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CENTER for URBAN TRANSPORTATION RESEARCH

Landscaping of Highway Medians at Intersections

Final Report

September 2013

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Center for Urban Transportation Research
University of South Florida
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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric Conversion

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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16. Abstract

Recent interest in road beautification initiatives as a way to help economic growth has led to a number of changes in landscaping policies in Florida. These changes raised the need to evaluate whether the criteria in the landscaping requirements in the Florida Department of Transportation's Design Standard Index 546 (SI-546) remain valid for providing guidance on the installation of trees on medians at intersections. This project evaluates the safety performance of SI-546 with respect to landscaping on medians at intersections through the following objectives: (1) review the current landscaping criteria; (2) develop a computational procedure to analyze landscaping configurations; and (3) perform an empirical study of the safety performances of SI-546. In the literature review, landscaping policies from 29 states were compiled and summarized, and SI-546 was found to be the leading, critical standard to set tree setbacks and detailed spacing requirements at highway medians near intersections. This study validated the current SI-546 and provided recommendations. In this study, a fully functional computational tool was developed. This tool allows landscape architects and design engineers to obtain a variety of visibility performance measures. For the assessment of median tree setback setting in SI-546, 300 median fixed-object crashes were analyzed. For the empirical analysis, the study intersections were divided into three groups: (1) those with median trees near the intersections, compliant with SI-546; (2) those without median trees near the intersections; and (3) those with median trees near the intersections noncompliant with SI-546. Seventy-two intersections were selected for data collection. From 174 crashes examined in this study, the sites compliant with SI-546 had the best safety performance, presenting the lowest crash counts for 4-way and T-intersections, crash rates, and injury severity levels among the three groups. Sites with trees noncompliant with SI-546 showed a higher crash rate at the different posted speed limits than those of the other groups.

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Mr. Fred Heery (FDOT Deputy State Traffic Operations Engineer)
Mr. Mark Greeley (FDOT former Research Performance Coordinator)

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Executive Summary

Recent interest in road beautification initiatives as a way to help economic growth has led to a number of changes in landscaping policies in Florida. These changes raised the need to evaluate whether the design criteria contained in the current Florida Department of Transportation's Design Standard, Index 546 (SI-546) remain valid for providing guidance on the installation of trees on medians at intersections. This research project validated SI-546 and evaluated the safety performance of SI-546 with respect to roadside landscaping on medians at intersections through the following objectives:

- Review the current roadside landscaping criteria.
- Develop a computational procedure to analyze landscaping configurations.
- Conduct an empirical study of the safety performance of SI-546.

This research project has successfully accomplished the following: 1) intensive literature review on landscaping criteria and policies, 2) development of a computational procedure to analyze landscaping configurations, 3) thorough validation of SI-546 using the latest AASHTO standards in 2011 edition of the *Green Book*, 4) detailed analysis on median tree setback setting via median fixed-object crash analysis, 5) analysis of source of noncompliance with SI-546 from collected field landscaping data, 6) evaluation of landscaping types of highway medians at intersections, and 7) development of landscaping-based crash predictive models.

In the literature review, landscaping policies from 29 states were compiled and summarized, as presented in Chapter 2. The remaining 21 states did not have specific landscaping policies and standards. SI-546 was found to be the leading, critical standard to establish tree setbacks and detailed spacing requirements for highway medians near intersections. Tennessee and Ohio cited SI-546 and the *Florida Median Handbook* for their intersection sight distance requirements. It was found that trees of four inches in diameter or less were generally allowed on low-speed facilities. For ground cover, a height of 24 inches from the ground was widely used in other states. Such values are consistent with SI-546.

The Florida landscaping and design standards, SI-546, are presented in Chapter 3. This research project has thoroughly reviewed and validated the current SI-546 and provided recommendations in a separate document for enhancing safe placement of plant material to comply with intersection sight distance and vehicle recovery areas using the latest AASHTO standards in 2011 edition of the *Green Book*.

In this study, a computational tool to calculate visibility measures on landscaping configurations was developed, as presented in Chapter 4. The computational tool runs in MS Visio using VBA macros. With the addition of this tool, the following landscaping performance measures were introduced:

- Average vehicle visibility
- Total time of unobstructed view

- Maximum time of unobstructed view
- Visibility profile

The setting of tree setback from the median nose was one of the recent revisions in SI-546. Median tree setback was to be verified from two points of view: median fixed-object crashes and crashes associate with median landscaping compliance with SI-546. From the point of view of direct fixed-object impact crashes, crash narratives and aerial imagery were used to obtain an approximation of the crash distance with respect to the median nose by intersection control type. A total of 300 sample crash reports were analyzed to obtain an estimated distance distribution of median crashes from media nose, as presented in Chapter 6. The collected information for facilities with posted speed limits below 50 mph and 50 mph or above is presented in Figures ES-1 and ES-2, respectively.

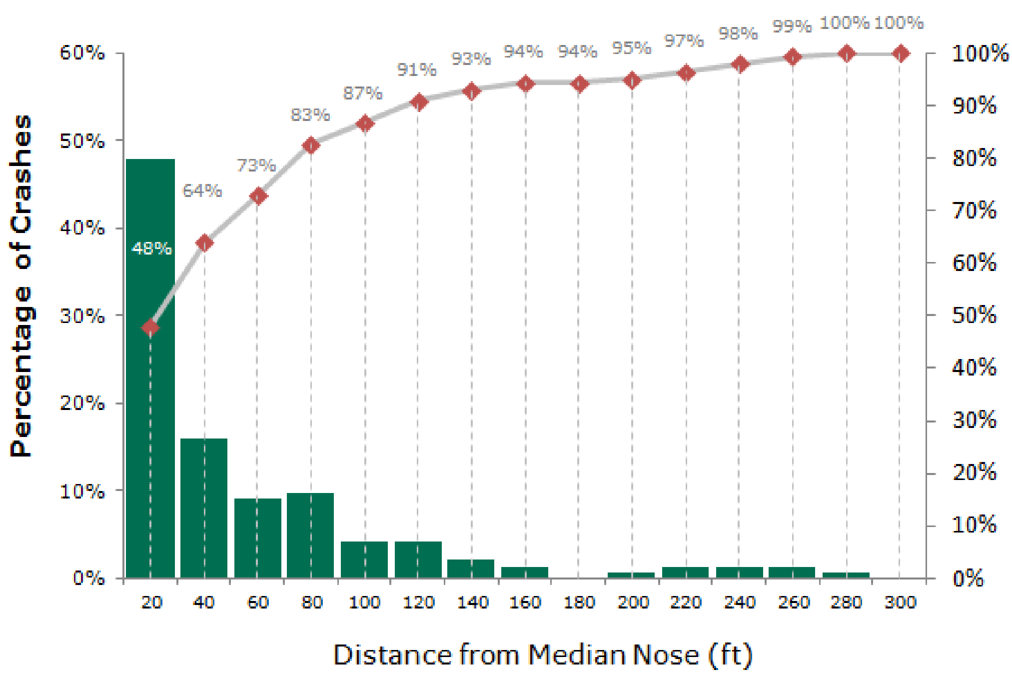

Figure ES-1. Distance from Median Nose for Sample Crashes at Intersections or Influenced by Intersection for Speed Limit <50 mph

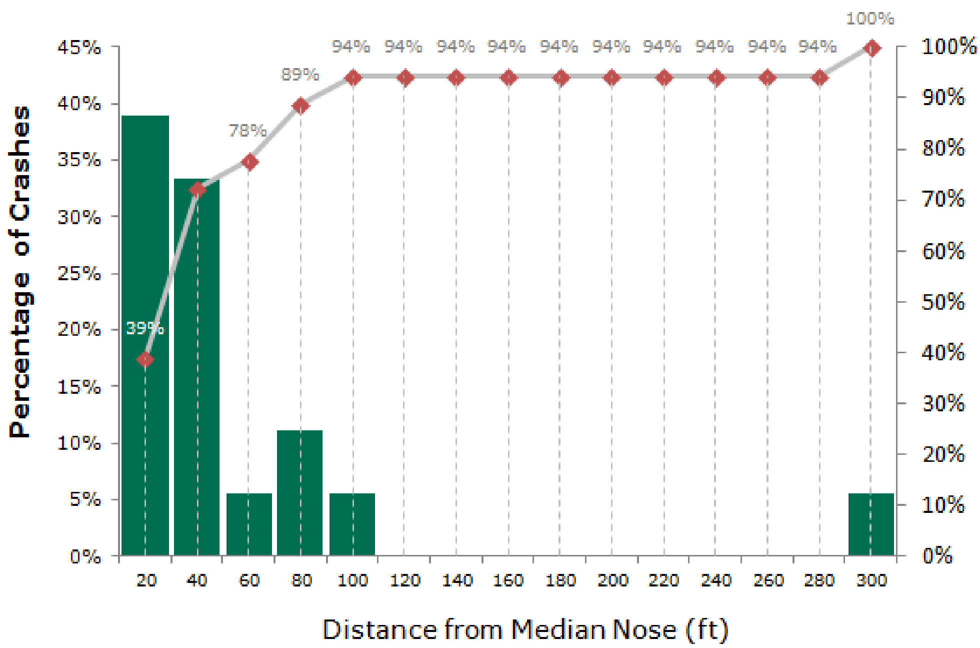

Figure ES-2. Distance from Median Nose for Sample Crashes at Intersections or Influenced by Intersection for Speed Limit ≥50 mph

The major findings and recommendations on the median tree setbacks are as follows:

- It can be observed from Figure ES-1 that the current median tree setback of 100 ft. in SI-546 for facilities with posted speed limit under 50 mph can potentially avoid 87 percent of median fixed-object crashes. The current standard provides a good protection level and does not allow tree planting in the zone where nearly 90 percent of the median crashes tend to occur. It also offers sufficient median space for context-sensitive design and tree plantings. If a consideration is given to avoid at least 90 percent of median fixed-object crashes, it is suggested that the median tree setback in SI-546 increase from 100 ft. to 120 ft.

