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16. Abstract

Over a three year period (2004-2006), there were more than 60,000 crashes involving fixed objects (trees, utility poles, culverts, bridge piers, etc.) located within South Carolina roadsides. These fixed object crashes accounted for 20% of all crashes in South Carolina, and nearly 50% of all fatal crashes. In comparison, only 30% of fixed-object crashes result in fatalities nationally. Responding to the growing concerns of roadside hazard involvement in crashes, SCDOT selected a research project to analyze roadside collision data, evaluate the sufficiency of current clear zones along state roadways, and assess the benefits associated with minimizing consequences of leaving the roadway by providing and maintaining adequate clear zones. Clemson University was selected to perform this work.

After using a combination of crash data, SCDOT roadway inventory data, and geographic information system analysis tools to identify 287 sites of interest in 14 counties across the state, Clemson researchers surveyed the sites with an instrumented van to identify exact parameters for roadside slopes and distances to obstacles in the clear zones. Of the 287 sites surveyed, 131 were randomly selected and analyzed for clear zone requirements. Of these, only 12 met the criteria using automated software processing. Taking into consideration, variations in actual operating speeds and the presence of curves at these sites, six more would no longer meet clear zone requirements. The research team also analyzed 58 control sites. For these 58 control sites, 47 met the minimum clear zone requirements, and only 11 did not. Using an odds ratio test for this sample, researchers determined that the odds of a site having a fixed object crash are 42 times higher if the minimum clear zone is not met. Considering the magnitude of the roadside hazard problem, and the deficiency of the clear zones in these areas, it appears that by providing recommended clear zones (or safe recovery areas) for motorists who leave the roadway, South Carolina could realize a notable decrease in roadway fatal and injury crashes. This is particularly significant realizing that many times it is for reasons other than driver error (i.e. blown tire, struck by another vehicle, avoiding an accident, avoiding deer, etc.).

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SUPPORT FOR THE ELIMINATION OF ROADSIDE HAZARDS

EVALUATING ROADSIDE COLLISION DATA AND CLEAR ZONE REQUIREMENTS

SEPTEMBER 16, 2009

CLEMSON UNIVERSITY

SUPPORT FOR THE ELIMINATION OF ROADSIDE HAZARDS:

EVALUATING ROADSIDE COLLISION DATA AND CLEAR ZONE REQUIREMENTS

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SUPPORT FOR THE ELIMINATION OF ROADSIDE HAZARDS:

EVALUATING ROADSIDE COLLISION DATA AND CLEAR ZONE REQUIREMENTS

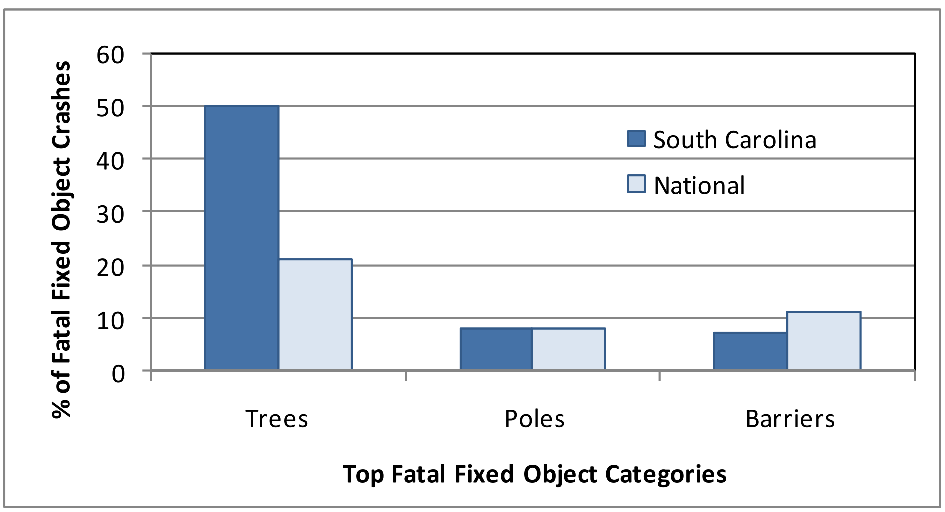
EXECUTIVE SUMMARY

Over a three year period (2004-2006), there were more than 60,000 crashes involving fixed objects (trees, utility poles, culverts, bridge piers, etc.) located within South Carolina roadsides. These fixed object crashes accounted for 20% of all crashes in South Carolina, and nearly 50% of all fatal crashes. In comparison, only 30% of fixed-object crashes result in fatalities nationally. Responding to the growing concerns of roadside hazard involvement in crashes, SCDOT selected a research project to analyze roadside collision data, evaluate the sufficiency of current clear zones along state roadways, and assess the benefits associated with minimizing consequences of leaving the roadway by providing and maintaining adequate clear zones. Clemson University was selected to perform this work.

The research effort began by analyzing three years of crash data to determine the magnitude of the problem and the factors associated with crashes involving roadside hazards. A number of interesting findings surfaced in this analysis:

- The greatest contributor to fatal crashes on the roadside in South Carolina is trees. ***Trees are involved in 25% of all fatal crashes in South Carolina, yet only 8% nationally***. These fatal crashes are estimated to cost South Carolina approximately $750 million per year, not including injury and property damage only crash costs which bring the total to nearly $1 billion per year.

- An analysis of the primary contributing factors in fatal fixed object crashes both nationally and in South Carolina showed a striking difference between the two in terms of the involvement of trees ***– 50% in South Carolina, yet only 21% nationally.***



- ***Almost 50% of tree-related crashes occur on secondary roads***, with another 25% on primary roads. While only 12% occur on Interstates, approximately 15% of the fatal tree crashes occur on Interstates. Interstate 26 tops the list for tree related fatalities, and Interstate 95 follows closely .

- ***72% of the tree-related crashes and 78% of the utility pole crashes occurred in curve sections***. Both tree and utility pole crashes in curves are particularly important when the clear zone requirement is taken into consideration because the Roadside Design Guide recommends that clear zones be increased by 10-50% along curve sections in areas where crash history indicates a need.

- Fatal utility pole crashes are consistent with national figures accounting for 8% of fatal fixed object crashes.

After using a combination of crash data, SCDOT roadway inventory data, and geographic information system analysis tools to identify 287 sites of interest in 14 counties across the state, Clemson researchers surveyed the sites with an instrumented van to identify exact parameters for roadside slopes and distances to obstacles in the clear zones. The van combines video-log capability with precision GPS location and a 360° rotating laser measurement device. The laser measures accurately within a few inches up to 50', and allows the determination of precise distances from the edge of the travel lane (pavement marking) to the nearest roadside obstacle (tree, pole, etc.) while also providing roadway cross-slope and roadside slope measurements.

Of the 287 sites surveyed, 131 were randomly selected and analyzed for clear zone requirements. Of these, only 12 met the criteria using automated software processing. Taking into consideration, variations in actual operating speeds and the presence of curves at these sites, six more would no longer meet clear zone requirements. The research team also analyzed 58 control sites. Control sites are areas that have no instances of fixed object crashes within the three year study period. For these 58 control sites, 47 met the minimum clear zone requirements, and only 11 did not. Using an odds ratio test for this sample, researchers determined that ***the odds of a site having a fixed object crash are 42 times higher if the minimum clear zone is not met***. The 95^{th} percentile confidence interval for this odds ratio ranges from 17.3 to 101.82 – indicating that the sites that do not meet clear zone requirements are significantly more likely to experience fixed object crashes.

Considering the magnitude of the roadside hazard problem, and the deficiency of the clear zones in these areas, it appears that ***by providing recommended clear zones (or safe recovery areas) for motorists who leave the roadway, South Carolina could realize a notable decrease in roadway fatal and injury crashes.*** This is particularly significant realizing that many times it is for reasons other than driver error (i.e. blown tire, struck by another vehicle, avoiding an accident, avoiding deer, etc.).

SUPPORT FOR THE ELIMINATION OF ROADSIDE HAZARDS:

EVALUATING ROADSIDE COLLISION DATA AND CLEAR ZONE REQUIREMENTS

SCDOT RESEARCH PROBLEM STATEMENT

A majority of South Carolina's fatal and serious injury collisions occur on rural two lane primary and secondary roadways. A majority of these collisions result from hitting fixed roadside objects on the shoulder such as trees, and utility poles. Drainage structures, mailbox structures, landscaping elements, and some illegal structural encroachments account for the remainder. Further, the American Association of State and Highway Transportation Officials (AASHTO) allows a 30 foot clear zone as a standard and this should be investigated to determine the benefits of such a clear zone or as close to it on these roadways as present right of way allows. This study may indicate that a need exists to advocate the procurement of additional right of way to assure an adequate clear zone. Also, research is extended to the Interstate System and similar roadways to determine if the present 30 minimum clear zone that is being used is adequate for these types of facilities. Collision data, posted speed limits, and 3-dimensional roadside laser measurement data are used to make such determinations.

RESEARCH OBJECTIVES

The goal for this proposal is to identify several counties that experience a high rate of such collisions. By using these as a pilot, a model could be generated that could apply to the rest of the state. After identified, the specific high hazard roadways would be inventoried regarding available right of way and location of collisions involving fixed objects, as described above, in the right of way. A parallel effort could then be pursued to remove the objects from the right of way creating a forgiving shoulder area to reduce these injuries and fatalities. This could also demonstrate to public officials, the motoring public and other leaders the benefits of correcting those hazards. The above rationale could be also applied to certain sections of Interstate types of roads where the hitting of fixed objects beyond the 30 ft. clear zone is a significant problem.

SPECIFIC RESULTS AND PAYOFF POTENTIAL

The benefit of clearing the obstructed roadside on some very high priority roadways could be realized through the proper identification of these routes using collision facts. But just as importantly, these facts can be used to educate all roadway safety stakeholders about the dangers and fatal consequences of not having a forgiving roadside free of obstacles. The idea is to increase awareness and support through properly applied and articulated facts involving collisions resulting from objects that can be removed from the roadside. The ultimate goal is to create a statewide initiative and public support for keeping roadsides on all roads free of obstacles, thereby reducing fatalities and injuries.

SUPPORT FOR THE ELIMINATION OF ROADSIDE HAZARDS:

EVALUATING ROADSIDE COLLISION DATA AND CLEAR ZONE REQUIREMENTS

INTRODUCTION

Over a three year period (2004-2006), there were more than 60,000 crashes along South Carolina roadways involving roadside hazards. A roadside hazard is defined as "any fixed object by the side of the road that, by virtue of its structure and placement, results in, or is likely to result in, an increased probability of vehicle damage, occupant injury or fatality in the event of a motor vehicle leaving the roadway," such as a tree, utility pole, culvert, or bridge pier [Kloeden et al., 1999]. These crashes with roadside hazards accounted for 20% of all crashes, and nearly 50% of all fatal crashes in South Carolina. In comparison, only 30% of all fatal crashes involve roadside hazards nationally [AASHTO, 2003].

Crashes with roadside hazards account for nearly 50% of all fatal crashes in South Carolina.

Of the fatalities resulting from roadside hazards, the majority involve the collision of a vehicle with a roadside tree. This is true for South Carolina as well as nationally; however, there are vast differences in the magnitude of the problem. Trees are involved in 25% of *all* fatal crashes in South Carolina, yet only 8% of all fatal crashes nationally [Neuman, 2003]. The associated economic cost of tree-related fatal crashes in South Carolina is estimated at $750 million per year. Including costs associated with injury and property damage only tree crashes would add an additional $175 million, bringing the total cost close to $1 billion per year.

In addition to trees, other roadside hazards also impact the safety of South Carolina roads. Figure 1 shows the top three categories of primary contributing factors in fatal fixed object crashes for both the U.S. and South Carolina. The most striking difference between the two was the involvement of trees – 21% nationally, yet 50% in South Carolina.

Utility poles and guardrail barriers are also noted in Figure 1 as contributors to fatal fixed object crashes in South Carolina. The use of guardrail to shield motorists from fixed objects is an option to mitigate crash severity. It is important to realize that the placement of guardrail in itself may serve as a roadside hazard that can result in serious injury or fatality should it be struck by a vehicle.

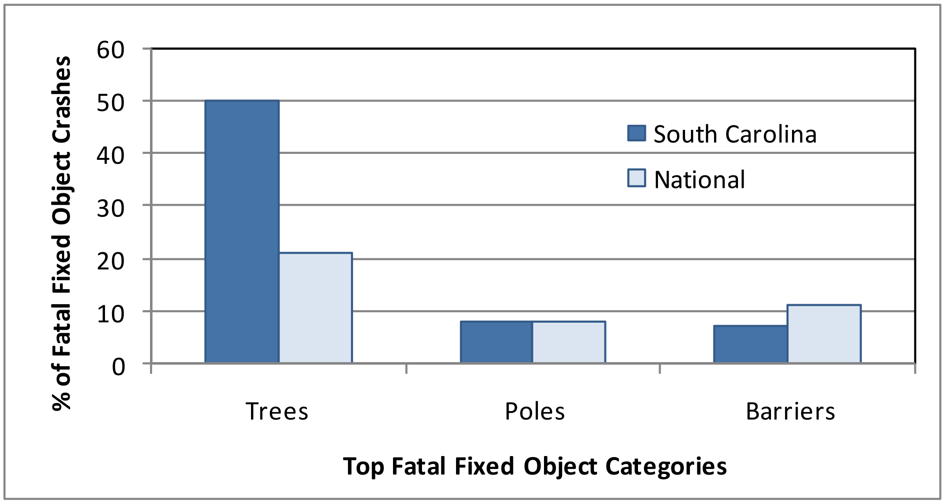


Figure 1 Primary contributing factors in fixed object crashes

50% of fixed-object fatal crashes in South Carolina involve trees, versus only 21% nationally.

The magnitude of the roadside hazard problem in South Carolina is obvious, and as such, reducing tree involved crashes should be a major priority. However, while trees may be the most frequently hit obstacle, they are not the only hazard of concern in the roadside. Utility poles, bridge piers, culverts, and mailboxes are also problematic. This research takes an in-depth view of each of these roadside hazards and describes the magnitude of the problem specific to South Carolina and provides recommendations for hazard mitigation and management.

SCOPE OF WORK

As outlined in the research problem statement, SCDOT was interested in conducting a pilot study to identify, inventory, and recommend roadside improvements for a select sample of roadways experiencing high numbers of fatal and injury crashes resulting from hitting fixed roadside objects such as trees, utility poles, drainage structures, etc. The pilot study included an analysis of the benefits associated with minimizing consequences of leaving the roadway by providing and maintaining adequate clear zones. Specifically, SCDOT requested the following elements:

- Procedures for identifying and prioritizing roadside clear zone improvements as well as recommendations for proactive clear zone practices.
- Evaluation of the sufficiency of a 30’ clear zone for varying roadway types.
- Assessment of the extent of hazardous obstacles located in the clear zone and illegal clear zone encroachments and on the select sample of roadways.
- Educational materials for officials and county stakeholders expressing the magnitude of the fixed object crash problem in South Carolina roadsides and the potential benefits of providing and maintaining sufficient clear zones.

The research plan developed by Clemson University aimed at developing positive procedures and methods for the identification and correction of roadside hazards. The approach included several work elements:

- Examine current and historical practices, legislation, guidelines, and standard operating procedures used by other transportation agencies with regard to clear zones.
- Analyze three years of crash data to identify roadways that experience a high incidence of run-off-the-road (ROR) fixed object crashes. Conduct an extensive field inventory of roadside terrain and hazardous objects using Clemson’s Transportation Systems Mobile Laboratory, a high tech instrumented vehicle capable of creating an attributed video-log and roadway geometrics with sub-meter accuracy.
- Define a methodology to enhance clear zone safety along various classes of state roads and consider implementation and policy aspects of such a methodology.
- Develop educational materials for elected officials and other stakeholders defining the benefits of providing and maintaining sufficient clear zones.

The report is presented in several sections including:

- Literature Review – a review of clear zone concepts and design guidance, and information on roadside obstacles and potential treatments.
- Methods – a discussion of data sources, sample selection, site data collection techniques, and analysis.
- Analysis and Results – covers general crash analysis regarding roadside hazards, descriptive statistics of the sample, analysis software, and results of the clear zone inventory.
- Conclusions – overall findings from the study and general directions of consideration for development of stakeholder educational materials.

LITERATURE REVIEW

The review of the literature will be compartmentalized into two areas as follows:

- Clear Zone Concepts
  - Early Vegetation Policy
  - Introduction of the Clear Zone
  - Current Guidance from AASHTO
  - South Carolina Interstate Vegetation Management Laws and Tree Ordinances
- Roadside Obstacles and Potential Treatments
  - Trees
  - Utility Poles

CLEAR ZONE CONCEPTS

EARLY VEGETATION POLICY

Development of the roadside began early in the history of our roadways. In 1936, Jesse Bennett wrote a book entitled, “Roadsides, the Front Yard of the Nation.” With the nation taking to their personal autos, the public desired roadsides that were aesthetic with amenities such as rest areas. While Bennett was pushing for “roadsides which can be obtained by preserving or creating a natural condition in keeping with the adjacent or surrounding country…outright economy in road maintenance”, policy-makers only saw the title. Our roadsides became perfectly manicured lawns. This was maintained through the 1950s, with agricultural machinery and chemicals used to mow-spray roadsides to manage weeds. [FHWA, 2004]

In 1965, the Highway Beautification Act was passed with the intent to conserve our nation’s “natural beauty”. In many cases, the implementation of the act let to landscaping and the use of non-native plant species which were sometimes invasive and took over the roadsides. The introduction of these plants led to additional requirements for maintenance, and it was not until the 1970s, that a more ecological approach was taken. However, the ecological approach was driven not by ideals of today’s environmentalists, but by the tight energy crunch of the early 1970s. Due to reduced maintenance budgets, maintenance departments had no choice but to mow and spray less which led to outcomes such as: increased presence of wildlife near the road, increased vegetation growth, and minimized herbicide use. [FHWA, 2004]

Vegetation does have functional as well as aesthetic purposes. Low growth vegetation in the roadside helps to stabilize the pavement and reduce erosion control. However, most of the early vegetation polices were focused purely on the appearance of the roadsides and did not mention potential safety effects of roadside tree plantings or the re-growth of trees near the roadside.

