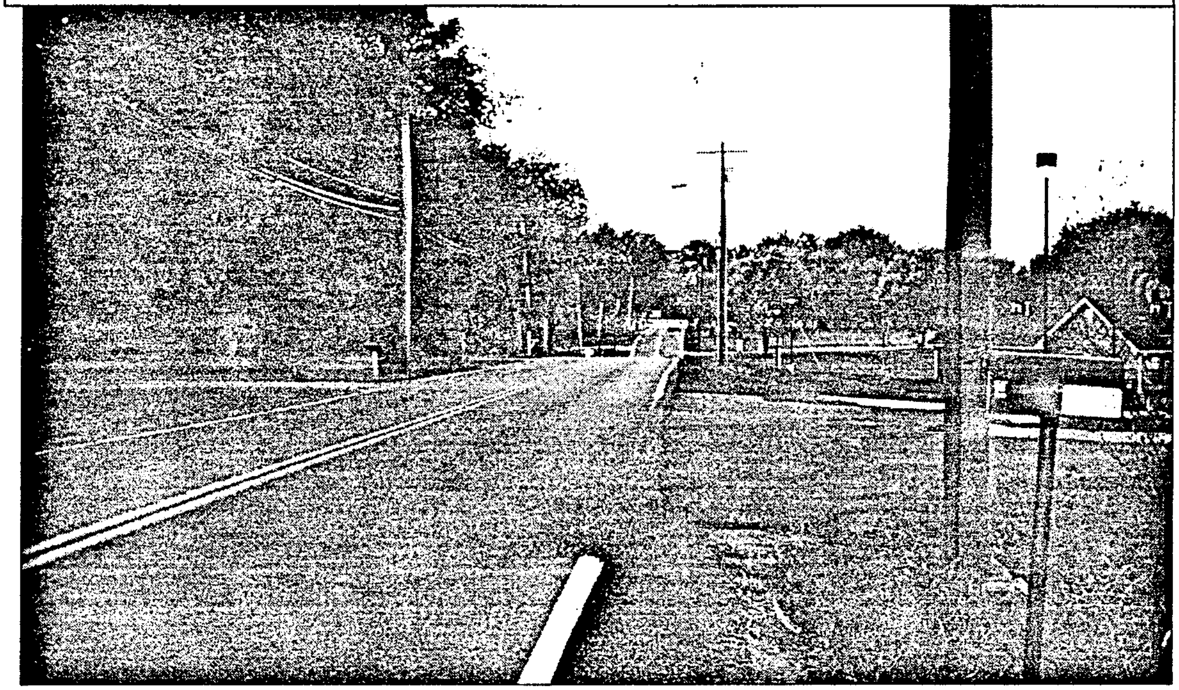

Photo 4: Curve, Centerline View

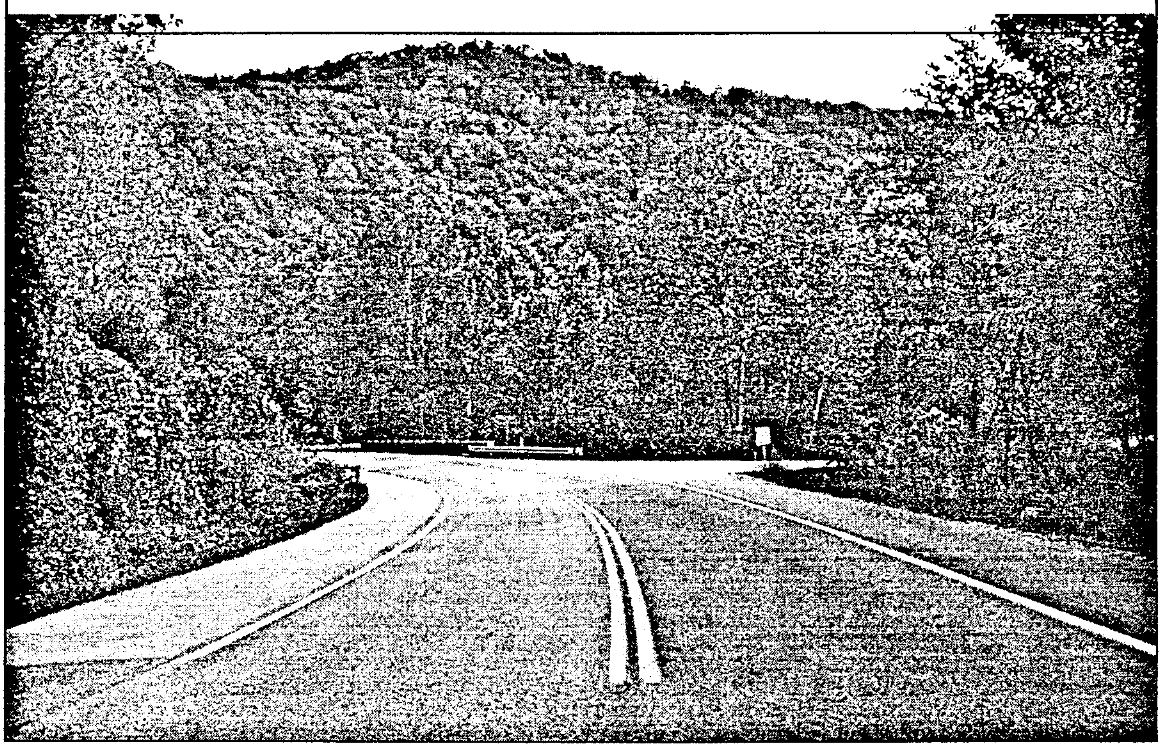

Photo Five – Bridge, Centerline View