- From the observation of Figure ES-2, the current median tree setback of 200 ft. in SI-546 for facilities with posted speed limit of 50 mph or greater can potentially avoid at least 94 percent of median fixed-object crashes. The current standard provides a very high level of protection and does not allow tree planting in the zone where nearly 95 percent of the median crashes tend to occur. Based on the distribution of median fixed-object crashes on the distance from median nose as shown in Figure ES-2, the reduction of median tree setback from 200 ft. to 100 ft. can still potentially avoid 94 percent of median fixed-object crashes and offers more median space for context-sensitive design and tree plantings. For facilities with a posted speed limit of 50 mph or greater, the reduction of median setback in SI-546 can be considered. It is necessary to note that this analysis was based a smaller sample of size of 52 due to less available data for high-speed facilities. It is recommended to maintain median tree setback of 200 ft. for facilities with a posted speed limit of 50 mph or greater and allow variance for the tree setback between 120 ft. to 200 ft. if deemed adequate.

The same dataset was divided into signalized and stop-controlled intersections for the point of view of fixed median object crashes. The results of this analysis are as follows:

- For signalized intersections, the mean distance from median nose for crashes with fixed objects was 57.7 ft. For stop-controlled intersections, this distance was 74.1 ft. The distance from the median nose to the point of collision with a fixed object tended to be somewhat closer for signalized intersections, likely because more drivers stopped and waited for gaps to make a permitted left turns.

- According to the statistical analysis based on collected landscaping and associated crash data in Chapter 6, for a significance level of 0.05 (95% confidence level) the distance from the median nose to the point of collision with a fixed median object is statistically equivalent for both signalized and unsignalized intersections.

An empirical study was conducted to evaluate the current SI-546 median landscaping criteria with respect to roadway safety. For the empirical study, study intersections were divided into three groups: 1) those with median trees near the intersection compliant with SI-546, 2) those without median trees near the intersection, and 3) those with median trees near the intersection noncompliant with SI-546. A chart of crash counts by intersection type is presented in Figure ES-3.

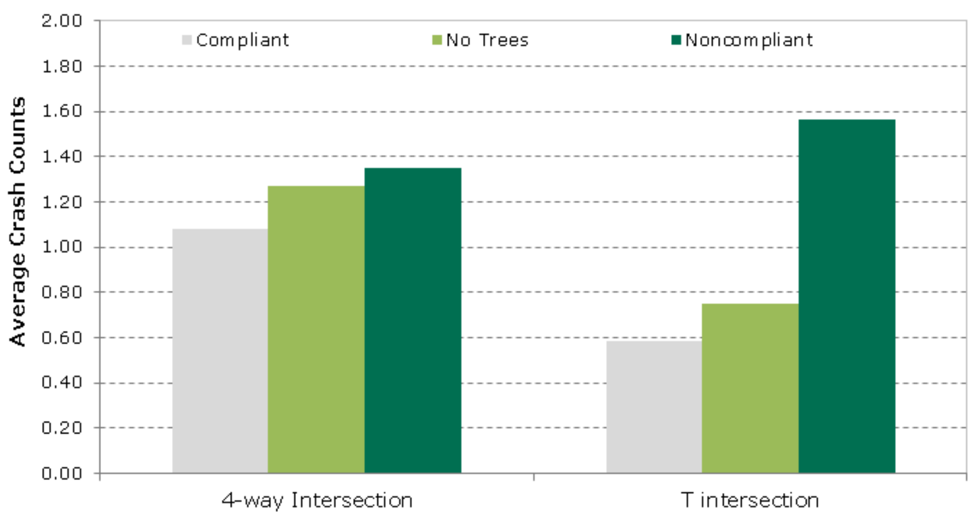

Figure ES-3. Comparison of Average Number of Crashes per Year per Intersection for Three Groups at 4-way Intersections and T Intersections

Seventy-two intersections were selected for data collection. For historical safety performance analysis, the latest available two years of crashes (2009 and 2010) within 300 ft. from the centerline of the intersection were used. The main findings of the empirical analysis are as follows:

- From historical records, information on 174 crashes from the studied 72 intersections was obtained. The sites with landscaped medians compliant with SI-546 had the best overall safety performance. For 4-way intersections, the average number of crashes per year per intersection was 1.08; for T-intersections, it was 0.58.

- For intersections with landscaped medians non-compliant with SI-546, the average number of crashes per year per intersection was 1.35 for 4-way intersections and 1.57 for T-intersections.

- Intersections with no landscaping had an average number of crashes per year per intersection of 1.27 for 4-way intersections and 0.75 for T-intersections.

- With non-landscaped intersections as the baseline, intersections with landscaped medians compliant with SI-546 presented 15 percent fewer crashes per year per intersection for 4-way intersections and 22 percent fewer crashes per year per intersection for T intersections.

- Intersections with landscaped medians non-compliant with SI-546 had 25 percent more crashes per year per intersection for 4-way intersections and 169 percent (almost two times) more crashes per year per intersection for T-intersections than those in compliance with SI-546.

- At each posted speed limit, sites with landscaped medians non-compliant with SI-546 dominated all of the other sites in terms of the highest number of crashes per year per intersection.

- The effect of non-compliant landscaping was more pronounced on facilities with a 40 mph speed limit. On these facilities, the average number of crashes per year per intersection was 1.81 for non-compliant sites. For sites with landscaped medians compliant with SI-546, the number of crashes per year per intersection was 0.67. For facilities with no landscaping, the average number of crashes per year per intersection was 1.10.

- When analyzed based on crash rates in number of crashes per year per intersection and per thousand vehicles, there was no statistically significant difference between sites with landscaped medians that were compliant with SI-546, those that were non-compliant, or sites with no trees. However, the significance level of the test was 0.13 (87% confidence level), which is close to the significance level of 0.1, to draw definitive conclusions on the effectiveness of SI-546 in isolation from other variables.

- Sites with landscaped medians compliant with the standard were observed to have 12 percent fewer crashes per year per intersection and 28 percent fewer crashes per year per intersection involving injuries than sites without median trees near the intersection. However, if landscaping is not properly located or designed, or does not comply with the design standards, 37 percent more crashes per year per intersection were observed than at sites without trees.

- There were statistically-significant differences in average crash counts, Property Damage Only (PDO) crashes, and minor injury crashes between the sites with landscaped medians compliant and noncompliant with SI-546 at a significance level of 0.1 (90% confidence level).

Two landscaping-based crash predictive models were developed in this study and are presented in Chapter 6—one for total crash frequency and the other one for injury crashes. The crash frequency model indicated for 4-way intersections that increased traffic volume, left-turn lane presence on the minor approach, and increased tree diameters increases the chance of crash occurrences. The main findings of these two crash predictive models are as follows:

- The total crash frequency model indicated that when other conditions remain the same, 68 percent more crashes could occur at sites without trees compared to sites with trees compliant with SI-546. It was also found that the chance of crash occurrence decreases as tree setback and tree spacing increase (inverse relationship). However, the significance level of these variables was 0.14 and did not reach the adopted standard level of significance of 0.1 (90% confidence level).

- For the injury crash model, sites without trees tripled the number of injury crashes compared to sites with trees compliant with SI-546 when all other variables remain constant. In this model, SI-546-related variables such as tree setback and spacing were significant at a significance level of 0.1 (90% confidence level). These variables expressed the inverse relationship between setback, tree spacing, and tree diameter with injury crash occurrence. That means the increased setback and tree spacing may have the potential of reducing the occurrence of injury crashes.

- The results indicate that median trees at highways near intersections may have the potential to reduce the number of crashes and even the injury severity levels of crashes if the landscaping plan provides proper visibility.

In addition to providing considerations for the median tree setback settings in SI-546, the major recommendations from this research project are as follows:

- It is beneficial to apply FDOT SI-546 at highway medians near intersections as a national and state guideline to enhance the roadway environmental conditions and improve intersection safety.

- Good landscaping in the median should follow SI-546 to provide not only a better roadway environment but also to improve roadway safety. Sites with landscaping near intersections with stop sign controls at minor roadways should strictly follow SI-546 within the clear sight triangle area to incorporate a context-sensitive solutions approach.

- Based on the distribution of distance from median nose for crashes with fixed median objects in this study, it was found that increasing the setback may have the potential to reduce the chances of a direct-impact crash with the tree. However, with the increase of median tree setback, the potential benefit of context-sensitive design with median landscaping may be reduced. Therefore, determination on the revision of median tree setback in SI-546 should consider the benefits from both crash reduction and context-sensitive design perspectives.

- Form the analysis of landscaping field data, an additional setback distance in the aforementioned range for landscaping designs with trees with the potential of reaching an 18-inch diameter at maturity should be considered.

- Because there is no statistically-significant difference between signalized intersections and stop-controlled intersections with respect to distance from median nose for crashes with fixed median objects, it is recommended that median tree setback standards be applied to both signalized and stop-controlled intersections.

- Based on the analysis of the sources of noncompliance with SI-546, as shown in Figures ES-4, tree spacing was found to be the major source of noncompliance. For trees with diameters at or under 11 inches, only 12 percent of approaches had compliant tree spacing. For trees with diameters over 11 inches, none of the study intersections had tree spacing that was compliant with the recommended spacing in SI-546. Additionally, it was found that the median trees at 35 percent of observed intersections were noncompliant with the required setback in SI-546. Therefore, it is recommended that priority be placed on tree spacing followed by median tree setbacks to improve compliance of median landscaping with SI-546.