INTRODUCTION OF THE CLEAR ZONE

It was the 1967 *yellow book*[1] published by the American Association of State Highway Transportation Officials (AASHTO) that first highlighted safety issues with roadside hazards. The first edition of the yellow book provided broad advice on the desirability of a clear zone width of 30 ft, with slopes no greater than 6:1 and free of hazardous obstacles. The AASHTO (1977) barrier guide provided further clarification of issues raised with respect to the influence of side slope and cross-sections on the performance of the clear zone, and extended the application of clear zones to lower volume and/or lower speed roads. AASHTO issued a *Roadside Design Guide* in 1988 which covered, and updated, the information in the barrier guide and the roadside safety sections of the yellow book. A metric version was published in 1996.

The 30 foot standard was derived from a study of crashes on the General Motors Proving Grounds by Stonex and Noble (1960). The Stonex reference reports the results of industrial safety developments at the proving ground with the focus of reducing consequences of run-off-road accidents. The original reference describes storm inlet drainage cross-sections and fills slopes tested and found to be traversable. There is no mention of clear-zone widths. Other sources suggest that Stonex made a presentation to the US Highway Research Board Committee on Geometric Design and to the Congressional Subcommittee on subsequent investigations of roadside safety conducted at the proving ground (Eno Foundation, 1968; Graham and Harwood, 1982). These investigations found that, with the improved roadside design adopted at the proving ground, most of the vehicles which left the roadway came to rest within 30 foot of the edge of the roadway. This would appear to be the basis of the Subcommittee recommendation for a 30 foot clear zone.

In 1978, Jones et al. reviewed the Stonex research and found once again that roadside improvements did reduce/eliminate driver injuries. However, they looked further into the distribution of lateral and angular encroachments, as opposed to longitudinal encroachments, and found that a significant number of these encroachments went beyond the 30 foot clear zone. Thus, the proving ground now has 98 feet of clear roadside as a standard – the distance at which no crashes with roadside hazards are likely to occur.

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[1] *Highway Design and Operational Practices Related to Highway Safety*, a 1967 report of the Special AASHTO Traffic Safety Committee

CURRENT CLEAR ZONE GUIDANCE FROM AASHTO

Designers must consider many variables when planning and constructing roadways. These considerations include safety, practicality, legality, affordability, and aesthetics. Designers are responsible for the areas that surround the roadway in addition to the actual roadway. The AASHTO defines this roadside area as that which is "beyond the traveled way (driving lanes) and the shoulder (if any) of the roadway itself" in the *Roadside Design Guide* (2002). Whenever a motorist strays from the traveled way it is considered an encroachment. Designers are responsible for preventing collisions with roadside hazards once an encroachment has occurred. The Roadside Design Guide "is intended for use as a resource document from which individual highway agencies can develop standards and policies" for designing roads and their surrounding roadside areas.

Crashes from encroachments lead the AASHTO to develop a clear roadside concept which began with their 1974 Highway Design and Operational Practices Related to Highway Safety report, also known as the second edition of the yellow book. This report stated that "for adequate safety, it is desirable to provide an unencumbered roadside recovery area that is as wide as practical on a specific highway section. Studies have indicated that on high-speed highways, a width of 30 feet or more from the edge of the through traveled way permits about 80 percent of the vehicles leaving a roadway out of control to recover." In 1977 this recommendation was modified in the AASHTO's Guide for Selecting, Locating and Designing Traffic Barriers to accommodate situations where 30 feet was disproportionate to the roadway environment requirements. This document modified the earlier clear zone concept by introducing variable clear zone distances based on traffic volumes, speeds and roadside geometry.

The 30 foot clear zone is based on tangent sections and near level roadsides. The roadside design guide gives adjustments to the clear-zone width requirements as related to fill slope and the outside of horizontal curves. Fill slopes between 3:1 and 4:1 are considered traversable, but not recoverable. They are permitted within the clear zone, but do not contribute to the clear-zone width. Fill slopes steeper than 3:1 are considered non-traversable and are not permitted within the clear zone.

Designers must use their own discretion when consulting the clear zone distance recommendations keeping in mind site-specific conditions, design speeds, rural versus urban locations, and practicality. The designer may choose to modify clear-zone distances for horizontal curvature. These modifications are normally considered only when crash histories indicated a need, or a specific site investigation shows a definitive crash potential that could be significantly lessened by increasing the clear zone width, and when such increases are cost effective. While the clear roadside concept should always be the designer's goal, compromises are bound to arise. For example, these recommendations will apply differently in urban areas versus suburban areas. Because of these variable circumstances there is a need for individual study. The *Roadside Design Guide* recommends that for reconstruction or resurfacing projects, the crash history be considered in determining the specific clear roadside treatment for each portion of a project. One final portion of a project that should involve the designer is the landscaping. Often times this consultation is overlooked, which can result in a defective design. Trees and shrubs may be planted for aesthetic reasons but may obstruct the view of drivers or later grow into an obstruction or roadside hazard. Any modification to the roadway or roadside without checking with the designer may compromise the original integrity of the design.

Table 1 Clear-zone distances in feet from edge of through traveled way

[U.S. Customary Units]

DESIGN SPEED	DESIGN ADT	FORESLOPES			BACKSLOPES		
		1V:6H of flatter	1V:5H TO 1V:4H	1V:3H	1V:3H	1V:5H TO 1V:4H	1V:6H or Flatter
40 mph or less	UNDER 750	7 – 10	7 – 10	**	7 – 10	7 – 10	7 – 10
	750 – 1500	10 – 12	12 – 14	**	10 – 12	10 – 12	10 – 12
	1500 – 6000	12 – 14	14 – 16	**	12 – 14	12 – 14	12 – 14
	OVER 6000	14 – 16	16 – 18	**	14 – 16	14 – 16	14 – 16
45–50 mph	UNDER 750	10 – 12	12 – 14	**	8 – 10	8 – 10	10 – 12
	750 – 1500	12 – 14	16 – 20	**	10 – 12	12 – 14	14 – 16
	1500 – 6000	16 – 18	20 – 26	**	12 – 14	14 – 16	16 – 18
	OVER 6000	18 – 20	24 – 28	**	14 – 16	18 – 20	20 – 22
55 mph	UNDER 750	12 – 14	14 – 18	**	8 – 10	10 – 12	10 – 12
	750 – 1500	16 – 18	20 – 24	**	10 – 12	14 – 16	16 – 18
	1500 – 6000	20 – 22	24 – 30	**	14 – 16	16 – 18	20 – 22
	OVER 6000	22 – 24	26 – 32 *	**	16 – 18	20 – 22	22 – 24
60 mph	UNDER 750	16 – 18	20 – 24	**	10 – 12	12 – 14	14 – 16
	750 – 1500	20 – 24	26 – 32 *	**	12 – 14	16 – 18	20 – 22
	1500 – 6000	26 – 30	32 – 40 *	**	14 – 18	18 – 22	24 – 26
	OVER 6000	30 – 32 *	36 – 44 *	**	20 – 22	24 – 26	26 – 28
65–70 mph	UNDER 750	18 – 20	20 – 26	**	10 – 12	14 – 16	14 – 16
	750 – 1500	24 – 26	28 – 36 *	**	12 – 16	18 – 20	20 – 22
	1500 – 6000	28 – 32 *	34 – 42 *	**	16 – 20	22 – 24	26 – 28
	OVER 6000	30 – 34 *	38 – 46 *	**	22 – 24	26 – 30	28 – 30

* Where a site specific investigation indicates a high probability of continuing crashes, or such occurrences are indicated by crash history, the designer may provide clear-zone distances greater than the clear-zone shown in Table 3.1. Clear zones may be limited to 30 ft for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

** Since recovery is less likely on the unshielded, traversable 1V:3H slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high-speed vehicles that encroach beyond the edge of the shoulder may be expected to occur beyond the toe of slope. Determination of the width of the recovery area at the toe of slope should take into consideration right-of-way availability, environmental concerns, economic factors, safety needs, and crash histories. Also, the distance between the edge of the through traveled lane and the beginning of the 1V:3H slope should influence the recovery area provided at the toe of slope. While the application may be limited by several factors, the foreslope parameters which may enter into determining a maximum desirable recovery area are illustrated in Figure 3.2.

In order to study high risk roadways and their traffic patterns in an effort to improve safety, the *Roadside Design Guide* suggests five steps for a comprehensive crash reduction program: (1) setting up a traffic records system, (2) identifying high-frequency crash locations, (3) analyzing high-frequency crash locations, (4) correcting the high-frequency crash locations, and (5) reviewing the results of the program. This detailed study of crash records can be used to identify all types of roadside hazards, from utility poles to trees.

Once a high frequency crash location is identified and analyzed, a correction must be made. Many engineered solutions exist to deal with fixed objects along the side of the road such as breakaway utility poles and safety treatments for drainage pipes and ditches. However, trees pose a unique problem as they are not something a highway designer can re-engineer Any tree greater than four inches in diameter is considered a fixed object. Even shrubs with multiple trunks or groups of small trees close together can be considered as having the effect of a single tree with a four inch diameter. In addition to their size, their location is another factor that influences their potential danger to motorist. Maintenance programs should be used to prevent seedlings from developing into roadside hazards and large trees should be removed from within the clear zone for new construction and for reconstruction. Roads with restrictive geometric designs and narrow off-road recovery areas, such as county and city roads, are the most challenging from a roadway safety standpoint and difficult to accommodate with design.

The Federal Highway Administration distributed a *Guide to Management of Roadside Trees* (1986) developed by the Michigan Department of Transportation that contains detailed information on identifying and evaluating higher risk roadside environments and provides guidance for implementing roadside tree removal. Three methods are provided for handling roadside tree issues. One method centers on keeping the motorist on the roadway through speed and DUI reduction – although it is acknowledged that these changes are not easily accomplished. Another method is to make roadway improvements to help the driver stay on the roadway. Roadway treatments can include pavement marking, rumble strips, and more expensive roadway improvements such as adding shoulders or flattening horizontal curves. However, even with these treatments, drivers may still encroach on the roadside. The most positive method focuses on off-roadway treatments with two options in order of preference: tree removal and shielding. It is suggested that tree removal should be considered when trees are determined to be both obstructions and likely to be hit. Crash histories, scars indicating previous crashes, and field reviews are listed as ways for determining these criteria.

SOUTH CAROLINA INTERSTATE VEGETATION MANAGEMENT LAWS AND TREE ORDINANCES

SCDOT must also contend with Interstate vegetation management laws and local tree ordinances as it strives to provide recommended clear zones on each side of the travel way. The information in this section is offered to illustrate the additional challenge present in establishing a safer roadside environment.

The Interstate Vegetation Management Statute (SC Code 57-23-800) requires the SC Department of Transportation to mow and manage vegetation in the medians, roadsides, and Interchanges along the interstate highway system. The statute also stipulates that mowing will not extend more than 30 feet from the edge of the Interstate Pavement. There are a few exceptions to this distance requirement for beautification, outdoor advertising, and wildlife management purposes. However, according to Table 1 and based on current South Carolina interstate speeds and traffic volumes, a recovery area greater than 30 feet and up to 46 feet should be provided. Neighboring states of Georgia and North Carolina have instituted more rigorous management policies for purposes of providing safer roadsides and to reduce the incidence of tree debris and road blockage during emergency situations such as ice storms and hurricanes. The Georgia Department of Transportation has been clearing vegetation 32 feet beyond the edge of pavement in urban areas and 50 feet beyond in rural areas to reclaim the recovery area that once existed along these roadways, but has re-established in the years since the roadways were built. GDOT also has a policy to eliminate or shield all fixed objects in medians of 64 fee or less. North Carolina has developed a new vegetation policy which incorporates a minimum of 40 feet of clear mowing area, a small growth area (no vegetation over 4 inches in diameter) of 10-20 feet, and a mature tree line beyond this distance.

Some local tree ordinances may also impact the SCDOTs ability to manage roadsides for safety concerns. Local community members and civic leaders are typically involved in establishing and maintaining tree ordinances. In some situations where the local government is larger, the city planner, mayor, arborist, or forester can be contacted for consultation. Tree ordinances can exist for both counties as well as municipalities. Typically, these types of ordinances are implemented to protect trees and natural environments. Often the goal is beautification or shade of local areas and developments such as roadways, parking lots, and neighborhoods. In South Carolina many of these rights for establishing tree ordinances are protected under the Local Government Comprehensive Planning Enabling Act of 1994, S.C. Code §6-29.

One program called Tree City USA has been facilitating the development of tree ordinances at the local municipality level. Founded by the National Arbor Day Foundation program with USDA Forest Service & National Association of State Foresters, Tree City USA has four requirements for participation, (1) a tree board or department, (2) a tree care ordinance, (3) a community forestry program as well as a two dollar per capita expenditure on forestry activities, and (4) Arbor Day observance and proclamation. Sometimes as a prerequisite to applying for this program street tree ordinance are passed.

The street tree ordinance is one of four types of tree ordinances that would be relevant to the SCDOT. The other four are landscaping, tree protection, and view protection. Street tree ordinances protect public street trees from damage or removal. Landscaping ordinances describe required landscaping, number of trees, and types of suitable plants/trees; they may require trees or landscaping in parking lots or buffer-yards. Tree protection ordinances limit the number and types of trees that may be removed and mandates replacement. Trees to be protected may be based on size, species, or a combination of both. Finally, view protection ordinances protect special view-sheds from alteration by tree addition or removal. This includes the protection of highway or road corridors. These ordinances impact designated scenic or historical areas and may often be found as Design Standards and Board of Architectural Review Standards.

Some of the requirements that result from these tree ordinances may stipulate that trees be planted in medians or buffers, that planting be limited in certain areas, or that original wooded areas be preserved. These regulations or even protection status may be based on tree size, typically measured in diameter at breast height (DBH), type of tree, if the tree is a native species or not, how rare a tree is, what its historical significance is, a minimum density factor or basal area calculation for trees in the area, or required maintenance. These requirements or ordinances may use unique terminology specific to trees such as significant, grand, protected, trophy, and landmark, which can vary from community to community. Permits may require replanting as compensation for the removal of trees and may require tree surveys by a forester, arborist, or civil engineer. Some permits can be obtained for lots of trees, whereas others will have to be acquired for each tree individually. The price for obtaining these permits varies as well.

Penalties for the violation of a tree ordinance are specific to counties and municipalities. Fines are a common penalty for a violation, which may be a blanket fee or on a per tree basis. Other options such as injunction, stop work order, revocation of a permit for both tree and building projects, and withholding the certificate of occupancy are several possibilities that halt a project and punish a violation through loss of productivity and operating costs. A performance bond which may have been sold to guarantee that the contractor upholds the proposed project or maintenance and upkeep on a completed project may be lost as well because of a violation. A final option for enforcement is for the county or municipality to issue a citation, which is typically treated as a misdemeanor with fines.

In October of 2003, the South Carolina Forestry Commission and the Strom Thurmond Institute at Clemson University published a Status Report on Tree Ordinances in South Carolina. Included in the report were maps and a summary table of counties and municipalities with tree ordinances. Those are provided to follow in Figures 2 and 3 and Table 2. The most cited ordinance for counties was tree protection followed by landscaping ordinances. No counties had street tree ordinances. These are more of an issue for municipalities. In fact, the most common type of regulation on tree protection for municipalities is tree protection followed by street tree protection. Municipalities with tree protection ordinances have particularly high socio-economic characteristics of income, level of education, low population density and growth rate.