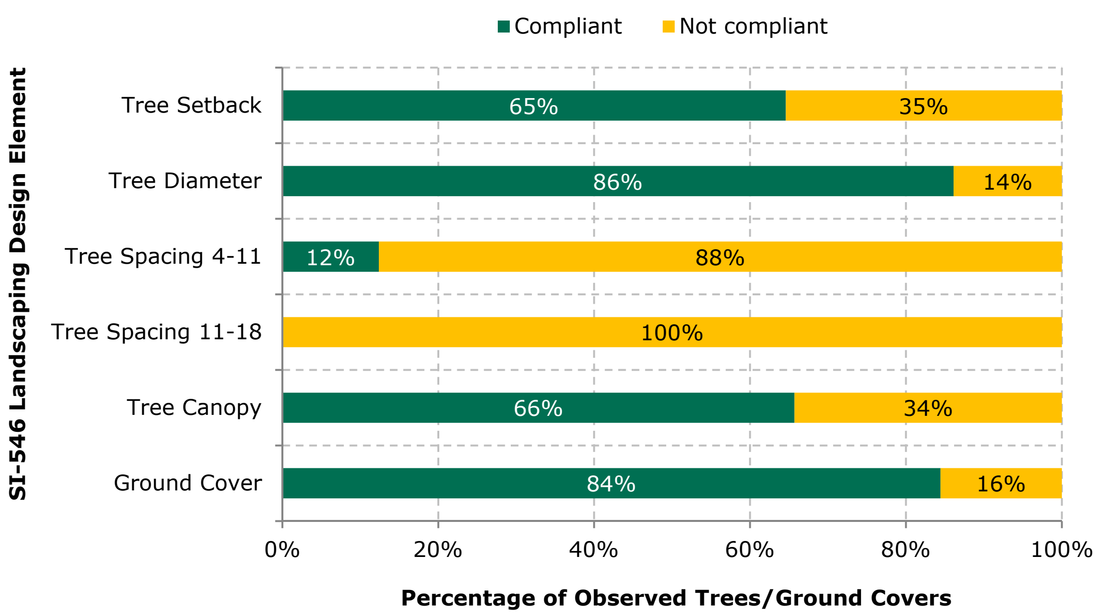

Figure ES-4. Compliance of Observed Landscaping Features with Respect to SI-546 Design Elements

- It is recommended that a landscaping tracking tool is implemented statewide. This tool could contain location information, landscaping plans, installation date, etc., as well as other general information and could be used to track maintenance and tree growth and serve as a valuable data source for safety analyses (e.g., before and after analyses).

- In this study, a fully functional computational tool was developed. This tool allows landscape architects and design engineers to obtain a variety of additional performance measures. It is recommended that the use of this tool be promoted. The tool can be upgraded to be an add-in for existing CAD packages and to incorporate effects such as grade and additional vehicle type.

- During the course of this study, more than 300 police crash reports were reviewed to find evidence of the distance of crashes from median nose. Indication of the point of the median crossing was inferred from the narrative of the crash. It is recommended that for crashes involving vehicles crossing through the median, a quantitative estimate of the crossing point be included in the crash narrative. This will provide valuable feedback for geometric roadway design.

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Chapter 1 Introduction

Landscaping is a design element present at the majority of transportation facilities. It is an essential component of roadway beautification and context-sensitive design initiatives. Divided highways with sufficiently wide medians may contain landscaping in the form of ground cover, plants, or trees. Placement and specifications of those landscaping components are subject to rules and regulations that vary across the states. In Florida, regulations with respect to landscaping on highway medians at intersections are specified in Florida Department of Transportation (FDOT) Standard Index 546 (SI-546).

Landscaping is generally allowed on medians at intersections as long as its design follows the guiding principles in *A Policy on Geometric Design of Highway and Streets* (AASHTO 2004) (AASHTO 2011). AASHTO 2004 states, "The driver of a vehicle approaching an intersection should have an unobstructed view of the entire intersection. Specified areas along intersection approach legs and across their corners should be clear of obstructions that might block a driver's view of potentially conflicting vehicles." AASHTO 2011 states, "The driver of a vehicle approaching an intersection should have an unobstructed view of the entire intersection and sufficient lengths of the intersecting roadways to permit the driver to anticipate and avoid potential collisions."

SI-546 limits the size and spacing of plants and trees on medians at intersections and serves as FDOT's interpretation of AASHTO's policies. Recent interest in road beautification initiatives as a way to help economic growth has led to a number of changes in landscaping policies. In light of those changes, FDOT has taken this as an opportunity to review the safety performance of the design regulations included in SI-546 by means of field studies and crash data analyses. The Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) assisted FDOT in this initiative by conducting an empirical study and developing tools to enhance the analysis of landscaping configurations at intersections.

This project focused on the safety aspects of landscaping on medians at intersections. The main objectives of this project are as follows:

- Review the current landscaping criteria.
- Provide a computational procedure to analyze landscaping configurations.
- Perform an empirical study of the safety performance of the design regulations included in SI-546.

To accomplish these objectives, landscaping policies in other states were carefully reviewed. In addition, historical documents on the development of the current standard were included in the review. All calculations of sight distance for SI-546 were also reviewed as part of this project.

A computational tool was developed in MS Visio to evaluate different landscaping configurations. With the aid of the computational tool, new landscaping performance measures were introduced.

An empirical study was conducted to evaluate the current SI-546 median landscaping criteria on roadway safety. The study intersections were divided into three groups, as follows: 1) those with median trees near the intersections, compliant with SI-546; 2) those without median trees near the intersections; and 3) those with median trees near the intersections noncompliant with SI-546.

Potential landscaped corridors and intersections to be studied in Florida were first identified based on input from landscaping architects, safety experts, and traffic operations engineers from the different FDOT districts. Considering the available project budget and the project objective to effectively evaluate and validate the current SI-546 median landscaping criteria on roadway safety, the empirical study aimed to select study locations that are representative and can be comparable for statistical analysis. A total of 72 unsignalized intersections, including both 4-way and T-intersections, across Florida were studied and analyzed, which far exceeded the originally-proposed 24 intersections in the technical proposal.

Detailed landscaping field data for these 72 unsignalized intersections combined with data for 174 crashes near intersections in 2009 and 2010 were collected to evaluate the safety performance of SI-546. Landscaped intersections were evaluated as either compliant or noncompliant with SI-546 and were compared to intersections with no landscaping.

To examine whether there are any differences on the distance from the median nose to crash location for crashes impacting median objects between signalized and stop-controlled intersections, this research also analyzed the distribution of the distance of crashes involving direct impact with a fixed median object from the median nose. The objective of the analysis was to obtain quantitative evidence for tree setback on divided highways at intersections and type of traffic control (e.g., stop and signalized). To cope with limited tree crash data, all crashes with fixed objects within the median were considered as the population of interest for the analysis. A total of 300 crash reports from Florida Crash Analysis Reporting System (CARS) were found to contain verifiable information and analyzed to determine and compare the distances from the median nose to crash locations between signalized and stop-controlled intersections.

Recommendations on calculation of visibility criteria, use of computational tools, and enhancement to the crash reporting system are provided in the final section of the study.

Chapter 2 Landscaping Policies in Other States

This section presents an intensive review of the policies and practices in other states related to landscaping on medians at intersections. The review was performed to gain a better understanding of the application of AASHTO's policy related to landscaping on medians at intersections. The literature review included other states' landscaping policies and, in some cases, phone interviews with landscaping architects or design engineers for clarification.

Landscaping Policy Benchmarks

AASHTO's landscaping policy for intersections can be divided into two main parts. The first is related to intersection visibility. AASHTO's policy says that all drivers should have an unobstructed view of the intersection. This first part of the criteria is necessary for drivers to maneuver at an intersection. There is little or no room for variances on the first part of the criteria. The second part of the policy deals with intersection approaches and does not strictly forbid landscaping. It provides flexibility for landscaping as long as it allows drivers to see potentially conflicting vehicles. Based on the second part of AASHTO's policy, many states have different criteria to determine significant visibility obstructions on intersection approaches. Florida established visibility criteria as enumerated in SI-546. For example, one criterion states that landscaping on medians at intersection approaches should allow two seconds of unobstructed visibility at the design speed. Many states have adopted Florida's visibility criteria. One of the objectives of the literature review was to find additional visibility criteria in other states to compare or benchmark to those established in Florida

Another important aspect of the literature review relevant to the objectives of this research was median tree setback criteria. Those criteria are related to the minimum distance from the median nose where trees can be planted. The median nose is the end of the median at the median opening. For example, in Florida, trees are not permitted within 100 ft. of the median nose on roadways having a speed limit less than 50 mph. The literature review also focused on tree setback criteria as benchmark criteria for landscaping policy in Florida. Additional criteria also were reviewed and are summarized in table format. The complete literature review compilation can be found in Appendix A.

Review of Landscaping Policies

The median planting policies of 29 states were reviewed for this research project. The remaining 21 states did not have specific landscaping policies and standards. Due to climate and geometric restrictions, eight of the reviewed states do not plant trees in medians, and median landscaping is limited to low vegetation and shrubs. Five of the reviewed states do not have standards for median planting but do have some practices based on discussions with state agents. The other 16 state policies that were reviewed have design requirements for median tree planting, as detailed in Table 2-1 and Appendix A.

Table 2-1. Selected Landscaping Criteria in Other States

State	Median Tree Placement Criteria	Setback Restriction
California	▪ Barrier required for speeds 45 mph or less ▪ Mature trees (4" or greater in diameter) require an 11' or more wide median	▪ Signalized Intersections: 100' from intersections ▪ Unsignalized Intersections: o 25 mph - 150' from intersections o 30 mph - 200' from intersections o 35 mph - 250' from intersections
Louisiana	▪ Only allows shrubbery and ground cover in the clear sight triangle area with heights less than 2.5' above roadway surface ▪ No trees allowed in clear sight triangles	▪ 30 mph - 300' from median nose ▪ 40 mph - 400' from median nose ▪ 50 mph - 500' from median nose ▪ 55 mph - 550' from median nose
Michigan	▪ Allows shrubs/trees with a mature diameter of 4" or less at 4'–6" above the ground line ▪ Trees to be planted at least 10' apart ▪ Center of trunk should be planted in planning zone limits	▪ 40' (opposite travel lane side) from median nose at median openings ▪ 70' (turn lane side) from median nose at median openings ▪ 300' from center point of intersections for all intersection ▪ 150' from centerline of crossroads
New Jersey	▪ Only smaller trees not get greater than 6" in diameter can be planted within median ▪ No required minimal tree spacing and generally closer because of size of trees	▪ Not allow trees to be planted within sight triangle area for all intersections: o 30 mph - 335' from decision point o 40 mph - 445' from decision point o 50 mph - 555' from decision point o 60 mph - 665' from decision point
Ohio	▪ No trees in medians within intersection sight triangles areas ▪ Low maintenance flowers, ground cover with 18" or less in height can be planted in sight triangle areas ▪ Minimal clearance of 16' above pavement should be maintained ▪ 4'–6' minimal distance from curb face to trees	▪ Not allow trees to be planted within the sight triangle area for all intersections: o 25 mph - 280' from decision point o 30 mph - 335' from decision point o 35 mph - 390' from decision point o 40 mph - 445' from decision point o 45 mph - 500' from decision point o 50 mph - 555' from decision point
Oregon	▪ Trees can be planted only where posted speed is 35 mph or less ▪ Curved/raised median with 8' or wider ▪ No planting higher than 24" above the pavement surface within intersection functional area ▪ Minimum clear height of 10' from pavement to bottom of branches	▪ Not allow trees to be planted within the intersection functional areas: o 19 mph - 215 to 315' o 25 mph - 335' to 490' o 28 mph - 405' to 595' o 31 mph - 485' to 710' o 34 mph - 565' to 835' o 37 mph - 605' to 960'
Texas	▪ Only low-growing varieties can be planted in intersection areas ▪ Most trees are within 2"–3" caliper ▪ Trees with mature caliper of 4" or greater cannot be planted within clear sight triangle areas	▪ Not allow trees larger than 4" caliper to be planted within sight triangle area for all intersections

The first part of the policy review was aimed at determining other states' policies regarding landscaping at intersections. The second part of the policy review was focused on summarizing those landscaping policies and providing detailed information. Table 2-1 presents an overview of the criteria being used for median tree placement and other plants. In general, trees with diameters larger than four inches are restricted. In addition, plants and other ground cover are limited to 24 inches of height to avoid obstructing driver visibility. The criteria presented in Table 2-1 are adaptations or interpretations of AASHTO's landscaping policy.

Both AASHTO *Green Books* (AASHTO 2004) (AASHTO 2011) do not specify setbacks for trees directly in the recommended polices. Instead, for the visibility criteria, they recommend that no object is to be placed within the sight triangles that may obstruct the driver's view. However, the Federal Highway Administration (FHWA) recommends that all trees on the median within sight triangle areas should not be higher than 2 ft. and at least 50 ft. away from the intersection (FHWA 2004).

For the setback requirement, nine states do not allow trees to be planted within sight triangle areas, which are determined by the speed and intersection types by AASHTO. Six states regulate setback restrictions from intersections ranging from 35 ft. to 300 ft. It was found that two states, Tennessee and Ohio, have cited SI-546 and the *Florida Median Handbook* for the intersection sight distance requirement. For example, Tennessee follows a very similar procedure of FDOT's SI-546 for sight distance at intersections.

Many states adapt the AASHTO standard for vehicle visibility criteria, which states there should be no obstruction within clear sight triangle areas. Only Florida, Tennessee, and Ohio specify the quantitative requirement. These three states have the same vehicle visibility criteria that say there must be at least 50 percent of the visual area of a vehicle and a 2-second full view of an entering vehicle. No visibility criteria with respect to median trees at intersections were found in other states' policies.

Furthermore, several states currently follow the visibility criteria suggested in the *Florida Median Handbook* (FDOT 2006). Five states—California, Michigan, Ohio, Oregon, and Tennessee—were selected for a detailed policy review to compare to the Florida standards (see Table 2-1). The detailed summaries of each state are listed in Table 2-2 through Table 2-7.

Table 2-2. Detailed Median Landscaping Policy for Florida

<table>
<tr><th colspan="6">Florida</th></tr>
<tr><td rowspan="4">Median Trees Guidelines at Intersections</td><td>Ground Cover</td><td colspan="4">Top of ground cover to sight line datum:
Ground cover only, > 18″
For ground cover in combination with trees and palms:
> 24″ for trees and palms ≤ 11″ diameter
> 18″ for Sabal Palms >11″ but ≤ 18″ diameter</td></tr>
<tr><td>Setback Restrictions (Trees/Trunked Plants)</td><td colspan="4">100′ from pavement edge for design speeds < 50 mph
200′ from pavement edge for design speeds ≥ 50 mph</td></tr>
<tr><td>Trunked Plants</td><td colspan="4">Diameter ≤ 4″
≥5′ above the sight line datum
Minimal space: 20′</td></tr>
<tr><td>Trees</td><td colspan="4">Diameter ≤ 18″
Distance to bottom of canopy 8′6″
<table><tr><td rowspan="8">Minimal tree spacing (center to center of trunk)</td><th>Speed (mph)</th><th>Diameter > 4″≤ 11″</th><th>Diameter > 11″≤ 18″</th></tr><tr><td>30</td><td>22</td><td>91</td></tr><tr><td>35</td><td>27</td><td>108</td></tr><tr><td>40</td><td>33</td><td>126</td></tr><tr><td>45</td><td>40</td><td>146</td></tr><tr><td>50</td><td>45</td><td>165</td></tr><tr><td>55</td><td>52</td><td>173</td></tr><tr><td>60</td><td>60</td><td>193</td></tr></table></td></tr>
<tr><td rowspan="5">Additional Guidelines</td><td>Vehicle Visibility Criteria</td><td colspan="4">2 second full view of entering vehicle
At least 50% of the visual area of a vehicle</td></tr>
<tr><td>Minimum Distance from Edge of Travel Lane</td><td colspan="4">General, 6′
With barrier wall or other safety design, ≥ 4′
With guardrail, ≥ 5′</td></tr>
<tr><td>Minimum Median Width for Tree Planting</td><td colspan="4">Urban, not specified
Rural, does not normally include landscaping with trees</td></tr>
<tr><td>Guardrail Requirements</td><td colspan="4">Not specified</td></tr>
<tr><td>Minimal Eye Setback from the Edge of Traveled Lane</td><td colspan="4">14′6′′</td></tr>
<tr><td colspan="6">Source: Florida Design Standard Index 546, Florida Design Index 700, Florida Median Handbook http://www.dot.state.fl.us/planning/systems/sm/accman/pdfs/mhb06b.pdf; Florida Highway Landscape Guide</td></tr>
</table>

Table 2-3. Detailed Median Landscaping Policy for California

	California		
Median Trees Guidelines at Intersections	Ground Cover	No obstruction within clear sight triangle	
	Setback Restrictions (Trees)	Signalized intersections: 100′ from intersections Unsignalized intersections: 25 mph – 150′ from intersections 30 mph – 200′ from intersections 35 mph – 250′ from intersections	
	Trunked Plants	Not specified	
	Trees	Diameter > 4″ measured 4′ above the ground Minimal 15′ vertical clearance from pavement to accommodate trucks No large trees in narrow medians (with less than 5′ from face of curb to trees	
		Minimal tree spacing (center to center of trunk)	Ranging from 15′ to 50′ for different cities
Additional Guidelines	Vehicle Visibility Criteria	No obstruction within clear sight triangle	
	Minimum Distance from Edge of Travel Lane	General, 5′ for speeds 35 mph or less With concrete barrier, ≥ 18″ for speeds 35 mph or less	
	Minimum Median Width for Tree Planting	Barrier required for speeds between 35–45 mph Mature trees (4″ or greater in diameter) require 11′ or more wide median	
	Guardrail Requirements	Not specified	
	Minimal Eye Setback from Edge of Traveled Lane	Normally 14′5′′, varies when there is on-street parking	

Sources: Caltrans Median Tress Setback Criteria, http://www.grandboulevard.net/toolbox/index.php?option=com_content&view=article&id=30%3Al-trees-in-median; Trees in Median Criteria, http://www.grandboulevard.net/toolbox/index.php?option=com_content&view=article&id=30%3Al-trees-in-median; Street Trees and Intersection Safety, http://www.uctc.net/papers/768.pdf.

Table 2-4. Detailed Median Landscaping Policy for Michigan

		Michigan	
Median Trees Guidelines at Intersections	Ground Cover	No obstruction within clear sight triangle zone (300′ × 300′ by 424′ in each quadrant)	
	Setback Restrictions (Trees/Trunked Plants)	40′ (opposite to travel lane side) from median nose at median openings 70′ (turn lane side) from median nose at median openings 300′ from center point of intersections for all intersections 150′ from the centerline of crossroads	
	Trunked Plants	No obstruction within clear sight triangle (300′ by 300′ by 424′ in each quadrant)	
	Trees	Diameter ≤ 4″ At 4′-6″ above ground line	
		Minimal tree spacing (center to center of trunk)	No requirement, but trees at least 10′ apart
Additional Guidelines	Vehicle Visibility Criteria	No obstruction within clear sight triangle zone (300′ × 300′ by 424′ in each quadrant)	
	Minimum Distance from Edge of Travel Lane	10′ from back of curb in turn lane 20′ from behind barrier curb 50′ from the edge of traffic lanes for freeways	
	Minimum Median Width for Tree Planting	Not specified	
	Guardrail Requirements	Not specified	
	Minimal Eye Setback from Edge of Traveled Lane	14′6″	

Sources: Typical Planting Procedures, *Michigan Roadside Design Manual*, http://mdotwas1.mdot.state.mi.us/public/design/files/englishroadmanual/erdm07.pdf; State DOT Design Division Engineer

Table 2-5. Detailed Median Landscaping Policy for Ohio

<table>
<tr><th colspan="4">Ohio</th></tr>
<tr><td rowspan="4">Median Trees Guidelines at Intersections</td><td>Ground Cover</td><td colspan="2">Low maintenance flowers, ground cover with 18" or less in height can be planted in sight triangle areas</td></tr>
<tr><td>Setback Restrictions (Trees/Trunked Plants)</td><td colspan="2">15 mph - 170' from decision point
20 mph - 225' from decision point
25 mph - 280' from decision point
30 mph - 335' from decision point
35 mph - 390' from decision point
40 mph - 445' from decision point
45 mph - 500' from decision point
50 mph - 555' from decision point
55 mph - 610' from decision point
60 mph - 665' from decision point</td></tr>
<tr><td>Trunked Plants</td><td colspan="2">Not allowed in medians within intersection sight triangle areas
Minimum 16' vertical clearance
30' for roadside of edge of traveled way</td></tr>
<tr><td>Trees</td><td colspan="2">Not allowed in medians within intersection sight triangle
Minimum 16' vertical clearance
30' of edge of traveled way for roadside