Table 2 Tree Ordinance Response Rates from Counties and Municipalitie

	Total Jurisdictions	Actual Responses	Known With Ordinance	Known Without Ordinance	Known Pending	Unknown
Counties	46	42 (91%)	22 (48%)	22 (48%)	-	2 (4%)
Municipalities	269	120 (45%)	81 (30%)	44 (16%)	2 (<1%)	143 (53%)
Total	315	162 (51%)	103 (33%)	65 (21%)	2 (<1%)	145 (46%)

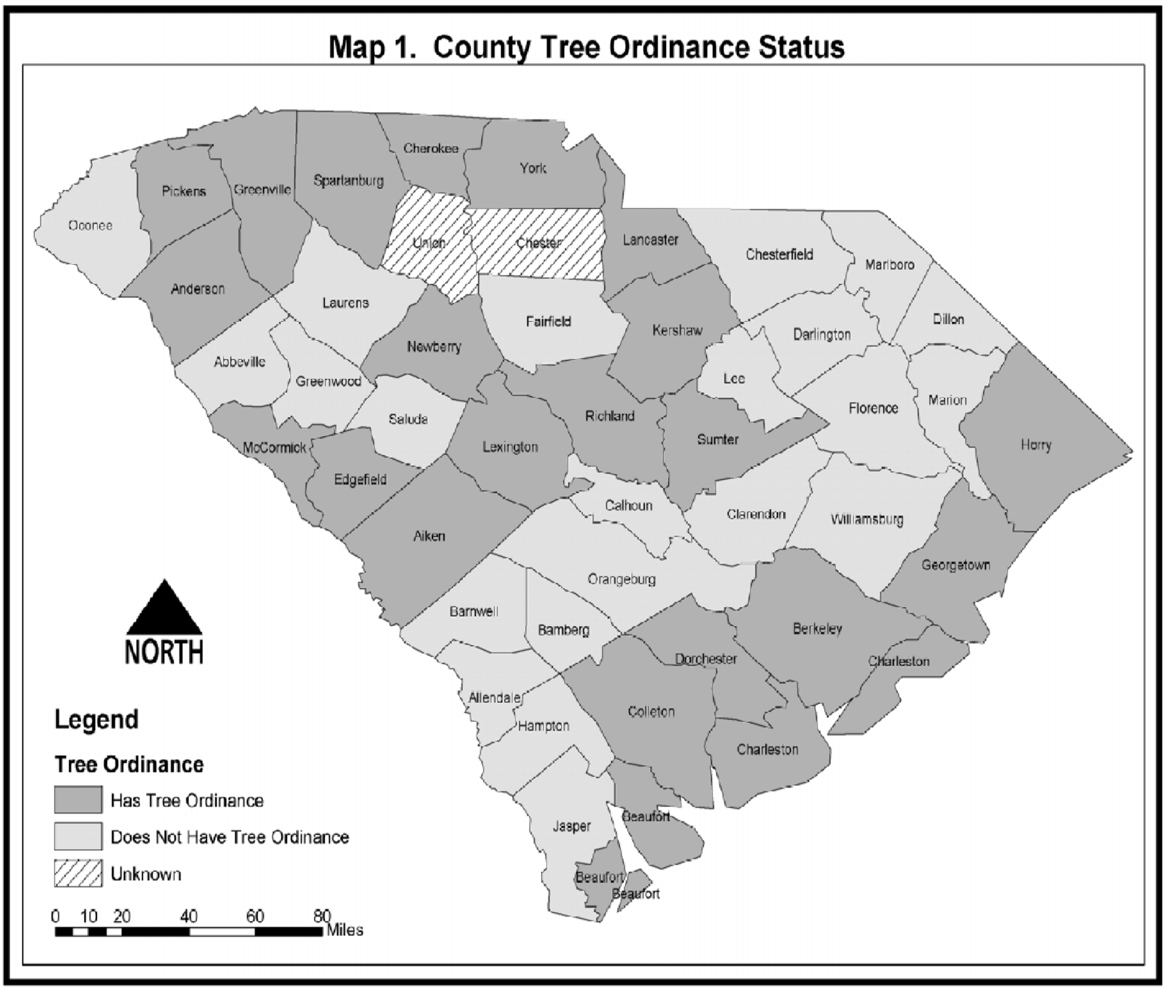


Figure 2 County tree ordinance status

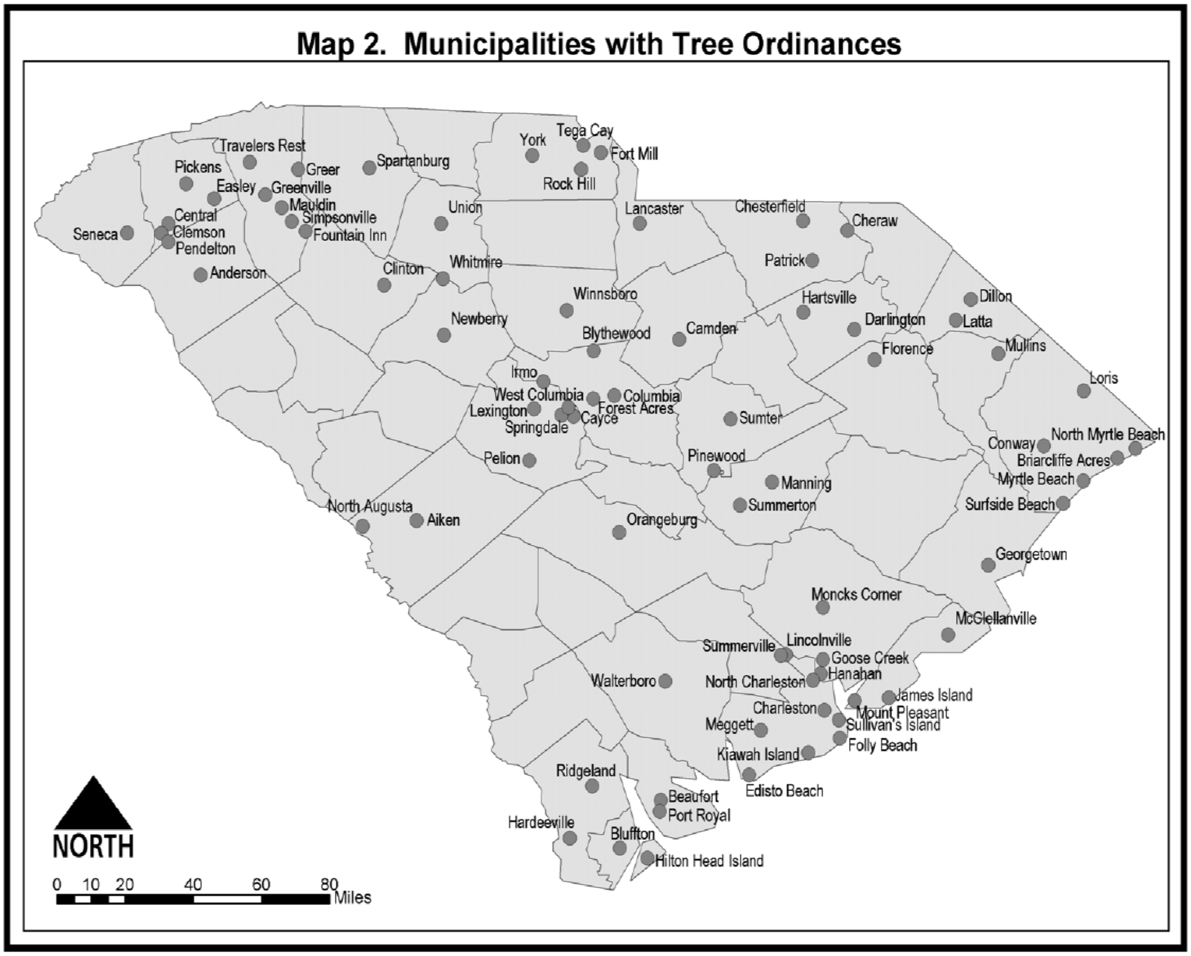


Figure 3 Municipalities with Tree Ordinances

Given the number of ordinances, it is impossible to provide clarity on each one in this document, but researchers did find a statement of partial exemption specifically for the SCDOT and CCPW that reads as follows:

> *"Partial Exemptions for SCDOT and CCPW*
>
> *The South Carolina Department of Transportation (SCDOT) and Charleston County Public Works (CCPW) shall be exempt from the provisions of this Article except the following:*
>
> *All trees species measuring 6 inches or greater DBH located in rights-of-way along Scenic Highways as designated in this Ordinance shall be protected and require a variance from the Charleston County Board of Zoning Appeals for removal per Article 9.4.5B and 9.4.6.*

> *Grand Tree Live Oak species in all present and future rights-of-way shall be protected and require a variance from the Charleston County Board of Zoning Appeals for removal per Article 9.4.5B and 9.4.6.*
>
> *All Grand Trees other than Live Oak species not located on a Scenic Highway are protected but may be permitted to be removed administratively when mitigated per Article 9.4.6."*

SOUTH CAROLINA CLEAR ZONE POLICIES

The South Carolina Highway Design Manual (Rev. 2006) provides guidance on roadside safety and designing for clear zones in Chapter 14. The introduction to the chapter states:

> *The ideal roadway would be entirely free of any roadside obstructions or other hazardous conditions. This is rarely practical because of natural, economic, and environmental factors. Chapter 14 presents clear zone distances which should adequately provide a clear recovery area for approximately 80 percent of errant vehicles that run off the road. In addition, the Chapter provides criteria for the use of roadside barriers, median barriers and impact attenuators where providing the clear zone is not practical.*

Chapter 14 also contains the following table with recommended clear zone distances for new construction and reconstruction. It should be noted that the table provided by SCDOT contains the same clear zone distance recommendations as those provided in the AASHTO *Roadside Design Guide*. The SCDOT recommended clear zone distances were used for all analysis in this research.

Table 3 Recommended Clear Zone Distances Table
(Figure 14.3A from SCDOT Highway Design Manual 11-2006 Revision)

Design Speed	Design Year ADT	Fill/Foreslope		Backslopes		
		6H:1V or Flatter	5H:1V to 4H:1V	3H:1V	5H:1V to 4H:1V	6H:1V or Flatter
40 mph or less	Under 750	7-10	7-10	7-10	7-10	7-10
	750-1500	10-12	12-14	10-12	10-12	10-12
	1500-6000	12-14	14-16	12-14	12-14	12-14
	Over 6000	14-16	16-18	14-16	14-16	14-16
40 – 50 mph	Under 750	10-12	12-14	8-10	8-10	10-12
	750-1500	14-16	16-20	10-12	12-14	14-16
	1500-6000	16-18	20-26	12-14	14-16	16-18
	Over 6000	20-22	24-28	14-16	18-20	18-20
55 mph	Under 750	12-14	14-18	8-10	10-12	10-12
	750-1500	16-18	20-24	10-12	14-16	16-18
	1500-6000	20-22	24-30	14-16	16-18	20-22
	Over 6000	22-24	26-32*	16-18	20-22	22-24
60 mph	Under 750	16-18	20-24	10-12	12-14	14-16
	750-1500	20-24	26-32*	12-14	16-18	20-22
	1500-6000	26-30	32-40*	14-18	18-22	24-26
	Over 6000	30-32*	36-44*	20-22	24-26	26-28
65 – 70 mph	Under 750	18-20	20-26	10-12	14-16	14-16
	750-1500	24-26	28-36*	12-16	18-20	20-22
	1500-6000	28	34-42*	16-20	22-24	26-28
	Over 6000	30-34*	38-46*	22-24	26-30	28-30

*Where a site-specific investigation indicates a high probability of continuing crashes, or such occurrences are indicated by crash history, the designer may provide clear zone distances greater than the clear zones shown in Figure 14.3A. Clear zones may be limited to 30 feet for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

Notes: 1. All distances are in feet and are measured from the edge of the traveled way.

2. For clear zones, the “Design Year ADT” will be the total ADT for both directions of travel for the design year. This applies to both divided and undivided facilities. Traffic volumes will be based on a 20-year projection from the anticipated date of construction completion.

3. The values in the figure apply to tangent sections of highway. See the discussion in Section 14.3.2.5 for possible adjustments on horizontal curves.

4. The values in the figure apply to all facilities without curbs. See Section 14.3.2.6 for curbed sections.

5. Clear zone distances for the 3H:1V fill slope have been omitted, because it is not typically used in South Carolina. See the AASHTO Roadside Design Guide for clear zone calculations where a 3H:1V slope is used.

ROADSIDE OBSTACLES AND POTENTIAL TREATMENTS

The areas of safety, operations, and aesthetics are all seen as important to the public, of which each yield designs of their own. As roadside design evolves, a push exists for the three areas to coexist without detracting from each other. It is understood that these areas of concern are intertwined, which is a fact that makes the complete design of roadways more complicated (NCDOT, 2007). States typically design their roadways according to the FHWA and AASHTO guidelines. In the past, clear zones were specified as having a minimum of 30 feet that contained no roadside hazards. Now, designing clear zone sizes are the result of design not a national set value. An issue that arises with this is when road design specifies a clear zone area that does not coincide with what others, such as the public, governmental officials, utility companies and other design engineers want in the realm of roadside aesthetics and roadside operations.

The AASHTO *Strategic Highway Safety Plan* identified 22 goals to pursue in order to significantly reduce highway crash fatalities. One of the products of the plan is a set of Guides (NCHRP Report 500 Series) covering various aspects of the road user, the highway, the vehicle, the environment, and the management system. Three currently available guides were of interest to the research team:

- Guide for Reducing Run-off-the-road Collisions
- Guide for Addressing Collisions with Trees in Hazardous Locations, and
- Guide for Reducing Collisions Involving Utility Poles.

Each of the guides provides objectives for the emphasis area and information on specific strategies and implementation methods. Each strategy provided in the manuals provides the user with an indication of whether the particular strategy has been tried with no results, is still experimental, or is proven. When strategies are proven, further information such as the accident modification factors are provided for use by the implementing agency. The research team reviewed each of these guides and also pulled supplementary information from past research to study roadside obstacles and their potential treatments.

TREES

There are benefits of having trees along our roadsides. Trees not only improve the visual appeal of roadsides, they also are an asset in controlling erosion and providing positive air quality benefits. However, trees located in close proximity to the roadway can have several adverse impacts such as increasing the number of injuries and fatalities that occur when vehicles leave the roadway, decreasing highway traffic sign visibility, decreasing sight distance around curves, producing debris build-up in drainage areas, and producing dangerous situations during periods of inclement weather such as strong winds or ice.

Collisions between vehicles and trees cause a large portion of the traffic fatalities in this country. Tree crashes occur most frequently on two-lane rural roads, and unlike other fixed-objects, the number goes down with increased traffic volumes. For average daily traffic levels of 1,000 vpd or less, 22 to 24 percent of fixed object crashes involve hitting a tree. Also, a 'high-crash' segment for tree crashes may experience no more than two or three tree-related crashes within a 5-year period, so problematic areas are not always easy to identify.

The Roadside Design Guide manual for roads maintenance workers identifies a general rule for situations pertaining to "fixed-object improvements in the shoulder," which agrees with the NCHRP. The manual's rule continues, "The appropriate treatment is generally to remove, relocate, retrofit, shield, or delineate, in this priority order" [AASHTO, 2002]. It is in the order presented by this rule that provides a guideline for the development of potential roadside maintenance programs. Organizations in charge, such as state departments of transportation, can build their maintenance policies around this rule. The challenging part for the development of these programs is determining when it is implausible to perform certain treatments. Also, specific steps must be implemented in order to ensure consistency when retrofitting, shielding, or delineating hazards.

With regards to safety, the National Cooperative Highway Research Program (NCHRP) denotes objectives and strategies to assist in improving the situation of tree involved crashes, specifically in the area within the clear zone. NCHRP specifies "strategies that focus solely on the safety aspects of trees and promote tree removal over other measures will not be acceptable to important constituencies," especially since many states have certain roads and highways that are scenic in nature and would be destroyed in essence if a large scale tree removal program was implemented [Neuman, 2003]. Table 4 comes from the NCHRP 500 series of reports that focuses on tree issues on roadsides and specifies the recommended methods of improving safety from trees for road users.

Table 4 Objectives and Strategies for Eliminating Tree Hazards in the Roadside Environment

Objectives	**Strategies**
Prevent Trees from Growing in Hazardous Locations	Develop, Revise, and Implement Planting Guidelines to Prevent Placing Trees in Hazardous Locations (T)[a]
	Mowing and Vegetation Control Guidelines (P)
Eliminate the Hazardous Condition and/or Reduce the Severity of the Crash	Remove Trees in Hazardous Locations (P)
	Shield Motorists from Striking Trees (P)
	Modify Roadside Clear Zone in the Vicinity of Trees (P)
	Delineate Trees in Hazardous Locations (E)
(T=tried), (E=experimental), and (Proven)	

For trees located on the roadside, the first step in deciding what must be done to provide the safest facility is specifying at what size trees become potentially hazardous. As mentioned above, consistency is vital, even for the process of determining if a tree is dangerous. The forestry industry uses tree trunk diameter as an important description of trees. Trunk measurements taken by the forestry industry are taken at a specific height of 4.5 feet above the ground (i.e., the diameter at breast height, or DBH) on the uphill side of the tree [Asplundh, 1979]. It is advised that the forestry industry's standard for measuring trees be understood, however not be adopted by the transportation industry for multiple reasons. First, 4.5 feet high is too high for the intentions of the transportation industry. Measurements should be taken at a height more suitable in predicting the severity of potential accidents. The suggested height is the "bumper" height of most vehicles, the typical height of impact, accepted to be near two feet above the ground (See Figure 4). Another alteration to the forestry industry's method is to measure the tree size on the side most likely to be struck by traffic, something that may take judgment or research. [UMN Extension Service, 2001].

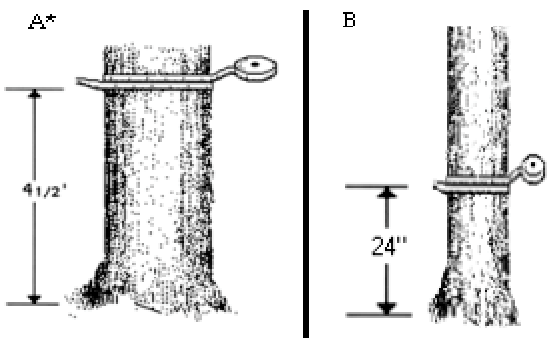


Figure 4 Measuring Tree Diameter at (A) DBH height and (B) Recommended Height

The issue shifts from where to take a measurement to what the measurements mean. A typical post used for sign support on the roadside has a size of four inches by four inches. Engineers therefore deem trees with a diameter of four inches as a hazard. For the purpose of efficiency and simplicity, organizations producing manuals and policies on this topic may choose to allow measuring the circumference of the tree trunk, instead of the diameter, at a height of two feet above the ground. Table 5 below suggests values used to determine if a tree is potentially hazardous to errant vehicles.

Table 5 Suggested Measurements to Determine if a Tree is Hazardous to Errant Vehicles

Measurement	English Units
Diameter of Tree	4 inches
Circumference	12.5 inches
Height to Measure	24 inches

Once you have determined whether trees are of a hazardous size, the next step is to determine whether they are within the clear zone area. To do this, the sideslope of cut and fill and height of cut and fill must be known. Ditch sections must be checked for traversability, and fill section must be checked for recoverability and traversability. In addition, if the tree is located along a section of roadway with curvature, additional distance should be provided in relation to the extremity of the horizontal curve. If the tree is within this area, the site should be treated with one of the options in the Roadside Design Guide. Removing the obstacle is an option, along with relocating trees (replanting) at a safe distance from the edge of the travelway. As the clear zone is extended, there are crash savings associated with each foot of distance removed from the travelway. Table 6 below provides the expected reduction in tree crashes for moving the tree line back in increments of 1 foot.