Minimal tree spacing (center to center of trunk): Not specified</td></tr>
<tr><td rowspan="5">Additional Guidelines</td><td>Vehicle Visibility Criteria</td><td colspan="2">Clear of trees or any other obstructions</td></tr>
<tr><td>Minimum Distance from Edge of Travel Lane</td><td colspan="2">4'; 6' for high risk areas
1.5' if bike lane or parking lane exits</td></tr>
<tr><td>Minimum Median Width for Tree Planting</td><td colspan="2">Not specified</td></tr>
<tr><td>Guardrail Requirements</td><td colspan="2">Not specified</td></tr>
<tr><td>Minimal Eye Setback from the Edge of Traveled Lane</td><td colspan="2">14'5" (preferred 17'10")</td></tr>
<tr><td colspan="4">Sources: Location and Design Manual (Section 200), Roadside Safety Landscaping Guidelines, http://www.dot.state.oh.us/Divisions/Engineering/Roadway/roadwaystandards/Location%20and%20Design%20Manual/LandscapingGuidelines_2010-4-16.PDF; State DOT Roadway Standards Engineer</td></tr>
</table>

Table 2-6. Detailed Median Landscaping Policy for Oregon

Oregon			
Median Trees Guidelines at Intersections	Ground Cover	24" or less in height can be planted within intersection functional area	
	Setback Restrictions (Trees/Trunked Plants)	19 mph - 215 to 315' 22 mph - 270 to 370' 25 mph - 335' to 490' 28 mph - 405' to 595' 31 mph - 485' to 710' 34 mph - 565' to 835' 37 mph - 605' to 960'	
	Trunked Plants	Posted speed of 35 mph or less Minimum clear height of 10' from pavement to bottom of branches	
	Trees	Posted speed of 35 mph or less Minimum clear height of 10' from the pavement to the bottom of the branches	
		Minimal tree spacing (center to center of trunk)	Not specified
Additional Guidelines	Vehicle Visibility Criteria	Follow Florida *Median Handbook* 2 seconds full view of entering vehicle At least 50% of visual area of vehicle	
	Minimum Distance from Edge of Travel Lane	1'–2' for ground covers, flowers 6' for trees	
	Minimum Median Width for Tree Planting	Curved/raised median with 8' or wider	
	Guardrail Requirements	Not specified	
	Minimal Eye Setback from Edge of Traveled Lane	14'6"	

Sources: *Highway Design Manual*, Chapter 5, *Florida Median Handbook*, Interim Version, http://www.dot.state.fl.us/planning/systems/sm/accman/pdfs/mhb06b.pdf; State DOT Senior Standards Engineer

Table 2-7. Detailed Median Landscaping Policy for Tennessee

<table>
<tr><th colspan="6">Tennessee</th></tr>
<tr><td rowspan="12">Median Trees Guidelines at Intersections</td><td>Ground Cover</td><td colspan="4">Top of ground cover to sight line datum:
Ground cover only, > 18”
For ground cover in combination with trees and palms:
> 24” for trees and palms ≤ 11” dia.
> 18” for sabal palms >11” but ≤ 18” dia.</td></tr>
<tr><td>Setback Restrictions (Trees/Trunked Plants)</td><td colspan="4">100’ from pavement edge for design speeds < 50 mph
200’ from pavement edge for design speeds ≥ 50 mph</td></tr>
<tr><td>Trunked Plants</td><td colspan="4">Diameter ≤ 4”
≥5’ above the sight line datum
Minimum space: 20’</td></tr>
<tr><td rowspan="9">Trees</td><td colspan="4">Diameter ≤ 18”
Distance to bottom of canopy 8’6”</td></tr>
<tr><td rowspan="8">Minimal tree spacing (center to center of trunk)</td><td>Speed (mph)</td><td>Diameter > 4”≤ 11”</td><td>Diameter > 11”≤ 18”</td></tr>
<tr><td>30</td><td>22</td><td>91</td></tr>
<tr><td>35</td><td>27</td><td>108</td></tr>
<tr><td>40</td><td>33</td><td>126</td></tr>
<tr><td>45</td><td>40</td><td>146</td></tr>
<tr><td>50</td><td>45</td><td>165</td></tr>
<tr><td>55</td><td>52</td><td>173</td></tr>
<tr><td>60</td><td>60</td><td>193</td></tr>
<tr><td rowspan="5">Additional Guidelines</td><td>Vehicle Visibility Criteria</td><td colspan="4">2 seconds full view of entering vehicle
At least 50% of the visual area of a vehicle</td></tr>
<tr><td>Minimum Distance from Edge of Travel Lane</td><td colspan="4">General, 6’
With barrier wall or other safety design, ≥ 4’
With guardrail, ≥ 5’</td></tr>
<tr><td>Minimum Median Width for Tree Planting</td><td colspan="4">Urban, not specified
Rural, does not normally include landscaping with trees</td></tr>
<tr><td>Guardrail Requirements</td><td colspan="4">Not specified</td></tr>
<tr><td>Minimal Eye Setback from Edge of Traveled Lane</td><td colspan="4">14’6’’</td></tr>
<tr><td colspan="6">Source: Tennessee Intersection Sight Distance Standard Drawings, http://www.tdot.state.tn.us/Chief_Engineer/engr_library/design/StdDrwgEng_PDFs/RD01SD2_000000.pdf</td></tr>
</table>

Chapter 3 Landscaping and Design Standard SI-546

This section presents context-sensitive solutions, Florida's highway beautification and its bold landscaping policy, an overview of SI-546, concepts relevant to the safety and operational aspects of landscaping on highway medians at intersections, visibility criteria recommended for landscaping design, and the recent revisions to SI-546.

Context-Sensitive Solutions

An effective transportation system provides safe, efficient, dependable, and environmentally-responsible transportation services to all of its users. Context-sensitive design (CSD) asserts that all decisions in transportation planning, project development, operations, and maintenance should be responsive to the context in which these activities occur, not simply the design process. CSD promotes a positive quality of life for residents and enhances the economic vitality of areas. It provides a project that meets the purpose and needs as defined by highway users, the local community, and the state. CSD ensures that projects are developed to maintain the safety and efficiency of the facility for its users and the community. It also preserves the environmental, scenic, historic, aesthetic, and natural resource values of the area.

FDOT is striving toward more context-sensitive design. Effective November 20, 2008, it became FDOT's policy to use a Context-Sensitive Solutions (CSS) approach on transportation projects and activities for all modes appropriate to scale, cost, location, and schedule, including pedestrians, bicyclists, and transit. It also takes into consideration adjacent land uses, local densities, and nearby destinations. According to FHWA, CSS is a collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic, and environmental resources while maintaining safety and mobility. CSS is an approach that considers the total context within which a transportation improvement project will exist. Examples of CSD landscaping of highway medians in communities are shown in Figure 3-1.

Figure 3-1. Examples of CSD Landscaping of Highway Medians in Communities

Highway Beautification and the Bold Landscaping Policy

Statewide policies to promote economic growth strive for ways to attract more businesses and visitors to Florida. One of the FDOT policies contributing to this goal is to implement bold roadside beautification projects (FDOT 2011), which includes installing trees at specially-designated sites. Each district, in conjunction with other agencies, is encouraged to prioritize roadside landscaping where highway beautification initiatives are most likely to help attract businesses. Several of the work plans that highlight the bold landscaping policy include the following:

- Strengthen the Department's Highway Beautification Policy to show renewed commitment.
- Increase landscape expertise in each district planning, design, construction, and maintenance office.
- Develop landscape project performance measures and targets tied to other department programs (safety, pedestrian and bicyclists, safe routes to schools, accessibility, drainage, transit, maintenance).
- Develop a system to track and monitor landscape projects over time and space. Create landscape projects with annual report cards on how the project matured and the cost and quality of care. Document what has been invested, where, and how the investment is growing.

To support the new landscaping policies, new tools and methodologies that help address landscaping and roadway design are necessary. This project supports this initiative by providing data and methodologies to analyze landscaping design and its effects on visibility and traffic safety.

Sight Distance and SI-546

SI-546 is FDOT's design standard for sight distance at intersections and is intended to clearly specify FDOT's interpretation of the AASHTO *Green Book*. SI-546 has been revised several times to ensure that the index reflects ongoing revisions of the AASHTO *Green Book*, the *Manual on Uniform Traffic Control Devices* (MUTCD), and FDOT policies. The information provided in SI-546 is intended solely for the purpose of clear sight development and maintenance at intersecting highways, roads, and streets. SI-546 controls the spacing between trees, the size of trunk diameter, the height of ground cover, and the height of trees within the clear-sight window. For landscaping at intersections, a landscape architect or designer must select plants to conform to the horizontal, vertical, sight distance, and clear zone criteria in compliance with SI-546.

The driver of a vehicle approaching or departing an intersection should have an unobstructed view of the intersection; this includes any traffic control devices and landscaping and must have sufficient lengths to anticipate and avoid potential collisions. These unobstructed views form triangular areas are known as sight triangles. These areas should be clear of obstructions that might block a driver's view of conflicting vehicles or pedestrians. The two types of sight triangles are approach sight triangles and departure sight triangles (AASHTO 2004). Approach sight triangles, shown in Figure 3-2, provide the driver of a vehicle approaching an intersection an unobstructed view of any conflicting vehicles or pedestrians.

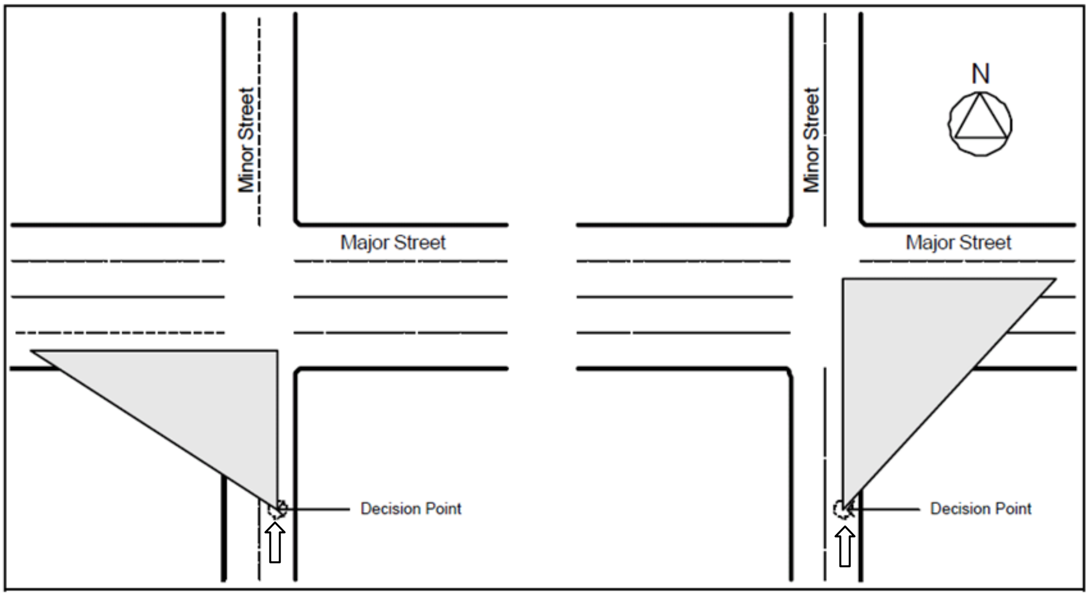


Figure 3-2. Approach Sight Triangle

These triangular areas should be large enough that drivers can see approaching vehicles and pedestrians and have sufficient time to slow or stop, thus avoiding a crash. Departure sight triangles, shown in Figure 3-3, provide adequate sight distance for a stopped driver on a minor roadway to depart from the intersection and enter or cross the major roadway. These sight triangles should be provided in each quadrant of a controlled intersection.