Table 6 Crash Reduction Factors for Moving the Tree Line Away from the Travelway

Tree Line Before Removal (Feet)	Expected Reduction in Tree Crashes (Crash Reduction Factors)										
	Tree Line After Removal (Feet)										
	6	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**20-30**
4	0.3	0.42	0.49	0.55	0.6	0.63	0.69	0.7	0.72	0.73	0.77
5		0.36	0.43	0.5	0.56	0.59	0.65	0.67	0.69	0.7	0.74
6			0.27	0.36	0.43	0.48	0.55	0.57	0.6	0.62	0.67
7				0.22	0.31	0.37	0.46	0.48	0.52	0.54	0.59
8					0.22	0.29	0.39	0.42	0.45	0.48	0.55
9						0.18	0.3	0.33	0.37	0.4	0.48
10							0.22	0.25	0.3	0.33	0.42
11								0.18	0.24	0.27	0.36
12									0.11	0.15	0.25
13										0.11	0.22
14											0.17

There are several existing guides that have been widely accepted based on thorough coverage of the treatment of one or more roadside safety hazards. For example, the *Guide to Management of Roadside Trees* by Zeigler (1986) is a key resource for reducing tree-related crashes. It addresses safety versus environmental issues.

The Michigan DOT Design Manual, along with other state design manuals include state-specific procedures for providing and maintaining clear zones. Michigan takes the approach that tree removal will be selective and generally "fit" conditions within the existing right-of-way and character of the road. The 1996 AASHTO Roadside Design Guide presents ideal clear zone distance criteria based on ADT levels, design speeds, and side-slopes. For speeds over 60 mph, the clear zone distances are generally in excess of 30 feet. This is the same information provided in the 2006 Revision of the SCDOT Highway Design Manual on page 14.3(3), for new construction or reconstruction projects. Unfortunately, many of the roadways experiencing problems with fixed object crashes are on secondary roadways with minimal potential for funding. Consequently, trees within the clear zone should be considered for removal if identified as hazardous sites. Therefore, Michigan developed the following criteria:

- Crash Frequency - Where there is evidence of vehicle-tree crashes either from actual crash reports or scarring of the trees
- Outside of Horizontal Curves - Trees in target position on the outside of curves with a radius of 2,952 ft or less.
- Intersections and Railroad Crossings - Trees that are obstructing adequate sight distance or are particularly vulnerable to being hit.
- Volunteer Tree Growth - Consider the removal of volunteer trees within the original intended tree line. Volunteer trees are those that have naturally occurred since original construction of the road.
- Maintain Consistent Tree Line - Where a generally established tree line exists, consider removing trees that break the continuity of this line within the clear zone.

UTILTY POLES

More than 90 percent of the highways currently in use in the United States were built prior to 1950. Many of these roads have narrow right-of-way, or lie in older, crowded urban areas. Since 1950 there has been tremendous growth in traffic. At the same time, the American public has created a demand for increased access to various utilities. It has become difficult to upgrade these older roadways to provide the desired capacity and safety for motorists, while trying to place more and more utility facilities on the same crowded right-of-way. The demand for good street and highway systems and for increasingly sophisticated utility service will continue to grow in America. [APWA, 1993]

Utility poles are unyielding items that are purposely placed in the ROW. Today there are over 88 million utility poles on highway right-of-way. They represent the 2^{nd} most likely single item in the roadside to be involved in fatal crashes – behind trees. In 1999, only 1% of pole crashes involved fatalities, whereas about 40% of pole crashes involve injuries. Weather and lighting conditions also affect pole crashes, with 25% occurring in adverse weather and nearly half occurring in dark conditions (25% in dark but lighted areas). Unlike tree crashes, utility pole crashes are more common in urban areas with higher traffic volumes. [Lacy, 2004]

Table 7 provides several utility pole treatment strategies and ranks them by implementation timeframe and relative cost to implement and operate. Several of the treatment strategies have shown proven success including: removing select poles from hazardous locations, relocating poles in hazardous locations to locations further from the road, shielding drivers from poles in hazardous locations, placing utilities underground, and decreasing the number of poles along a corridor. Further caution should be with deciding on treatments for areas with problematic utility poles, because there can be significant issues associated with the need for additional ROW, environmental impacts associated with changing locations, and agency procedures. [Lacy, 2004]

Removing poles in high-crash locations can be done using two different approaches. The first is a proactive approach to locate utility poles with high-crash potential. The best way is to perform a windshield study. Simply drive the area of concern and address the question, “Is this pole necessary?”

The poles may be abandoned and serve no purpose; these pole should be removed immediately. The second approach is reactive and can be done by consulting maintenance record system and crash statistics.

There are some issues that arise with utility pole removal. There needs to be direct coordination and cooperation with the utility companies, who own most of the poles. The utility companies should be highly involved throughout the pole removal process. There are also costs involved with physically removing the pole and relocating the actual services for active poles.

Table 7 Utility Pole Treatment Strategies

Timeframe for Implementation	Relative Cost to Implement and Operate			
	Low	**Moderate**	**Moderate to High**	**High**
Short (less than 1 year)	16.2 A1 Remove poles in high-crash locations[a] 16.2 A2 Relocate poles in high-crash locations farther from the roadway and/or to less vulnerable locations[a] 16.2 A4 Shield drivers from poles in high-crash locations 16.2 A5 Improve the drivers' ability to see poles in high-crash locations	—	—	—
Medium (1–2 years)	16.2 B1 Develop, revise, and implement policies to prevent placing or replacing poles within the clear zone[b]	16.2 A6 Apply traffic calming measures to reduce speeds on high-risk sections	16.2 A3 Use break-away devices 16.2 C3 Decrease the number of poles along the corridor[c]	16.2 C2 Relocate poles along the corridor farther from the roadway and/or to less vulnerable locations[c]
Long (more than 2 years)	—	—	—	16.2 C1 Place utilities underground[c]

[a]Placement here is based upon the assumption that this will be for application to individual poles with a history of hazard.
[b]The development of policies will be a relatively low-cost effort, but the potential results of the new policies could require fairly significant resources and time to implement.
[c]Placement here is based upon the assumption that this will be for application along corridors, involving a large number of poles.

In order to perform the relocation alternative, there needs to be extensive and accurate safety information and maintenance record system. Crash data tells the story of the accident and will help determine the relevance of the utility pole to the severity of the accident. It is necessary to evaluate the entire area in question because removal of one pole may not solve the safety issue. It would not be cost effective to remove a pole when it is surrounded by large trees. Transferring the object struck to another object is not acceptable.

Typical impact measures will include the number, severity, and rate of target crashes. The target crashes should include all run off the road, fixed-object, and any other crashes involving the striking of the utility poles. Once again there are same issues with relocating poles. The utility companies need to be highly informed and cooperative to relocate the poles. There is also a review process that slows the time of the project and can extend it to over a year. The costs involve removing the pole(s) and then replacing the utilities and the pole(s).

Utilities should be placed underground in areas where there is a history of high-crash rates and where utility poles are placed close to the road. In order for this approach to be successful, then the proper clear zone areas need to be applied. This ensures that other objects do not create potential crashes. There should be traversable, recoverable slopes where practical.

There are high costs involved with placing the utilities underground. Pole lines carry a multitude of different utilities and there may not be adequate room underground. Right-of-way costs may also be a problem. There needs to be coordination between the state transportation agency and the local agencies. If a united approach is taken there can be cost-sharing policies while significantly increasing safety.

This method targets the corridors where the density of utilities poles affects the frequency of crashes. The less utility poles there are, the less likely they will be hit. The problem with this approach is that in order to effectively reduce the number of utility poles, larger utility poles are needed. Larger utility poles are directly associated with an increase in the severity of crashes. Once again issues arrive that require a cooperative effort to come to an acceptable solution. It will be costly to remove poles and upgrade to larger poles. Many times this a good approach when the utilities are being upgraded or the roadway geometrics are be redesigned.

METHODS

The scope of work for this research project was large encompassing analysis of clear zones across the state in multiple counties, on multiple types of routes, and for numerous types of fixed-object hazards. The project required numerous data sources (both existing and new), methods for sample selection, new data collection technologies, and software development to support data analysis. Each of these elements of the methodology will be described in more detail in the following sections.

DATA SOURCES

Two existing data sources were initially required in order to be able to select an appropriate sample of site for detail inventory and analysis of clear zone requirements. These included three years of South Carolina crash data, and information from the SCDOT RIMS database.

SOUTH CAROLINA CRASH DATA

Three years (2004-2006) of South Carolina crash data with GPS location coordinates were received from SCDOT. Data was queried using Microsoft Access to identify crashes involving fixed objects of all types. The fields used to identify fixed objects included both the first harmful event (FHE) and the 8-character sequence of events (SOE) field which represents four separate events including impacts with fixed objects. The majority of the fixed object crashes were identified using the FHE field, however, in each year approximately 1.5-3 thousand additional fixed object crashes were identified using SOE. After pulling the fixed object crash data from the sequence of events, multiple fixed object types may be identified for each crash due to multiple objects being struck, and multiple vehicles doing the striking. The hierarchy for classifying the crashes follows:

1. tree
2. poles(all), posts
3. culvert
4. mailbox
5. bridge(all)
6. guardrail(all)
7. other fixed objects

After identifying and classifying all of the fixed object crashes, the crashes had to be geocoded. However, there were a number of problems associated with the coordinate data provided in the SC crash database. A series of nested queries were conducted to identify potential candidates for geocoding and to fix problems which could be identified and resolved, such as use of state plane instead of lat/long. Appendix A contains a technical paper that was submitted and accepted for publication by the Transportation Research Board on this process and the outcomes. Overall, approximately 85% of the crash records had coordinate data that could be geocoded (See Table 8). Once geocoded, there were still a number of crashes that fell outside the bounds of the state, and quality control checks were implemented to flag and remove these from the database. Over 80% of the total fixed object crashes were available for analysis. One of the systematic errors identified is the use of state plane coordinates by the Greenville Police Department. This is the only jurisdiction in the state using this coordinate system. Had the problem not have been identified and fixed, Greenville would have not been represented in the fixed object analysis.

Table 8 Breakdown of filters that sort out usable and unusable location data in SCDOT crash files

	2004		2005		2006	
	Amount	% of Total	Amount	% of Total	Amount	% of Total
Total	22217	100.00	21546	100.00	20713	100.00
LAT Add 2 Zeros	78	0.35	185	0.86	34	0.16
LAT Add 1 Zero	1063	4.78	1246	5.78	435	2.10
LON Add 2 Zeros	96	0.43	247	1.15	41	0.20
LON Add 1 Zero	1087	4.89	1256	5.83	429	2.07
Usable LAT/LON	18503	83.28	17937	83.25	17530	84.63
Usable State Plane	126	0.57	154	0.71	124	0.60
Total Usable	18629	83.85	18091	83.96	17654	85.23
No LAT, No LON	1423	6.41	1373	6.37	1273	6.15
No LAT Only	39	0.18	110	0.51	0	0.00
No LON Only	35	0.16	117	0.54	4	0.02
LAT <6 Characters Only	6	0.03	41	0.19	1	0.00
LON <6 Characters Only	7	0.03	57	0.26	3	0.01
LAT/LON Over 59 Values	1662	7.48	1451	6.73	1615	7.80
Coordinates Out of Range	416	1.87	306	1.42	163	0.79
Total Unusable	3588	16.15	3455	16.04	3059	14.77

SCDOT ROADWAY INVENTORY MANAGEMENT SYSTEM (RIMS)

In addition to the SCDOT crash databases, a need existed for information about the crash site locations that could not be obtained from the police reported data. Elements such as the number of lanes, functional class, traffic level, and posted speed limit were necessary to stratify the sample and determine the required clear zone. SCDOT allowed the research team access to the inventory portion of the enterprise data system at the Greenville District office. Researchers were able to manually extract data for crash sites of interest and verify that no work had been done in the area as of the time of the photo-log contained in the system (see Figure 5). The photo log also helped to provide information on missing or questionable data. Unfortunately, the RIMS search required route and milepoint information for quick searching and the base map that was used for locating the crashes to roadways did not have that level of information. However, the pan and zoom options were used to identify the locations. The RIMS database was a useful tool for the initial sample selection and site verification. Figure 6 contains a screen capture from the Pavement Viewer showing the photo-log, county, route type, route number, 2006 AADT and other location information.

Figure 5 Site identified as having recent reconstruction using video-log

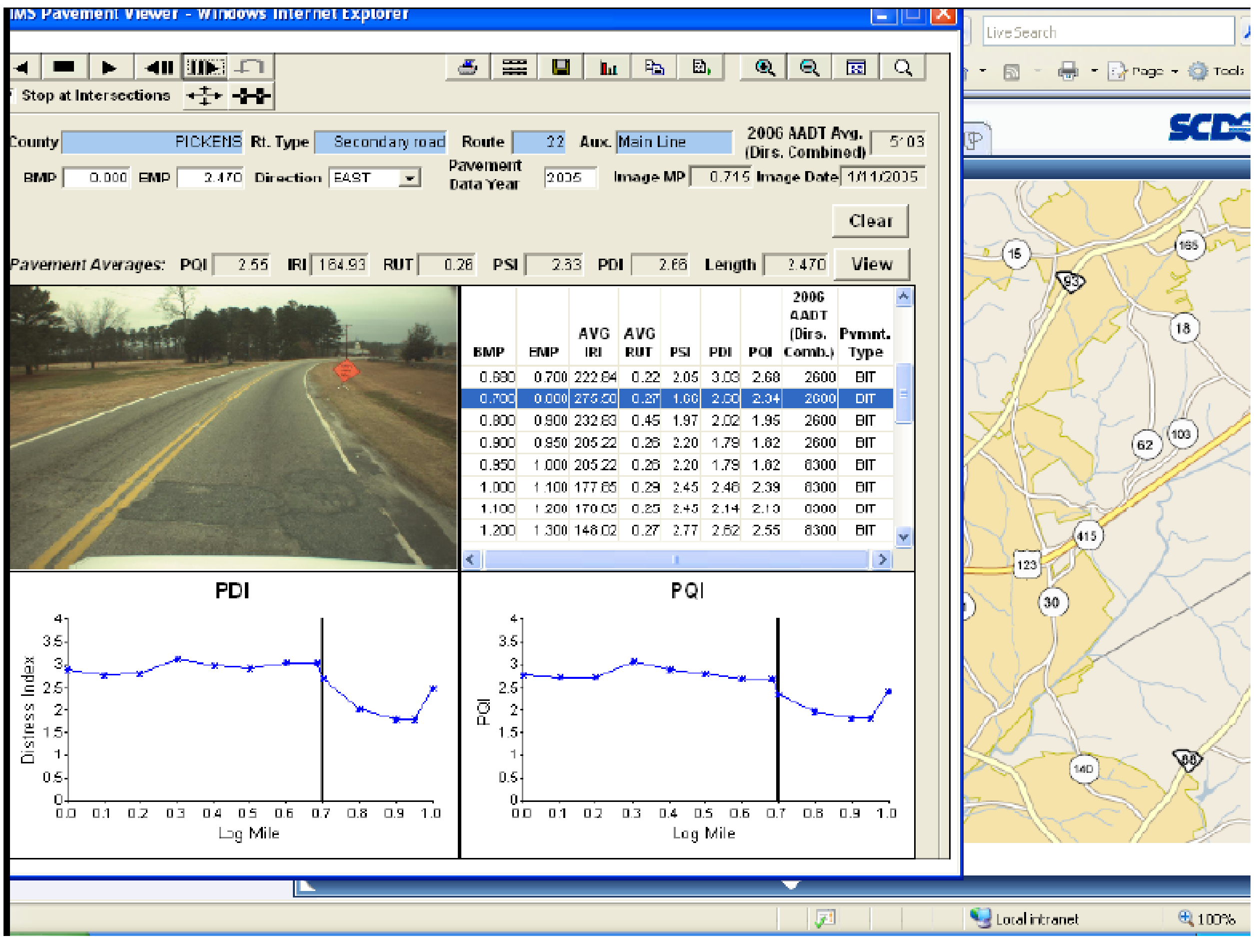


Figure 6 Screen-shot of RIMS Pavement Viewer showing several data fields of interest

SAMPLE SELECTION

Historically, researchers have defined high-hazard sites based on high frequency or high rates of crashes over relatively short periods of time (3-5 years). The highway safety literature is filled with examples of studies where locations with the highest crash counts/rates were purposely selected for countermeasure implementation. Nearly all of these studies have shown very impressive safety improvements (10%-50% reduction in crashes are typical), regardless of the type of countermeasure. The phenomenon of repeated measures of data in the long-run drifting towards a mean value is known as “regression-to-the-mean”. Regression can occur up or down (see Figure 7).

The more effort that goes into purposely choosing locations that are extreme, the stronger the regression-to-the-mean effect is likely to be. Recent research regarding statistical methods for safety studies to be included in the Highway Safety Manual has identified problematic results when regression-to-the-mean bias is not considered. While this effect is not so much a problem for simple comparative analysis, the development of a methodology for state-wide application and program evaluation should account for regression-to-the-mean effects and include new approaches to safety data analysis.