Several studies indicate that high-quality landscaping potentially can improve transportation safety. A study conducted in downtown Toronto, Canada, showed that the placement of landscape improvements, including trees and plants, decreased the total number of crashes by 5–20 percent on all five arterial roadways (Naderi 2003). Another study in Texas demonstrated how landscape improvements positively impacted road safety; the study showed a 71 percent reduction in total crashes after the improvement was made (Mok, Landphair and Naderi 2006). However, the potential benefits of landscaping can result in sight distance problems if not properly planned or implemented. Therefore, when tree installations are considered for highway medians in the vicinity of intersections, sight distance should be closely taken into design consideration.

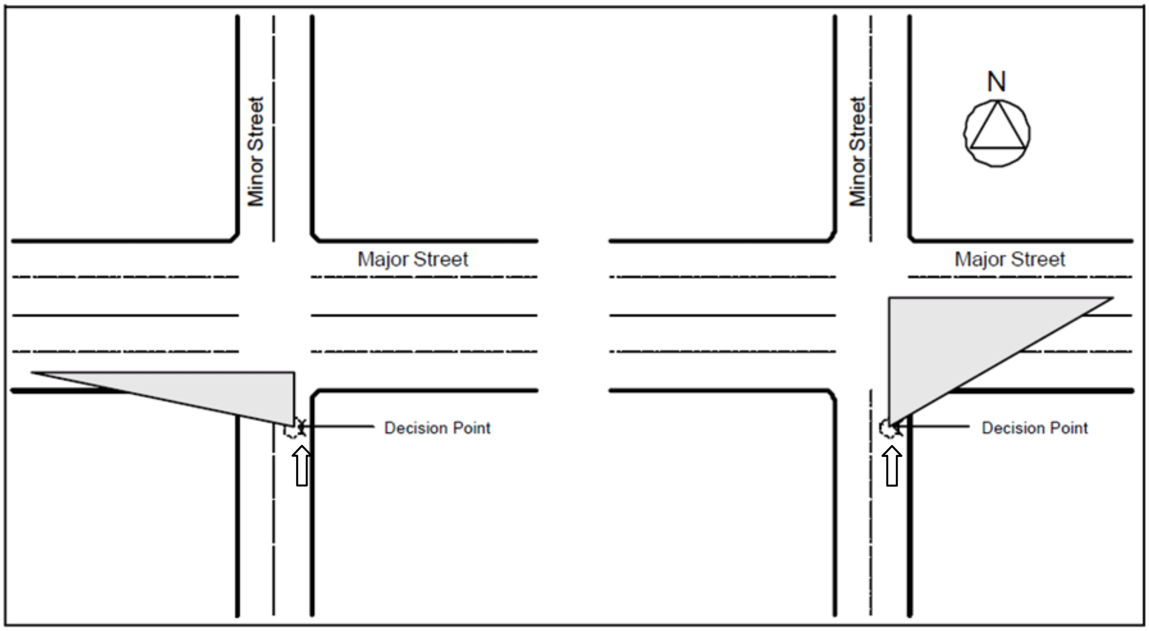


Figure 3-3. Departure Sight Triangle

Visibility Criteria

Visibility criteria are applied at intersection approaches that may pose visibility obstructions to both the major approach driver and the minor approach driver. The visibility criteria in Florida state that a vehicle is visible as long as 50 percent of its visible area is free of obstruction. In places where visibility is obstructed by 50 percent or more, the landscaping design should allow for two seconds of unobstructed visibility (FDOT 2006). Additional visibility criteria in the *Florida Highway Landscape Guide* (Lott and Graham 1995) suggest that landscaping within the limits of the clear sight should not block more than 50 percent of a driver's view of a passenger car stopped on the minor approach. It also recommends that the driver on the major road should have a clear view of at least 66.6 percent of a passenger car stopped at the minor approach. This visibility concept is presented in Figure 3-4.

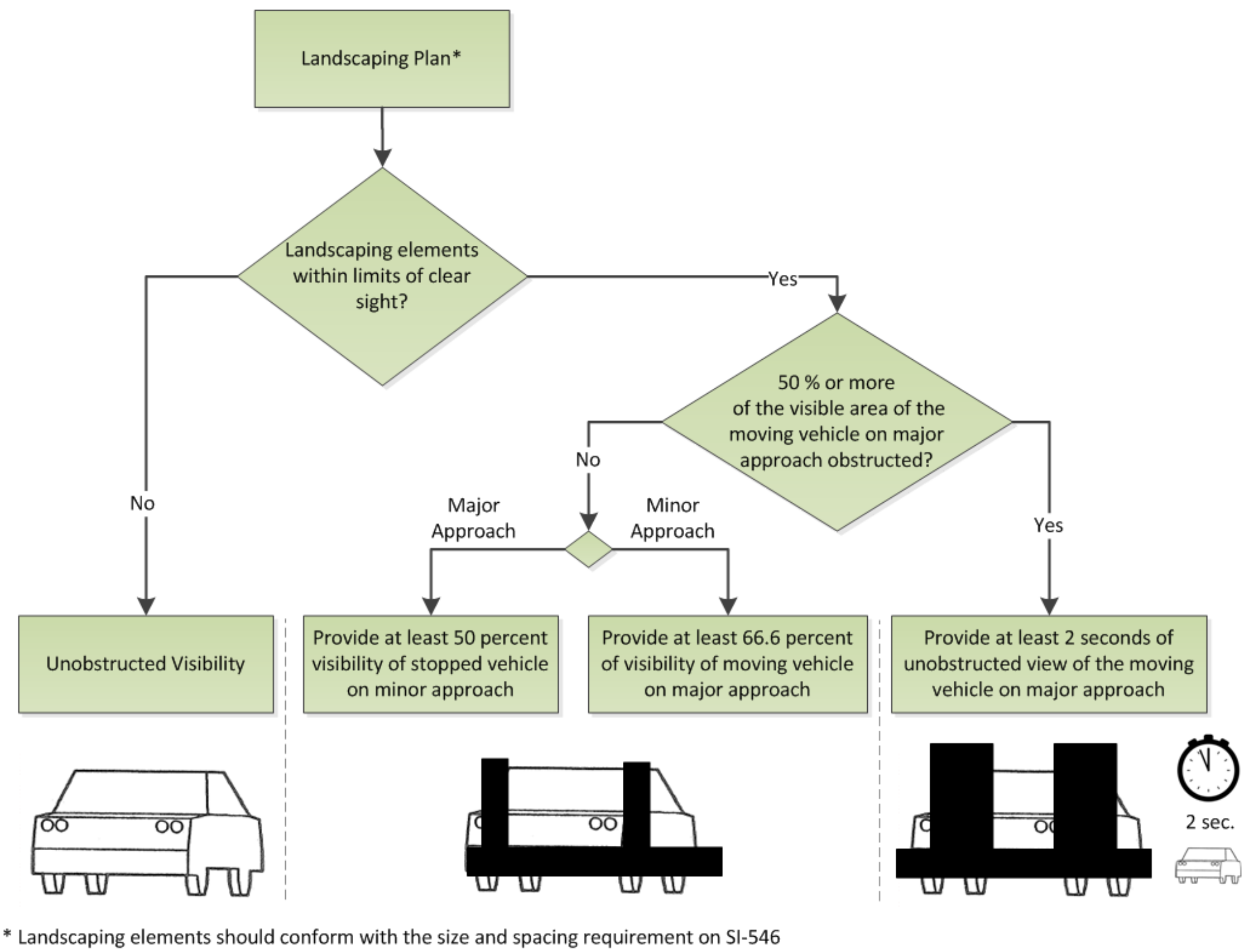


Figure 3-4. Visibility Criteria for Landscaping on Highway Medians at Intersections

Recent Revisions to SI-546

FDOT revised its policy on median landscaping at intersections to be more consistent with its CSS policy. In the past, landscaping in the median areas adjacent to left-turn lanes was limited to ground cover. FDOT Roadway Design Bulletin 10-04 (February 23, 2010) allowed some flexibility regarding the installation of trees in the medians adjacent to left-turn lanes. These revisions do not change the requirements to provide intersection sight distance or to maintain a clear sight window. This design bulletin revises the requirements for median landscaping at intersections as shown in SI-546 of the 2010 Design Standards. The major changes in design requirements regarding medians at intersections are presented in Table 3-1.

Table 3-1. Summary of Major Changes in SI-546

Sheet No	Median Tree Placement Criteria
Sheet 1 of 6	**General Note 5** Trees: Trees can be installed with sod, pavers, gravel, mulch, ground cover, or other Department approved material. The clear sight window must be in conformance with the "WINDOW DETAIL" modified to attain the height requirements listed in 'Ground Cover' above. 1) Size and spacing shall conform to the tabular values below. 2) Requirements for placement within an intersection median: **i.** Horizontal clearance for the mature specimen shall be maintained as specified in Index 700. Specimens whose mature trunk diameter is greater than 18 inches shall not be permitted. **ii.** Where no left turn lane is present, size and spacing shall conform to the tabular values. No trees shall be permitted within 100' of the median nose (measured from the edge of pavement). **iii**. Regardless of whether the intersection is signalized or not, when a left turn lane is adjacent to the median, the following requirements apply: • For low speed facilities (design speed less than 50 mph), size and spacing shall conform to the tabular values. No trees shall be permitted within 100' of the median nose (measured from the edge of pavement). • For high speed facilities (design speed 50 mph or greater), size and spacing shall conform to the tabular values. No trees are permitted within 200' of the median nose.
	2. Eliminate figure in lower right corner on Sheet 1of 6 titled SPECIAL AREAS LIMITED TO GROUND COVER.
	3. Append to General Note 1 the following sentence: At intersections listed in the Department's High Crash Intersection Report, designers shall give attention to keeping to a minimum, objects that distract or affect sight distance.
Sheet 2 of 6	1) PICTORIAL, CHANNELIZED DIRECTIONAL MEDIAN OPENINGS: Eliminate requirement that the median adjacent to left turn lane is an area "Limited to ground cover." Retain ground cover only limitation (shadowing) shown on other median and so designate.
Sheet 5 of 6	Eliminate requirement that the median adjacent to left turn lane is an area "Limited to ground cover."
Sheet 6 of 6	Eliminate requirement that the median adjacent to left turn lane is an area "Limited to ground cover."

The restrictions on landscaping on medians at intersections before the modification to SI-546 are presented in Figure 3-5. It can be observed that the median section limited to ground cover extends to the full length of the left-turn lane.

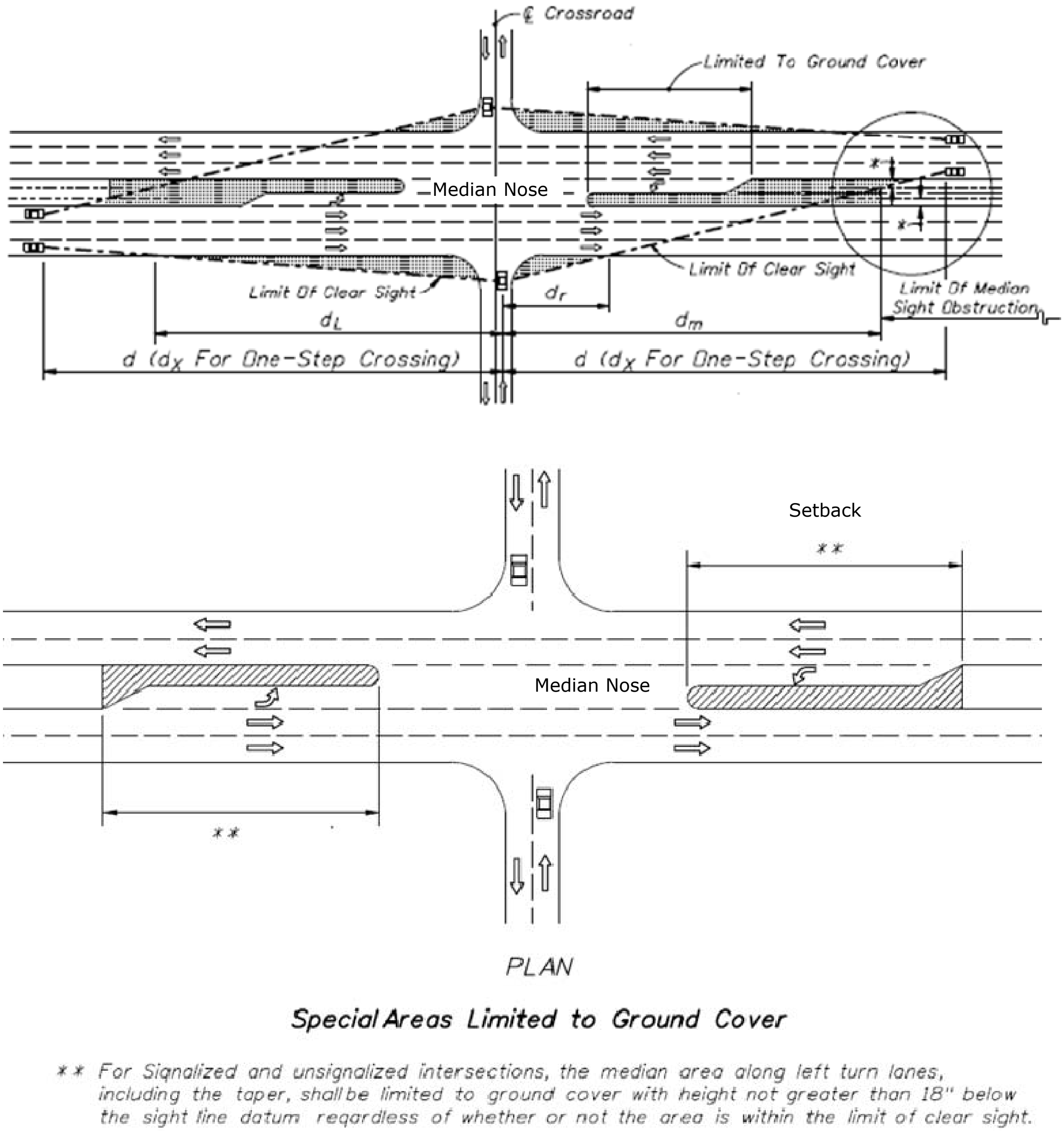


Figure 3-5. Special Areas Limited to Ground Cover before Modifications to SI-546

After the 2010 modifications of SI-546, the ground cover restrictions were relaxed to 100 ft. from the median nose for facilities with design speeds less than 50 mph and 200 ft. for facilities with speeds more than 50 mph.

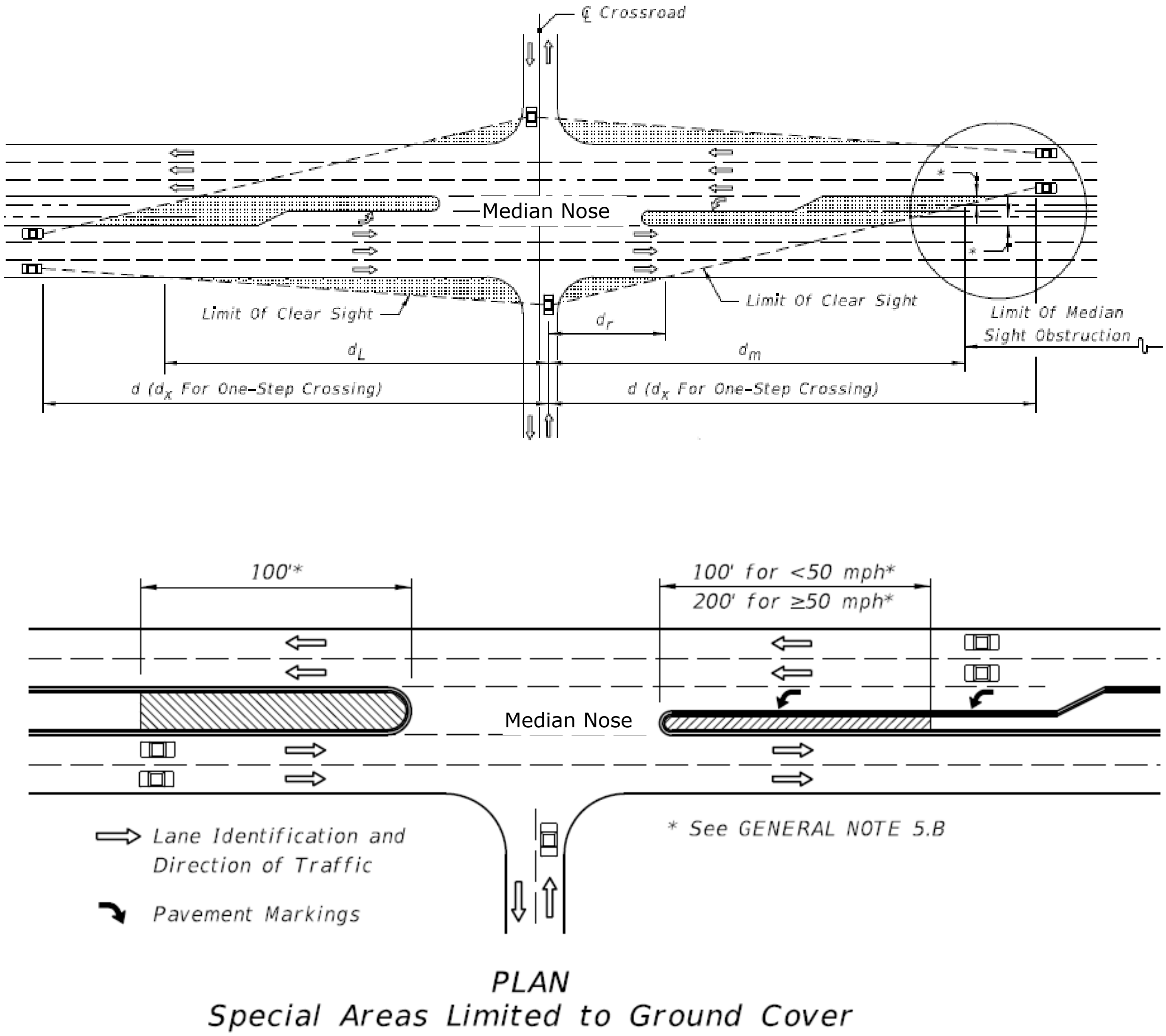


Figure 3-6. Special Areas Limited to Ground Cover after Modifications to SI-546

Revision of Current Standard

The calculations originating the tree spacing table of SI-546 were revised based on the visibility criteria in the current version of the standard. In addition, the research team conducted the validation of the calculations of sight distance in the current SI-546 and provided some recommendations for enhancement.

Chapter 4 Visibility Simulator Tool

This section introduces the computational tool developed to evaluate visibility measures of landscaping configurations at intersections.

Motivation for a Software Tool

The goal of the tree spacing table in SI-546 is to allow landscaping elements within the limits of the intersection sight window while providing adequate visibility for vehicles on the intersection approaches. Figure 4-1 shows the perception and shadow diagrams used in SI-546 to evaluate the visibility criteria for trees. The perception diagram presents the two-second unobstructed view criterion. The shadow diagram presents the visual obstruction of an 18 in. diameter tree on a passenger vehicle.