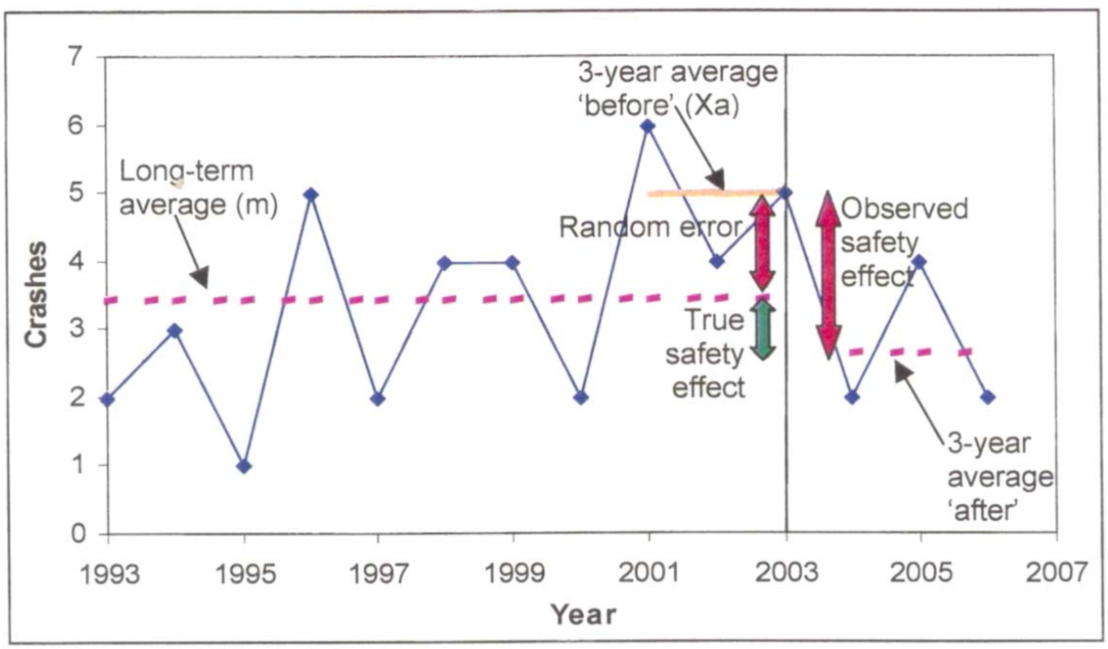


Figure 7 Regression -to-the-mean Effect

However, new safety tools such as SafetyAnalyst and the Highway Safety Manual have data requirements that are often beyond the current capabilities of state data systems. In the absence of these software tools and analysis datasets, the next best option is to select sites that are common across a variety of selection methods. For this study, researchers ranked sites based on mileage-based crash rates, total frequencies, visual inspection of crash patterns, and through kernel density plots generated in the geographic information system. The final statewide site list and selected sample can be found in Appendices B and C.

The first step in starting to identify potential study sites was to use the GIS system to analyze route level crash rates. For this analysis, fixed-object crashes were grouped together for all years and sorted by type of fixed object prior to determining the crash rate. However, rate alone could not be used to automatically select sites. Some sites with very small roadway lengths and one crash had very high crash rates, and these were not considered for further analysis. As sites were identified, the crashes belonging to each site were flagged with the appropriate site number and a site identifier level was created in the GIS. Figure 8 shows an example of tree site number 207 and associated crashes.

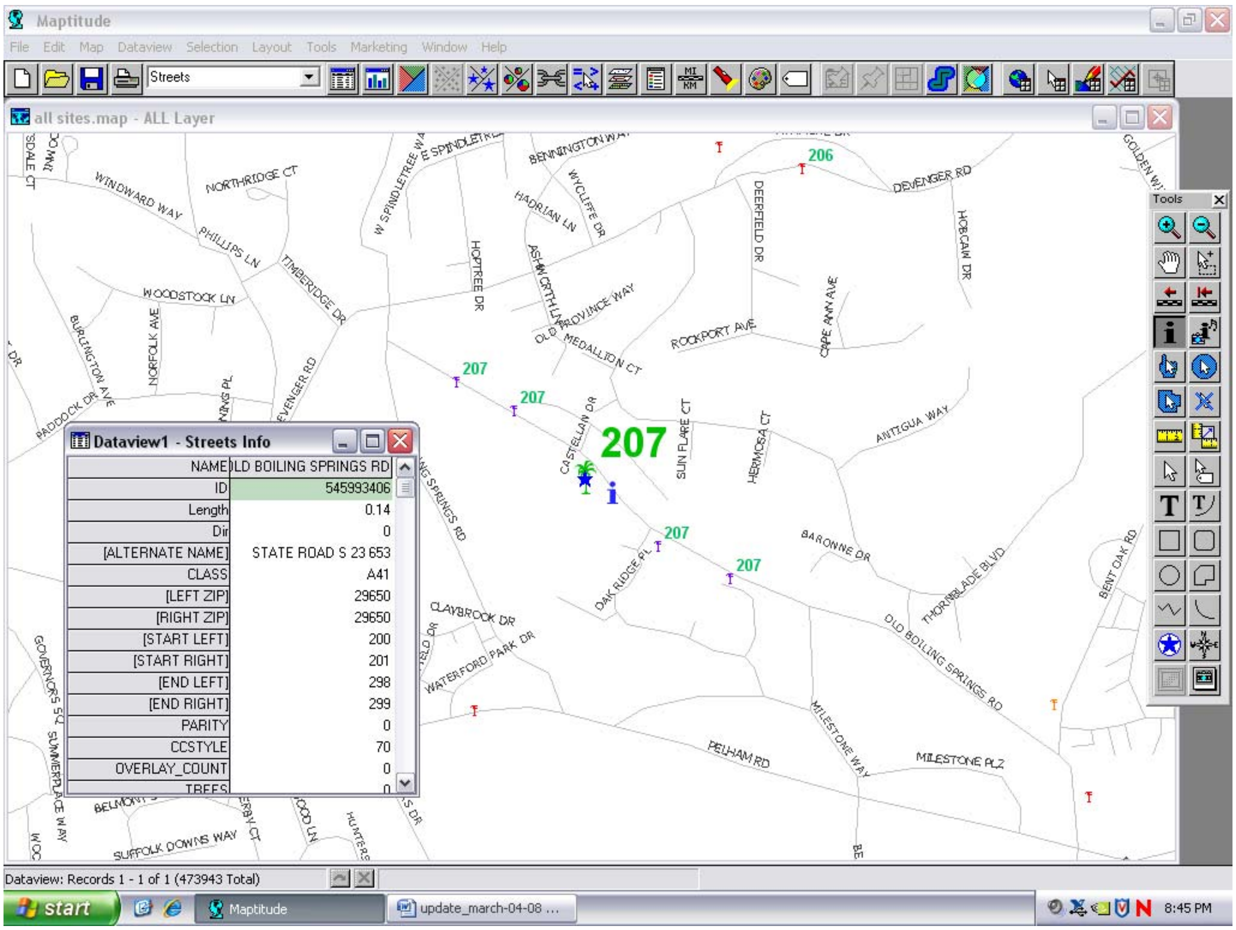


Figure 8 Tree Site Number 207 and Related Crashes

The second search method involved analyzing fixed-object crash frequencies for individual routes on a county by county basis. From this method, I-26 in Dorchester was identified as the top of the candidate list. As highlighted in Figure 9, 26 crashes were identified along one particular stretch of I-26 in Dorchester. While this is definitely a site of interest, sites like this on high-traffic roadways have inflated crash frequencies due to the volume of traffic. While rates highlight short segments, and segments with low volumes, on the opposite end of the spectrum, frequencies highlight high volume sites. With few overlapping sites, researchers turned to visual pattern analysis and density plots.

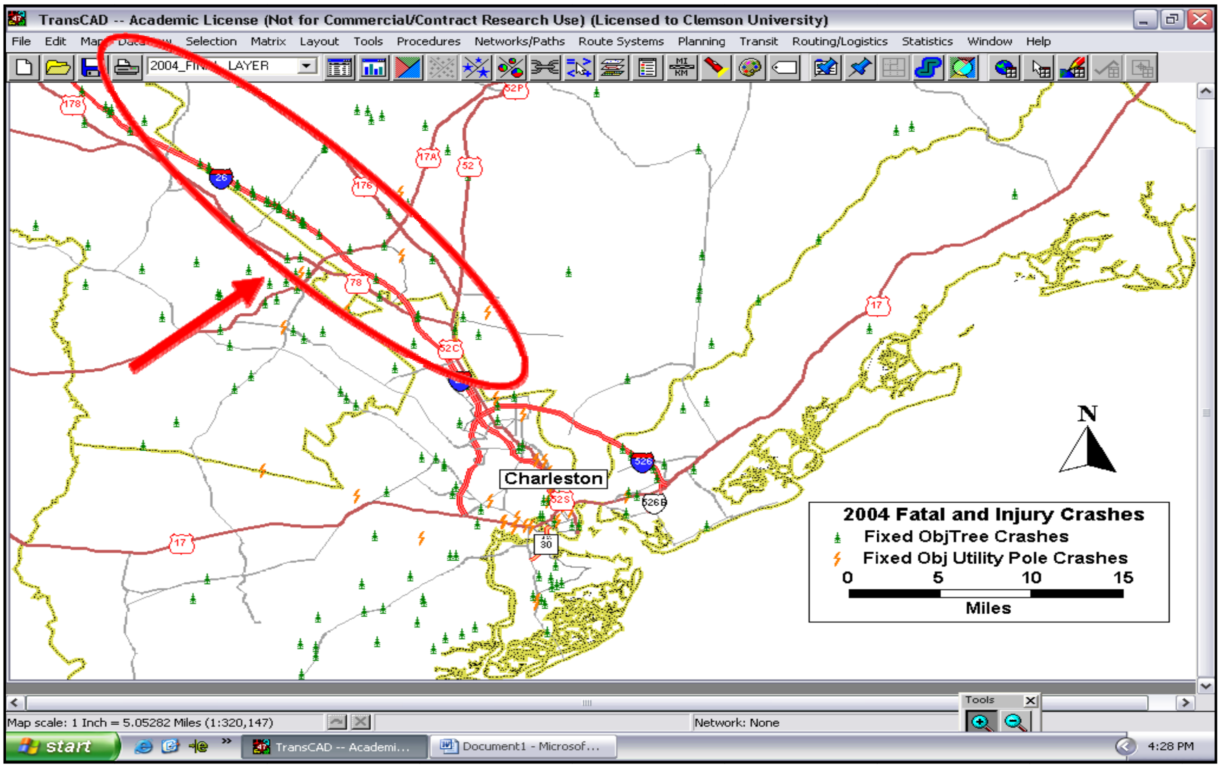


Figure 9 Interstate-26 Tree Crash Location with 26 Fatalities

With the availability of geocoded crash data, researchers visually inspected the crash data for unusual patterns and trends. For display purposes, the crashes were divided into individual groups based the type of fixed object crashes to minimize data overlap (see Figure 10). An interesting trend was noted in the linear patterns of tree crashes extending from Columbia and Charleston . As suspected, the linear pattern approaching Charleston occurs on I-26 (see Figure 11). Focusing on Columbia, the linear tree crash patterns represent I-20 and 76. Patterns were also noted in tight clusters of crashes like site 206 (Figure 12), and in curve sections of roadway like site 210 (Figure 13). Figure 10 also shows clusters of utility pole crashes (circles) occurring in more urban areas, which is logical because of the density of poles and their close proximity to the road in more densely populated areas.

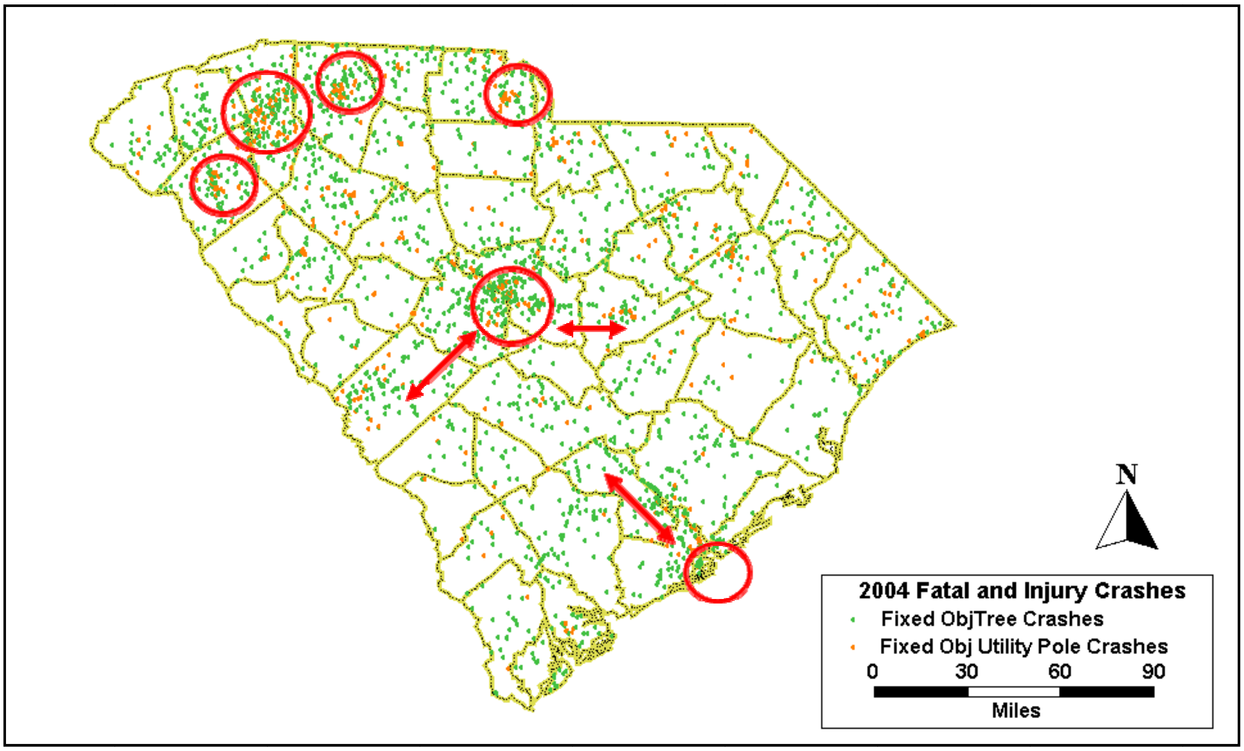


Figure 10 Tree and Utility Pole Crash Locations for 2004

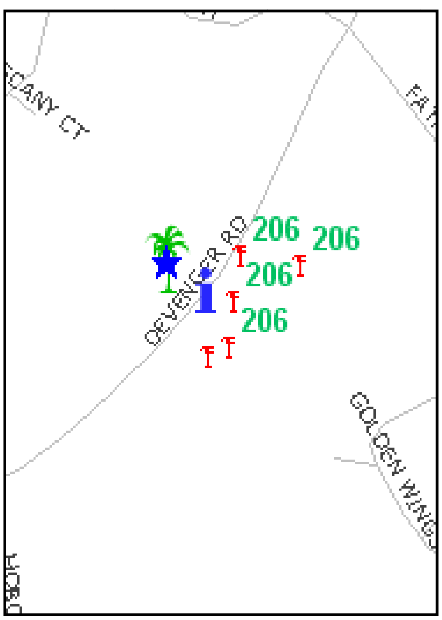


Figure 11 Crash pattern - tight cluster of tree crashes for Site 206

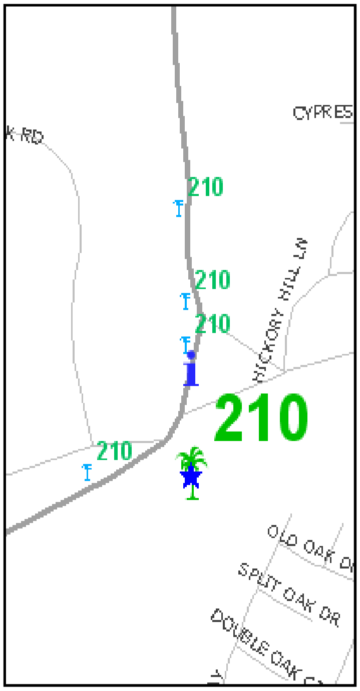


Figure 12 Crash Pattern - tree crashes along curve at Site 210

Once these three methods had been exhausted, the research team used kernel density analysis (Figure 15) in GIS to identify areas with high densities of crashes (same type of fixed-object crash occurring in fairly tight geographic areas). This analysis was primarily used to determine if any areas with significant clusters of crashes had been left out of the site selection process. By overlaying the current sites, it was possible to identify several dark spots (high densities) with no site location numbers. Several more sites were identified, and the statewide crash site list was compiled. During a steering committee meeting, the list was pared down to include only 15 counties from which a balanced sample was to be selected. The counties included: Aiken, Anderson, Bamburg, Berkeley, Cherokee, Colleton, Dorchester, Greenville, Horry, Laurens, Lexington, Orangeburg, Richland, Spartanburg, and York. As mentioned previously, the final site list in included in Appendix C.

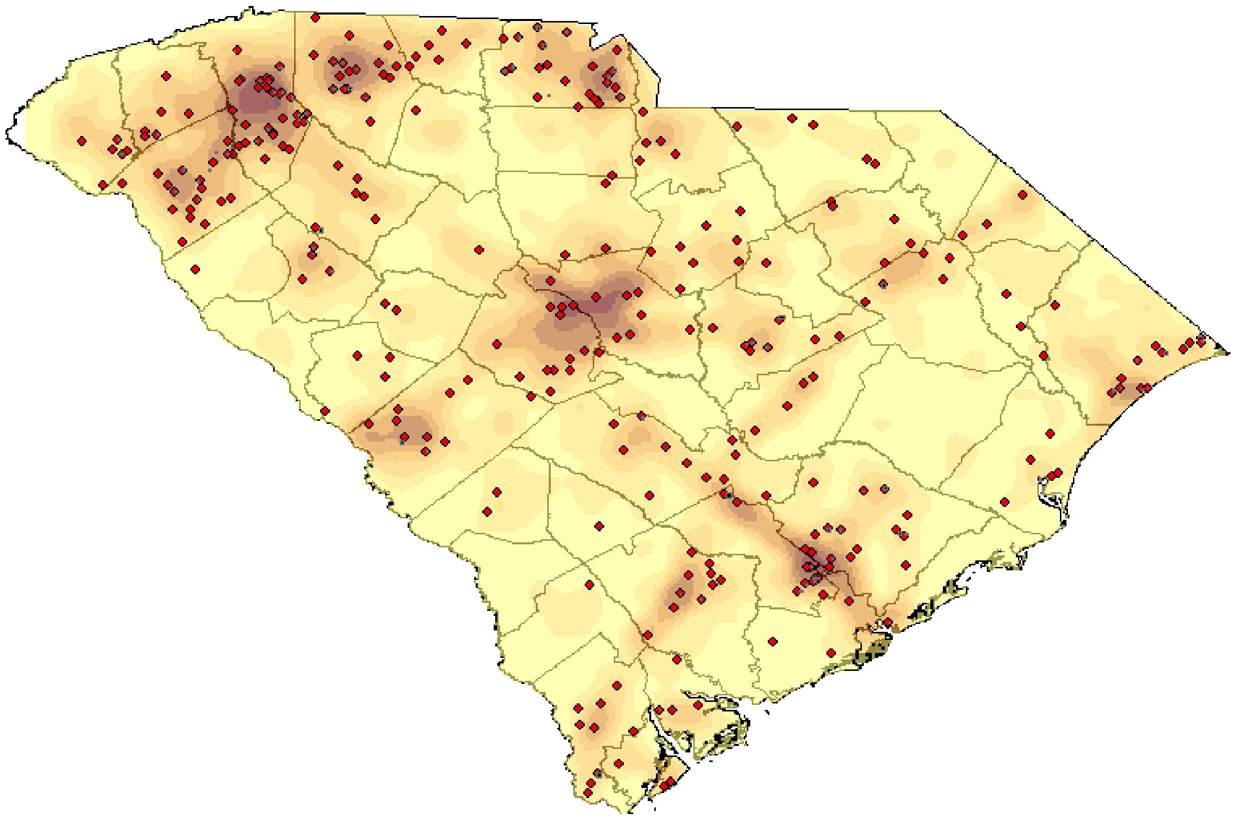


Figure 13 Kernel Density Analysis of Tree Crashes

In total, 287 sites were selected from the 15 counties in the process, with about half of them representing tree sites. There were few mailbox sites, because most mailbox sites are only single crashes and were not well represented in any of the selection methods.

SITE DATA COLLECTION

After using a combination of crash data, SCDOT RIMS data, and the geographic information system to identify 287 sites of interest, Clemson researchers surveyed the sites with an instrumented van to identify exact parameters for roadside slopes and distances to obstacles in the clear zones. The van combines video-log capability with precision GPS location (Figure 14) and a laser measurement device that allows the capture of distance information to the nearest solid object. The laser rotates 360° and takes 400 measurements within one revolution at a rate of 20,000 samples per second. A graphic portrayal of the laser measurement is shown in Figure 15. The data output produces a spiraling tunnel of information about the closest objects to the van. The laser measurement device is accurate within a few inches up to 50', and allows the determination of precise distances from the edge of the travel lane (pavement marking) to the nearest roadside obstacle (tree, pole, etc.). The laser measures amplitude of the return signal from each object, and as such, pavement markings are easily identified because their amplitude is in the range of 100-160, whereas the pavement returns readings ranging from 20-40.

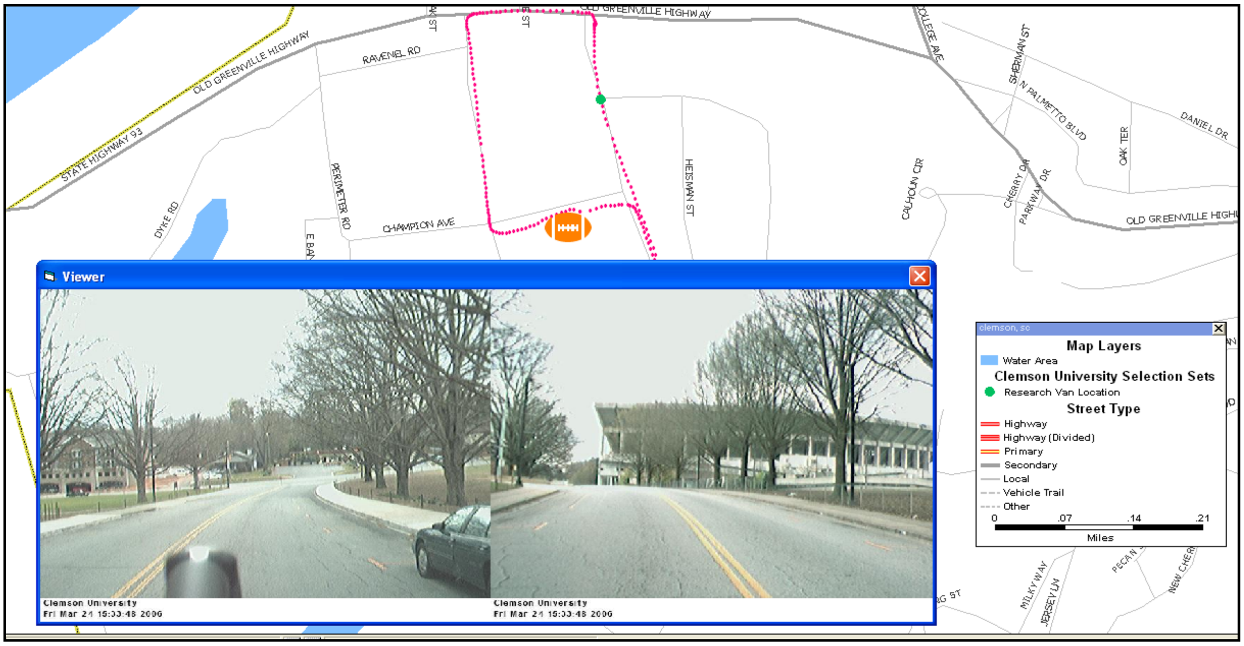


Figure 14 Video-log and GIS Output from Clemson Mobile Transportation Laboratory

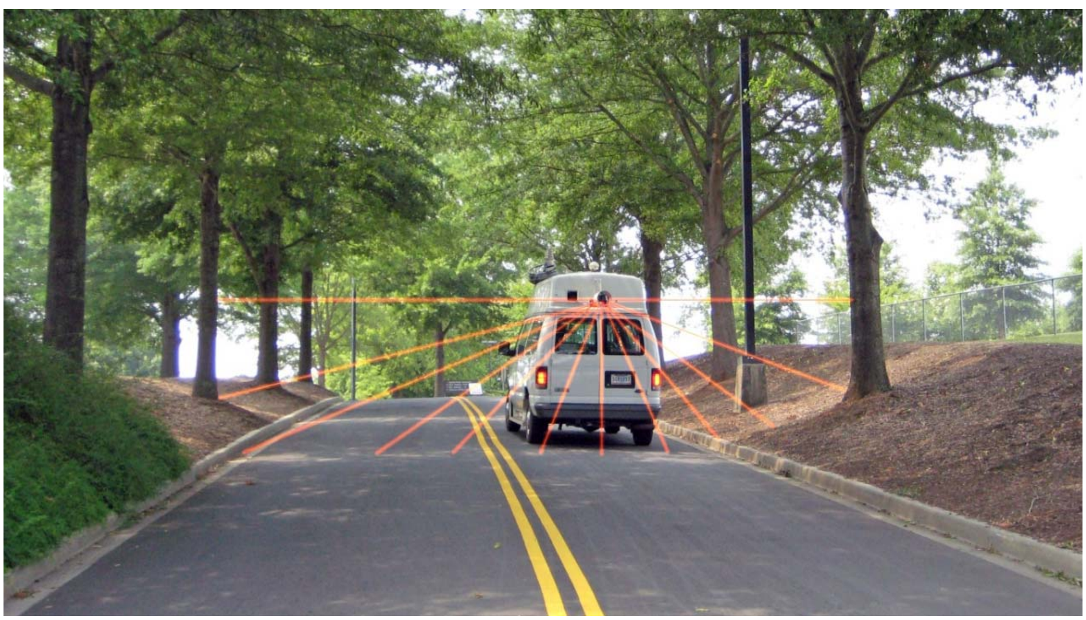


Figure 15 Instrumented Van with 360-degree rotating laser measurement device

Figure 16 shows the laser data obtained for a roadway section with a guardrail. This data has been overlaid on a video-log photo of the site to show how the readings identify different surfaces. The original measurements are in inches from the laser. The bar on the right side of graphic indicates the amplitude level. The measurements make it possible to calculate straight line distances from the pavement markings noted with X's to the guardrail. At this site, the guardrail is 8.84 feet from the pavement edge of pavement. The distance of 8.84 feet is the horizontal component distance, not the distance along the sideslope.

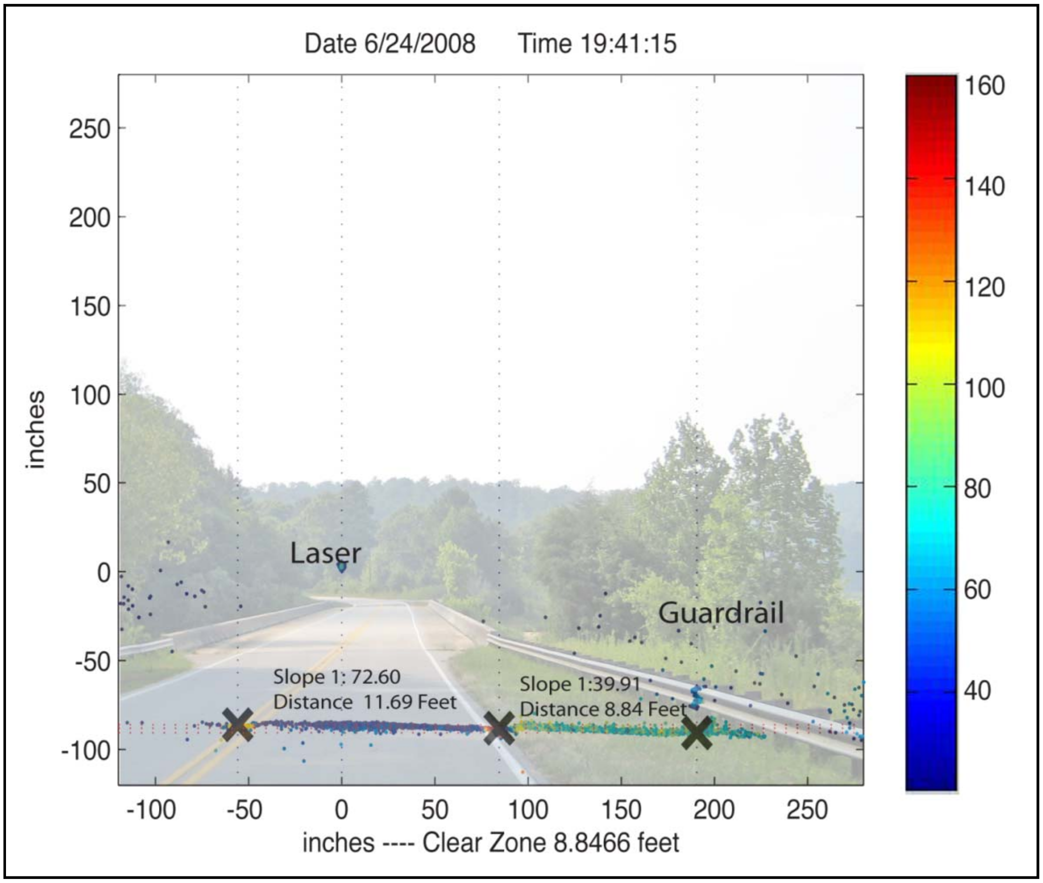


Figure 16 Overlay of point output from laser measurement device with video-log photo

A sophisticated software package was developed to allow researchers to align both the video-log and the laser output both in time and space for analysis purposes. In addition, the laser data had to be calibrated using either a known horizontal or vertical surface to accurately identify the sideslope measurements. These calibrations were necessary for each individual file. Once set, the calibration would be applicable for the entire file. If the calibration procedure is not performed, the data is likely to be skewed causing error in the sideslope and distance to obstacle calculations.

Finally, the software allows the user to select multiple linear segments (see Figure 17) to correspond with changes in the roadside terrain. By clicking at various points where major changes in the side slope occur, the software calculates horizontal distances for each segment and provides the slope of the individual segments. For this particular measurement, there are 4 slope segments. Starting at the edge of the travel lane, the segments are numbered from left to right. The graphic provides measurements in inches, although the program calculates segment lengths in feet. The segment between A and B is segment 1. Segment 1 has a slope of 6H:1V with a horizontal distance of 2.9 feet. Segment 2 is between B and C, and so on. The three columns in the top left corner of Figure 17 represent the segment number, horizontal slope component of the sideslope in __H:1V, and horizontal distance of the segment. The program also automatically checks for traversable and recoverable slope status and either includes or excludes sections from the total clear zone and clear zone run out area. Below the graphic is information on the total horizontal distance (total dist.) from the edge of the traveled way to the obstacle, the calculated functional clear zone (clear zone) based on slopes for each of the segments, and the desired clear zone (desired) based on the predominant slope, roadside slope configuration, and site characteristics such as speed limit and ADT. If the clear zone value is less than the desired range, then the site is classified as not meeting clear zone requirements.

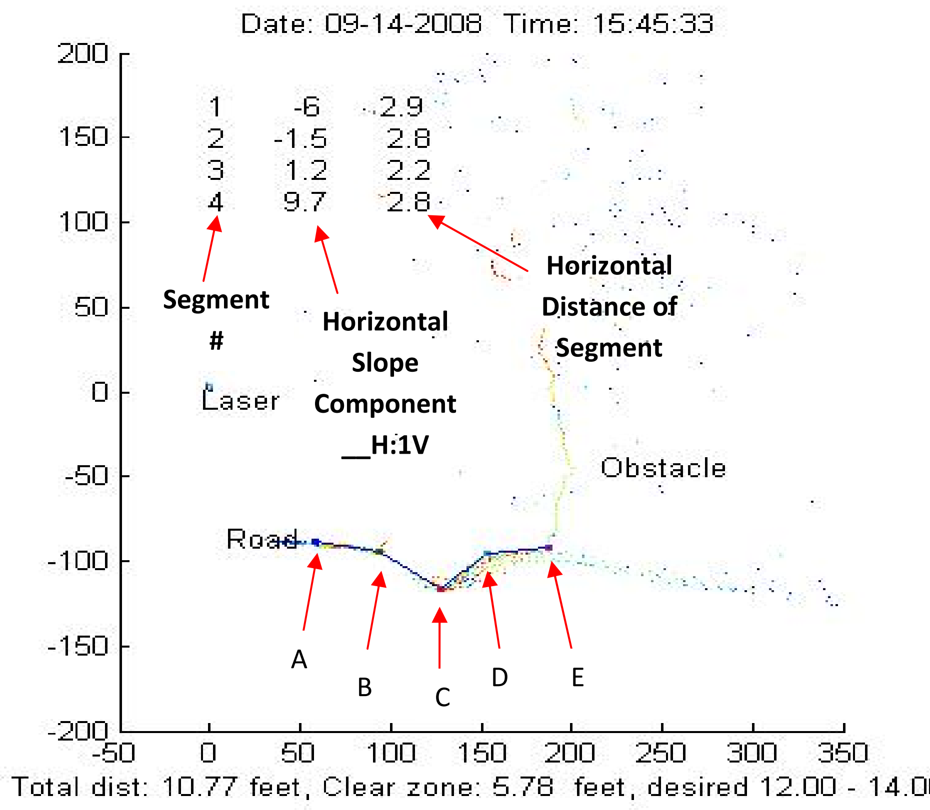


Figure 17 Roadside Slope Segmentation

The measurement samples (dots) indicate the location of the first hard surface edge that is touched by the laser. Thus, trees, poles, and other solid items appear as linear features. Also, note that the figures represent measurements taken over 1 second. There are multiple rotations of the laser during that one second, and at the same time the van is moving down the roadway. So the roadside slope is in a constant state of change, and each second can be slightly different from the next and may even have some variation within the same graphic. The slope measurements are made to coincide with the major point distributions.

Below the graphic (Figure 17) is information on the available clear zone, the total distance from edge of travelway to obstacle, and the desired clear zone based on the applicable foreslope, backslope, or combination of slopes. In Appendix E, additional information is given for each site including: site number, site type, latitude and longitude of the reference crash, route number, route type, number of lanes, speed limit, ADT, whether the site is in a horizontal curve, direction of travel, a summary of all crashes associated with the site including first harmful event and severity level, and the clear zone analysis. Also included are pictures of the site location maps with crash locations indicated, the laser measurement scatter plot, and the corresponding picture of the site taken from the video-log.

The software requires data entry of the speed and traffic volume associated with the site along with the foreslope or backslope in order to determine the required clear zone. The software also allows for calculation of multi-slope ditch section clear zones. For the initial analysis, the speed was input as the posted speed limit. Posted speed limit is highly correlated with operating speeds and thereby related to safety. According to NCHRP Report 504 [Fitzpatrick et al., 2003], for a given section of highway, the posted speed limit is the pertinent maximum or minimum speed determined by law. In general, 85th percentile operating speed is used to set the posted speed limit.

Fitzpatrick et al. collected speeds of free-flowing vehicles during dry pavement conditions on week days between 7:00 am and 6:00 pm. For all functional classes of roadways and speed ranges, they found that a strong relationship exists between operating speed and posted speed limit. A model was developed for 85th percentile speeds Q_{85} where $E[Q_{85}]$ is the expected value of Q_{85}.

$$E[Q_{85}] = 7.675 + 0.98 \times \text{Posted Speed Limit}$$

The linear model indicates that the 85th percentile speed varies at the same rate with posted speed limit. However, the 85th percentile speed is higher than the posted speed limit by approximately 7-8 mph. This suggests that the actual operating speed of most roadways is approximately 7-8 mph above the posted speed limit. Assuming that this relationship is also representative of operating speeds in South Carolina, then a more conservative clear zone estimate would be calculated using the posted speed limit plus 7-8 mph. The same research indicates that the posted speed limit usually represents approximately the 50th percentile operating speed of the roadway. Because no data exists for current operating speeds for all roadways in the state, the research team assumed the value of the posted speed limit for use in determining the clear zone distance.

DESCRIPTIVE STATISTICS

Given the array of fixed objects of interest in this study, and the relatively small sample size for each of the fixed object types, the analysis will focus primarily on descriptive statistics of the crash problem. One very effective statistic for this type of retrospective cohort study is the odds ratio. The odds ratio is a measure of effective size, describing the strength of association between two binary data values. The odds ratio is simply the odds of an event occurring in one group to the odds of it occurring in another group, or to a sample-based estimate of that ratio. In this research we are interested in whether or not a site will experience fixed object crashes based on whether the roadside hazards are located inside or outside of the required clear zone for the site characteristics. Unlike other measures of association for paired binary data, such as relative risk, the odds ratio treats the two variables being compared symmetrically, and does not require data from the population nor fully randomized samples.

The joint distribution of binary random variables X and Y can be written as:

	$Y = 1$	$Y = 0$
$X = 1$	p_{11}	p_{10}
$X = 0$	p_{01}	p_{00}

or, for this research:

	Does not meet Clear Zone	Meets Clear Zone
Fixed Object Crash Site	p_{11}	p_{10}
Control Site	p_{01}	p_{00}

where p_{11}, p_{10}, p_{01} and p_{00} are non-negative "cell probabilities" that sum to one. The odds for Y within the two subpopulations defined by $X = 1$ and $X = 0$ are defined in terms of the conditional probabilities given X:

	$Y = 1$	$Y = 0$
$X = 1$	$p_{11} / (p_{11} + p_{10})$	$p_{10} / (p_{11} + p_{10})$
$X = 0$	$p_{01} / (p_{01} + p_{00})$	$p_{00} / (p_{01} + p_{00})$

Thus the odds ratio is

$$[(p_{11} / (p_{11} + p_{10})) / (p_{10} / (p_{11} + p_{10}))] / [(p_{01} / (p_{01} + p_{00})) / (p_{00} / (p_{01} + p_{00}))]$$

$$= p_{11}\, p_{00} / p_{10}\, p_{01}$$

For odds ratios equal to one, the odds of an event occurring is equally likely for both groups. For odds ratios greater than one, the odds of the first event X =1 are higher. An odds ratio less than one indicates that the second event has higher odds of occurrence.

DATA ANALYSIS AND RESULTS

CRASH DATA FINDINGS

Roadside hazards are involved in nearly 50% of all fatal crashes in South Carolina, and only 30% nationally..

Over a three year period (2004-2006), there were more than 60,000 crashes involving fixed objects (trees, utility poles, culverts, bridge piers, etc.) located within South Carolina roadsides. These fixed object crashes accounted for 20% of all crashes in South Carolina, and nearly 50% of all fatal crashes (Table 9). In comparison, only 30% of fixed-object crashes result in fatalities nationally. The greatest contributor to fatal crashes on the roadside in South Carolina is trees. Trees are involved in 25% of *all* fatal crashes in South Carolina with an associated economic cost of $750 million each year. This cost does not include costs associated with injury and property damage only tree crashes, which adds up to an additional $175 million, bringing the total close to $1 billion per year.

Clemson University researchers have been examining the factors surrounding fixed object crashes occurring on our roadsides with emphasis on trees, utility/light poles, culverts, bridge piers/railings, and mailboxes. One of the first tasks undertaken for this research was to compare South Carolina fixed object involvement in fatal crashes with national numbers. Figure 1 (Introduction Section) shows the primary contributing factors in fatal fixed object crashes both nationally and in South Carolina. The most striking difference between the two was the involvement of trees ***– 21% nationally, yet 50% in South Carolina.***

Table 9 Fixed Object Crashes by Type and Severity Level for 2004

2004	FATAL	INJURY	PDO	TOTAL
TREES	231	2553	3060	5,844
POLES	39	810	1398	2,247
CULVERT	26	212	274	512
MAIL BOX	5	184	443	632
BRIDGE	8	127	320	455
GUARD RAIL	33	656	2470	3,159
OTHER	119	3293	5956	9,368
SUB-TOTAL	461	7835	13921	22,217
TOTAL	22,217			

Additional crash analysis indicated other trends with tree-related crashes in South Carolina. Similar to national numbers, almost 50% of tree-related crashes occur on secondary roads, with another 25% on primary roads, and 12.5% on both Interstates and county roads (see Table 10). Another important finding in relation to clear zone requirements is that 72% of the tree-related crashes occurred in curve section, which is higher than the national figure (Table 11). A slightly higher percentage of pole crashes were indicated as taking place in curve sections (78%). Both tree and utility pole crashes in curves are particularly important when the clear zone requirement is taken into consideration because the Roadside Design Guide recommends that clear zones be increased by 10-50% along curve sections in areas where crash history indicates a need. A selective clearing approach in curves will have a positive impact given the number of incidents in curve sections. Another issue that may also be impacting the numbers is the limited sight distance in the curves. Clearing trees on the inside and outside of curve sections allow drivers to see the road ahead, and have additional clear zone in the event of an emergency.

72% of the tree-related fixed object crashes occurred in curve sections

Table 10 Fixed Object Crashes by Type and Route Category

RCT ---> All Years	Interstate	US Primary	SC Primary	Secondary	County	Other
Trees	1837	1767	2289	7571	2268	3
Poles	393	1237	1248	2709	813	0
Culvert	36	172	272	722	151	0
Mail Box	14	125	264	930	369	1
Bridge	334	178	200	290	82	1
Guard Rail	6719	607	673	561	134	0
Other	2322	3864	4607	12020	3445	0
Total	11655	7950	9553	24803	7262	5
% Total	*19*	*13*	*16*	*41*	*12*	*0*

Table 11 Fixed Object Crashes by Type and Road Character

RD. char ---> All Years	Straight Level	Straight Grade	Straight Hill Crest	Curve Level	Curve Grade	Curve Hill Crest	Total
Trees	183	1403	2416	10768	2149	159	17078
Poles	105	585	809	4135	1222	47	6903
Culvert	9	106	191	977	193	6	1482
Mail Box	18	113	199	1124	346	11	1811
Bridge	63	139	222	565	130	44	1163
Guard Rail	536	1826	2844	3364	397	112	9079
Other	421	2286	3612	16856	3576	207	26958
Sub-Total	1335	6458	10293	37789	8013	586	64474
		28% STRAIGHT			72% CURVE		

LASER DATA FINDINGS

Of the 287 sites visited, 131 have been analyzed for clear zone requirements (Table 12). Of these only 12 met the criteria through the automated process. If you consider operating speeds within 10 mph above the posted speed limit, 3 of the sites would no longer meet clear zone requirements, another 4 would be at the minimum clear zone for that range, and 5 would still meet the clear zone requirements and have clear zones larger than required.

Table 12 Inventoried Sites by County and Fixed Object Type

	Fixed Object					
County	**Bridge**	**Culvert**	**Mailbox**	**Poles**	**Trees**	**Total**
Aiken	4	5	2	8	4	**23**
Anderson	2		1			**3**
Bamberg		1				**1**
Berkeley	1	1		1	8	**11**
Cherokee	2			1	2	**5**
Colleton	1	2			2	**5**
Dorchester	3			2	2	**7**
Greenville	2			5		**7**
Horry	5	2	1	1		**9**
Lexington	2	3	2	3	3	**13**
Orangeburg	1	2		3		**6**
Richland	5	3	1		4	**13**
Spartanburg	1	2	1	1		**5**
York	1	5	2	5	10	**23**
Total	**30**	**26**	**10**	**30**	**32**	**131**

Each site has a detailed clear zone inventory report in Appendix E. A sample of the two-page inventory report can be found in Figures 18 and 19. The first page of the report gives the county, site number, site information (ADT, # lanes, GPS location, posted speed, etc), a location map for the site, a summary of crash history for the site, and the clear zone information for a representative crash location. The second page provides the general site information again for reference purposes, and it also gives the laser measurement scatter plot along with a corresponding photo from the video-log.

The sample report contains information for a tree crash site in Aiken, South Carolina on Secondary Highway 440. This is a two lane roadway with a speed limit of 35 mph and an ADT of 4,500 vpd. The section of roadway has a horizontal curve present (radius unknown). In the near vicinity, there were six crashes involving roadside trees. The site is on a fill section with slope segments of -25H:1V (2.2 ft) and -2.1H:1V (6.5 ft). The total distance from the edge of the traveled way to the tree is 8.7 feet. Because the -2.1 H:1V slope is not traversable, it cannot be used toward the desired clear zone distance which is

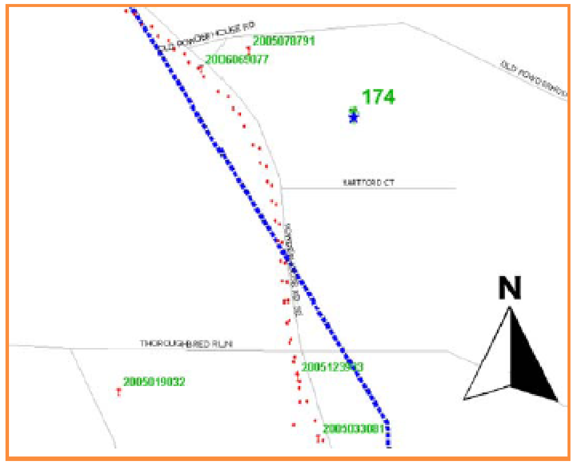
12-14 feet for an ADT of 4500 vpd and a speed limit of 35 mph. Thus, the available clear zone distance is only 2.2 feet. The required clear zone for this particular location is not met.

Aiken SC **174Tree**

SITE DETAILS

SITE ID:	174
NSIT	174Tree
LATITUDE	33522356
LONGITUDE	-81696757
PRIMARY NAME:	owderHouse RD SE
SECONDARY NAME:	State Highway 440
ROUTE TYPE:	Secondary
LANES:	2
SPEED LIMIT (mph):	35
ADT:	4500
HRZL. CURVE:	Yes
DIRECTION:	SE

GIS:



Summary

NSITE ID	ANO	FIRST HARMFULL EVENT	CRASH SEVERITY
174Tree	4021581	Tree	Not Injured
174Tree	2005025864	Tree	Possible
174Tree	2005033081	Tree	Not Injured
174Tree	2005078791	Tree	Non-incapacitating
174Tree	2005123933	Tree	Possible
174Tree	2006069077	Tree	Not Injured

CLEARZONE ANALYSIS

ANO: 2006069077

ADT :	4500	HRZL CURVE:	Yes
SPEED LIMIT(mph)	35	TOTAL AVAL DISTANCE(ft)	8.7
DIRECTION	SE	APPLICABLE CLEAR ZONE(ft)	2.24
INSPECTION TIM	17:54:01	DESIRED CLEAR ZONE(ft)	12-14
INSPECTION DATE:	9/28/2008		

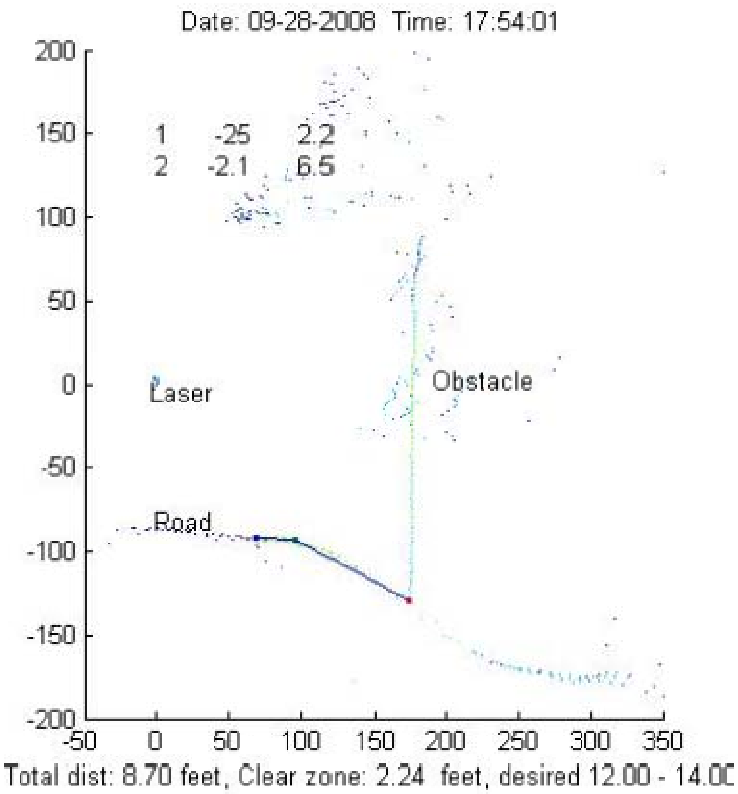
Minimum Clearzone Not Met

Figure 18 First Page of Detailed Clear Zone Site Inventory Report

Aiken SC **174Tree**

ANO:

LASER MEASUREMENT:



SITE DETAILS:

SITE ID:	
NSITE:	174Tree
LONGITUDE:	-81696757
LATITUDE:	33525333
PRIMARY NAME:	owderHouse RD SE
SECONDARY NAME:	State Highway 440
ROUTE TYPE:	Secondary
LANE	2
SPEED LIMIT (mph):	35
ADT:	4500
DIRECTION:	SE
HRZL CURVE:	Yes

VIDEO -LOG PHOTO

Sun Sep 28 17:54:01 2008

Figure 19 Second Page of Detailed Clear Zone Site Inventory Report

The fill section sideslope for the sample given in Figures 18 and 19 was found in two segments. The first segment was a slope of -25H:1V for a horizontal distance of 2.2 feet, the second segment had a slope of -2.1H:1V for a distance of 6.5 feet. The second segment is steeper than 4H:1V, and therefore is not included in the clear zone because the vehicle cannot redirect nor come to a stop on this slope (see Figure 20). The segment two sideslope is also steeper than 3H:1V, and thus is not traversable either. The resulting available clear zone is limited to the 2.2 feet in segment one. At a slope of -25H:1V, with posted speed of 35 mph and 4500 ADT, a clear zone in the amount of 12-14 feet is required. The available 2.2 feet is significantly less than required. The required clear zone calculation also assumes a straight section of roadway, since this site is on a horizontal curve section, AASHTO recommends increasing the clear zone in proportion to the radius of curvature for the particular posted speed (as shown in Figure 21. The amount of the adjustment ranges from 10% increase to 50% increase.

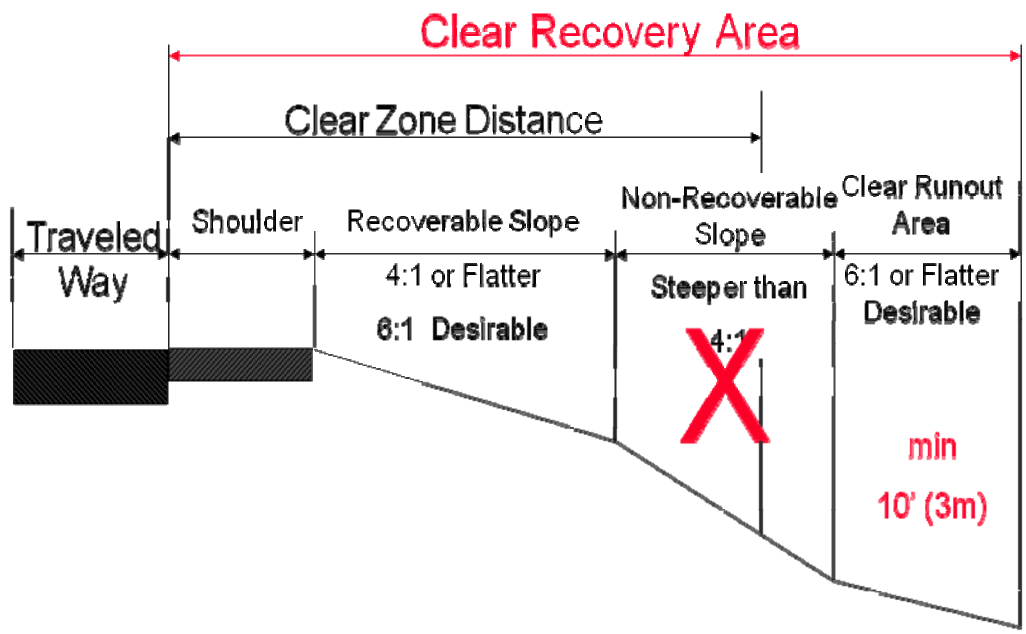


Figure 20 Clear Zone Recovery Area

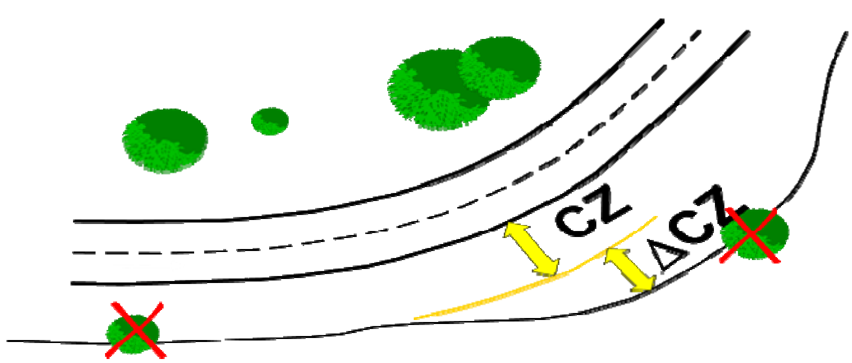


Figure 21 Horizontal Curve Clear Zone Adjustment

A similar approach to the one described here was used to assess each clear zone. The research team analyzed 131 sites across an array of route types and fixed object crash types. Table 13 provides the breakdown by route type and gives information on the average difference between minimum clear zone requirements, and available clear zones. On average, clear zones are deficient by at least 9 feet on secondary roads. Of course this varies by site, but for 16 sites, this is a large variance from minimum clear zone requirements.

Table 13 Number of Inventoried Fixed Object Crashes by Route Type and Fixed Object Type with Average Difference between Required Clear Zone and Available Clear Zone

Fixed Object Crash Type	Route Type									
	Interstate		US Primary		SC Primary		Secondary		County	
	Avg. Diff.	**Count**	**Avg. Diff.**	**Count**	**Avg. Diff.**	**Count**	**Avg. Diff.**	**Count**	**Avg. Diff.**	**Count**
Bridge	-17.3	15			-7.2	3	-11.0	7		
Culvert			-10.7	8	-4.2	10	-1.5	2		
Mail Box					-12.5	1	-11.3	8	-7.6	1
Poles			-10.4	3	-12.2	7	-6.8	11	-0.4	1
Tree	-7.6	2	-7.4	3	-5.6	11	-9.0	16		
Total		**17**		**14**		**32**		**44**		**2**

The odds of a site having a fixed object crash are 42 times higher if the minimum clear zone is not met.

The team also analyzed 58 control sites (see Appendix F). Control sites are areas that have no instances of fixed object crashes within the three year study period. Most of the control sites are located along the same roadways as fixed object crash sites (either prior to or after the crash sites), but did not have the fixed object crash history. For these 58 sites, 47 met the minimum clear zone requirements, and only 11 did not. Using an odds ratio test (Table 14) for this sample, researchers determined that the odds of a site having a fixed object crash are *42 times higher* if the minimum clear zone is not met. The 95th percentile confidence interval for this odds ratio ranges from 17.3 to 101.82 – indicating that the sites that do not meet clear zone requirements are significantly more likely to experience fixed object crashes.

Table 14 Odds Ratio for Fixed Object Crashes

	Does Not Meet Required Clear Zone	**Meets Required Clear Zone**
Fixed Object Crash Sites	**118**	**12**
Control Sites (No Fixed Object Crashes)	**11**	**47**

There was also a comparison of average differences between the minimum required clear zone and the available clear zone for several ranges of minimum clear zones (Table 15). As the clear zone requirement increased, so too did the clear zone deficiencies for the fixed object crash sites. On average, approximately 35% to over 50% additional clear area is needed across the range of sites to meet desired clear zone conditions. For the control sites, the excess clear zone was found to be higher for smaller clear zone requirements, lower for larger required clear zones. For all ranges of required clear zone 10' to 24', a significant difference was found between the samples.

Table 15 Sample Sizes and Average Difference Between Minimum Clear Zones and Available Clear Zones for Fixed Object Crash Sites and Control Sites

	Fixed Object Crash Sites		Control Sites	
Minimum Required Clear Zone (feet)	**# Sites**	**Avg. Diff from Req'd. Clear Zone**	**# Sites**	**Avg. Diff from Req'd. Clear Zone**
10-14	28	-4.4	13	9.3
14-18	35	-6.5	22	2.4
20-24	23	-7.6	18	0.6
24-30	12	-14.6	1	-12.6
30+	9	-17.9	0	--

Overall, the rotating laser data collection was found to be an incredibly useful tool in determining current clear zone availability without having crews in dangers way on the roadside. There is one noted limitation though with the current laser set up. When the sideslopes are steep and separated from the edge of the traveled way by an ample shoulder, there is a visual occlusion for the laser measurement (See Figure 22). For example in Figure 23, a section of I-26 in Dorchester is shown with abrupt changes in the roadside slope. The laser measurements for these areas completely drop off and no measurements are provided beyond the flat paved and grassy shoulder area. While this is a limitation on the measurement side, it still provides valuable information about the traversable and recoverable sections of the roadside because the height of the laser and the distance from the beginning of the steep slope provide enough details on the geometry to determine whether the slope is traversable. In this situation, even though the trees are located a distance of 30' from the roadway, the side slope exceeds the 3H:1V traversable slope range. Therefore, errant vehicles would not be able to stop, but would proceed down the fill section to the toe of the slope where the trees are located. This brings up an important point – it is not only the distance between the traveled way and the roadside obstacle that are critical for safe recovery – the actual sideslopes must also be recoverable. In a few limited cases, the obstacles are actually set a proper distance from the traveled way, yet the sideslopes preclude the clear recovery area from being met. Thus, there will likely be fixed object removal as well as grading required to achieve necessary clear recovery area.

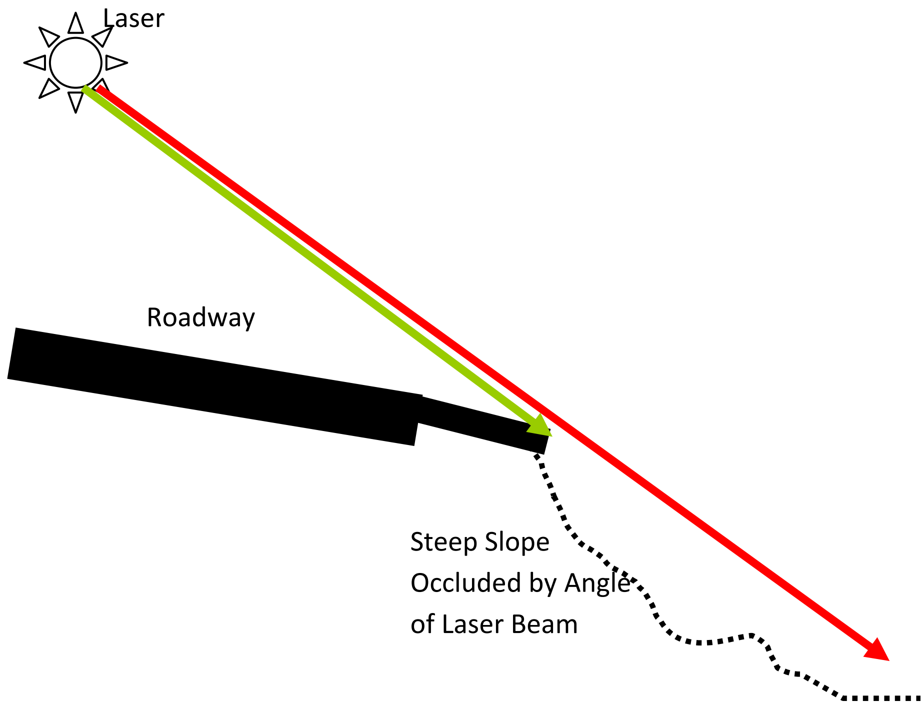


Figure 22 Laser Measurement Occlusion

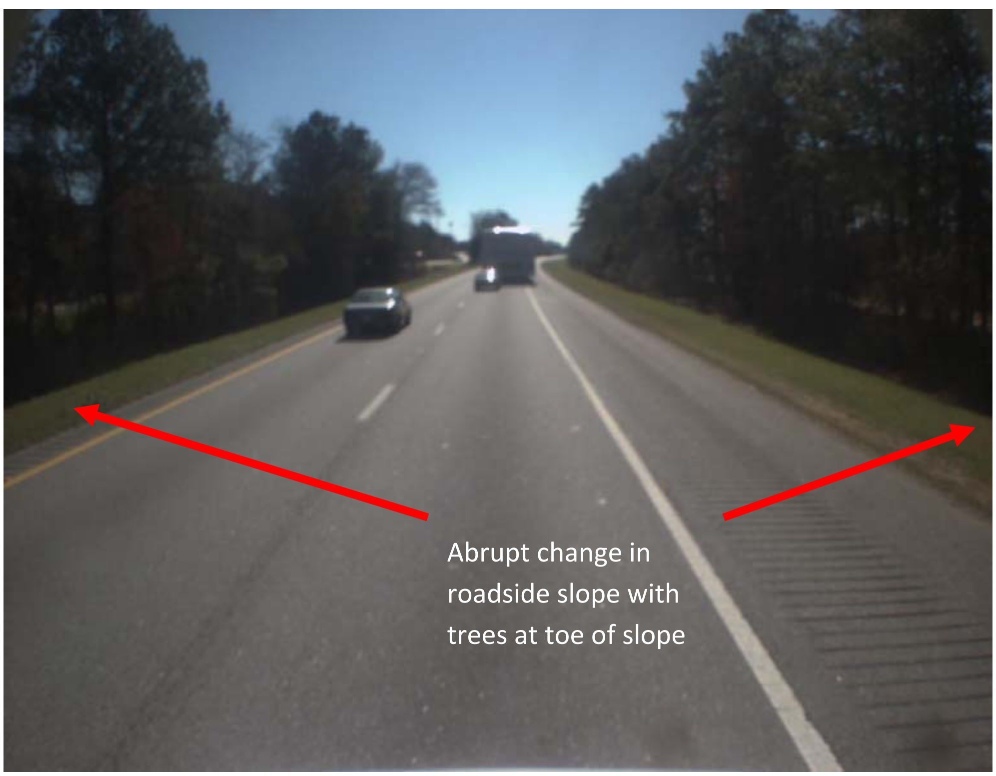


Figure 23 Video-log of a Section of I-26

EVALUATION OF THE 30’ CLEAR ZONE

After completing the initial review of the clear zones for the 131 roadside hazard crash sites, there were only 9 sites whose desired clear zones included or exceeded the 30’ threshold. Of these, none of the sites actually had a 30’ clear recovery area, and the available clear area ranged from 19’ to 4’, indicating that an additional 11’ to 26’ would be required to bring these sites up to even current standards. Thus, the effectiveness of the 30’ clear zone policy cannot be evaluated given the current sample. However, this information indicates that sites with existing roadside hazard crash problems are likely to be lacking in required clear recovery area.

CONCLUSIONS

The findings from this research portray a notable and significant problem with roadside hazards in South Carolina. With one of the top five highest fatality rates in the country , and the fact that trees are involved in a quarter of those fatal crashes, a serious effort to reduce tree-related crashes has the potential to make a large impact in the state's fatality rate. Utility poles and other roadside hazards such as mailboxes and culverts are also problematic, but to a lesser extent than trees. Neighboring southeast states, Georgia and North Carolina, have been working on recovering clear zones through vegetation management and utility relocation programs, and have been successful in those efforts. These programs can be used as models for South Carolina as the conditions in the state are similar.

Georgia began a rehabilitation and safety program for Interstates and limited access roadways back in 2001. It expands the Georgia Department of Transportation's existing pavement preservation program by incorporating all feasible safety improvements, including pavement rehab; additional and upgrade of guardrails, barrier walls and pavement markings, placement of ground-in rumble strips and maintaining a sufficient recovery area within the right-of-way. The goal of the program is to reduce the number of collisions, injuries and fatalities on the limited-access roadway resulting from vehicles leaving the road by 80 percent. Since fatalities are twice as likely to occur as a result of hitting a tree as any other fixed object, vegetation removal is an important part of the entire safety program. The Georgia Department of Transportation has been clearing vegetation 32' beyond the edge of pavement in urban areas and 50' beyond in rural areas to reclaim the recovery area that once existed along these roadways, but has re-established in the years since the roadways were built. GDOT also has a policy to eliminate or shield all fixed objects in medians of 64' or less. The state has set minimum clear zone distances for various roadway types, ADT levels, and fixed object classification. These values are requirements for all heavy maintenance and reconstruction projects in the state. Figure 26 gives examples of the recovery area before, during, and after clearing activities.


(a)

(b)


(c)

Figure 24 A section of freeway in Georgia (a) Before, (b) During, and (c) After Clear Zone Recovery

The North Carolina Department of Transportation Vegetation Management Section has also put a new Clear Zone Improvement Program (CZip) into place in recent years. The program was developed as an effort to incorporate safety, operations and aesthetics while providing a clear recovery zone adjacent to the road. NCDOT bases its brush and tree management program primarily on the roadside safety of the traveling public along its controlled access highways. The Department has for years allowed for a safety recovery zone, based on Federal Highway Administration and AASHTO guidelines, of 40 feet from the edge of the travel to allow errant vehicles to recover (See Figure 25).

Many acres of forested areas along these wide rights-of-ways have been left during highway construction. In addition, reforestation and regeneration of tree species have created a woods line which is generally 40 to 50 feet from the edge of the travel way as required by safety setback guidelines. As limbs from this tree line protrude out to reach additional sunlight towards the pavement edge, the routine mowers back off which allows the tree line to creep into the safety recovery zone. The Department, because of this and also sign clearance, must manage this woods line edge by some method. None of the concepts in CZip are new or outside of the activities already being used by maintenance crews today. The major roadside maintenance activities are:

1. Mowing, machine clearing of the right-of-way
   - A boom mowers
   - Right of way trimmers
   - Hand pruning
2. Control of vegetation by use of herbicides
3. Erosion control
4. Repair seeding
5. Debris removal

The goals of the program are to:

- Provide motorist a safe recovery zone in which to redirect errant vehicles
- Reduce road closures and emergency clearing following hurricanes, ice, storms, etc.
- Reduce long term maintenance associated with traditional planting
- Develop a colorful, low--cost area that includes native plant material where practical

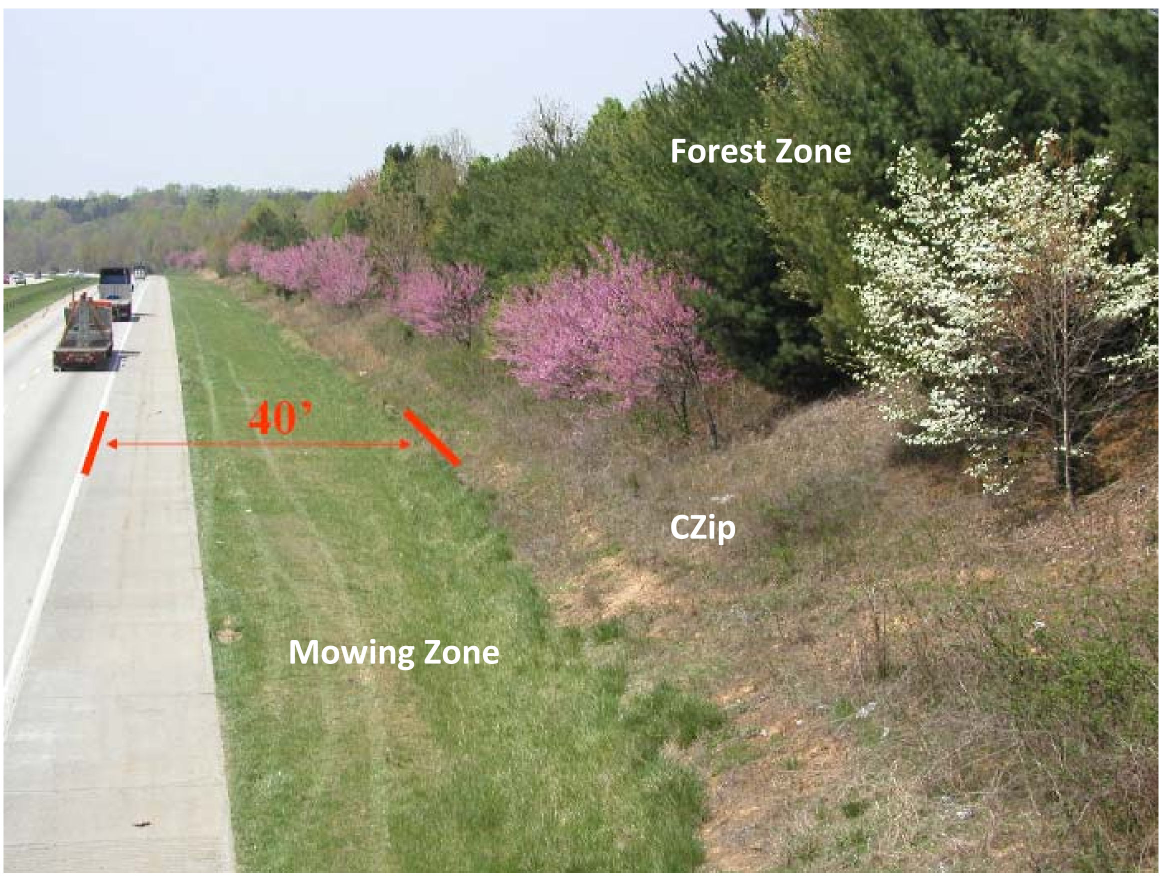


Figure 25 NCDOT Clear Zone Improvement Program

In development of the program, the North Carolina Division of Emergency Management studied seven major disasters between 1996 and 2000 requiring FEMA related disaster relief. It was found that on average, 48% of the relief funds were spent on debris removal, 20% on public utilities, 14% on emergency protection measures, 8% on buildings and equipment, 6% on roads and bridges, and 4% on other. In 2002, there were two ice storms in January and February that cost $22.5M and $7.5M in debris removal (tree removal) alone. In conclusion, it was found that:

- Debris removal is twice as expensive as any other disaster related activity
- Debris removal is far-and-away the most time consuming to manage, and
- States are under constant pressure by FEMA to control costs.

NCDOT has also come up with a number of performance measures to track their vegetation control program and has found that it is successful in storm debris clean up with reductions in clean up time following a storm, reductions in debris removal costs, and reductions in road closings due to storm debris.

Figure 26 Tree Line Creeping into Clear Zone

While there are a number of environmental advocacy groups that oppose tree removal, clearing vegetation from the recovery area has several benefits for transportation agencies and the motoring public including:

- decreasing the number of injuries and fatalities caused by vehicles hitting trees;
- improving highway traffic sign visibility;
- improving sight distance around curves;
- eliminating the possibility of trees falling across the roadway during inclement weather;
- allowing reestablishment of drainage ditches - improving the overall drainage of the roadway, preventing flooding of the roadway which may result in wet surface collisons

According to the USDOT, each fatality results in a $3 million economic impact to the state; this includes but is not limited to lost time, insurance cost, and lost wages. Considering that trees are involved in 25% of the fatal crashes in South Carolina (~240+ each year), it appears that by providing recommended clear zones (or safe recovery areas) for motorists who leave the roadway, South Carolina could realize a notable decrease in roadway fatal and injury crashes. This is particularly significant realizing that many times it is for reasons other than driver error (i.e. blown tire, struck by another vehicle, avoiding an accident, avoiding deer, etc.).

Given the magnitude of the roadside hazard problem in South Carolina, it appears that by providing recommended clear zones for motorists who leave the roadway, South Carolina could realize a notable decrease in roadway fatal and injury crashes.

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