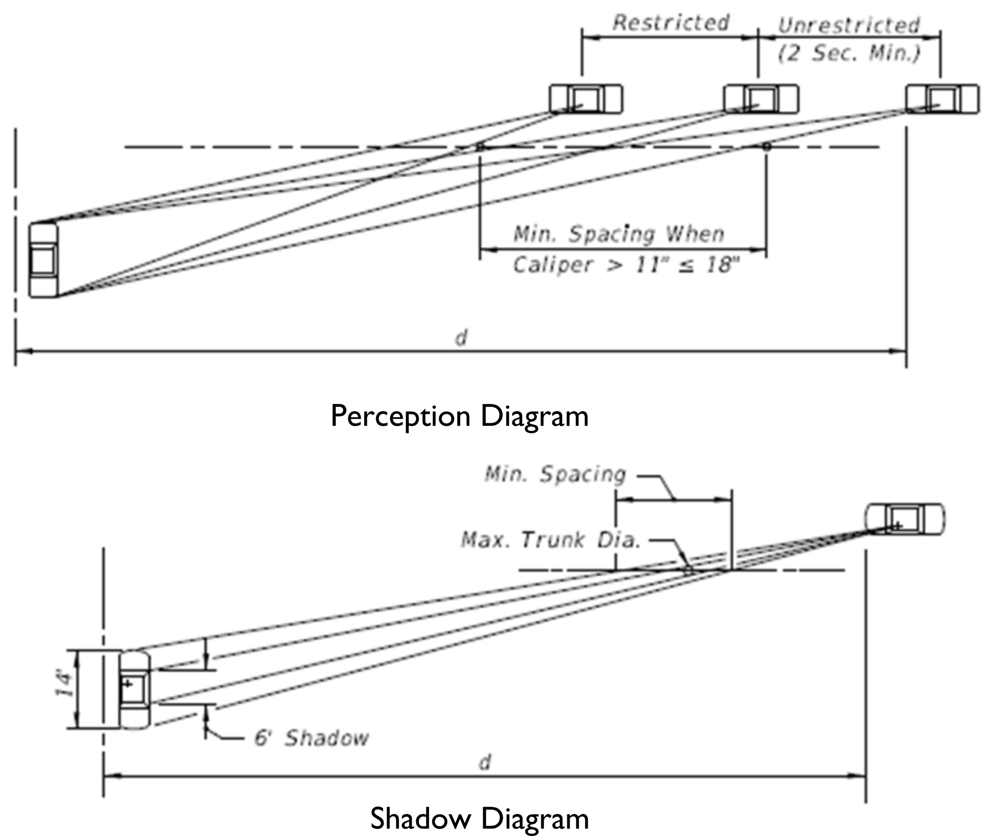


Figure 4-1. Perception Diagram and Shadow Diagram in SI-546

The visibility criteria and the perception and shadow diagrams constitute a general guidance to evaluate visibility performance of landscaping configurations. Diagrams are based on certain conditions such as the straight line trajectory of the moving vehicle, the equally-distributed visible area of the observed vehicle, etc., among others. For more complex landscaping configurations, design engineers or landscaping architects should demonstrate that the visibility criteria of SI-546 are met. This demonstration requires additional efforts in computations of the visibility performance measures. To handle more flexibility in the design of landscaping configurations, a computational tool was developed as part of this research project.

Software Tool Concepts

The base terminology used in the development of the software tool is introduced in this section.

Observer

This represents the viewpoint of the driver. The observer could be located at the minor approach on the decision point, looking at the vehicles on the major approach. In this case, the observer will be fixed and the moving vehicle will be on the major approach. The second case for the observer is from the viewpoint of the vehicle on the major approach. In this case, the observer is moving with the typical speed and trajectory for the major approach looking at a static vehicle on the side street.

Vehicle profile

Vehicle profile is represented by a line or vector. It represents the vehicle visible area density per linear unit. When observed on the side a vehicle has a visibility profile as illustrated in Figure 4-2.

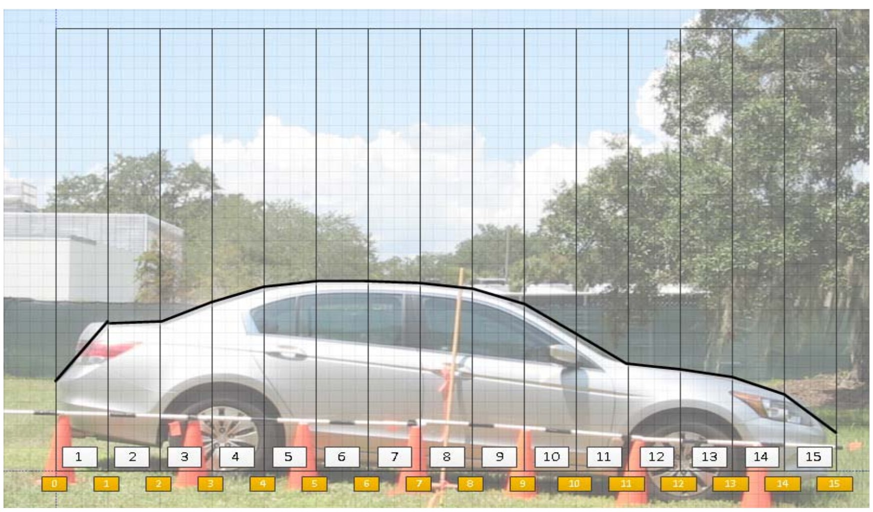


Figure 4-2. Example of Visibility Profile of a Passenger Car

With the help of the scale, the visibility profile of the vehicle is converted into an x-y plot (see Figure 4-3). This will allow calculating using the visible area per linear unit. The visibility profile has an irregular shape, and it is difficult to approximate mathematically. However, the cumulative visible area density function is a non-decreasing function of the vehicle length and can be aspirated by a high-order polynomial (see Figure 4-4). To implement the vehicle profile equation, the vehicle length was normalized so that it ranges from 0 to 1, with the normalized length the profile curve fitted (see Figure 4-5).

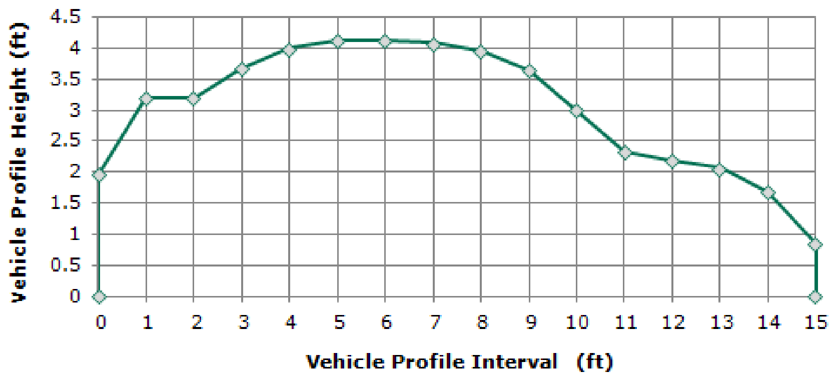


Figure 4-3. x-y Plot of Visibility Profile of a Passenger Car

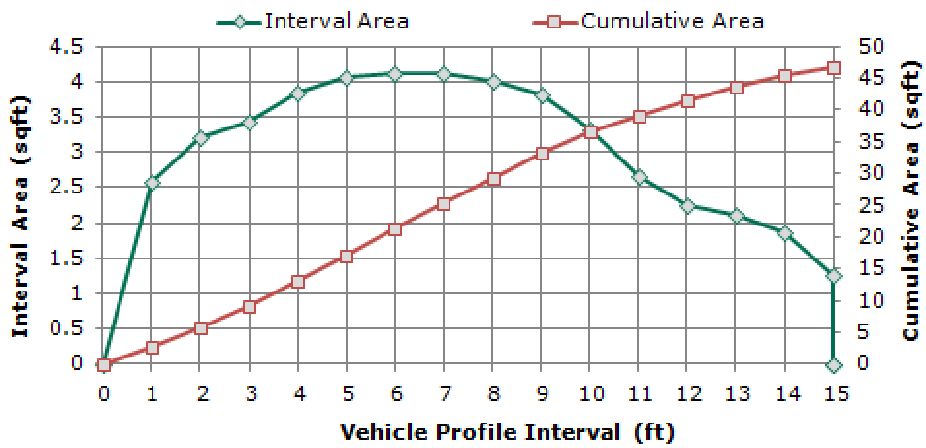


Figure 4-4. Visible Area per Linear Unit (area)

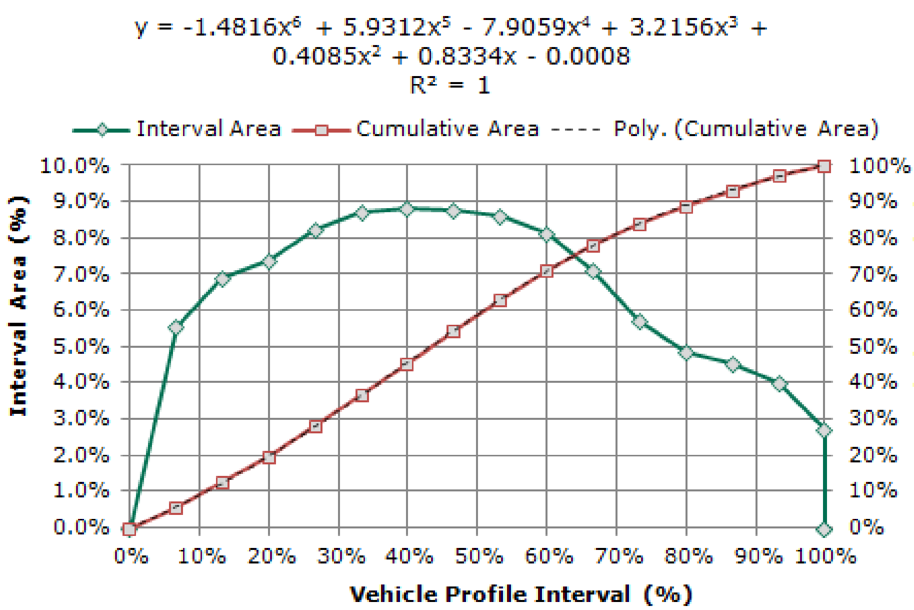


Figure 4-5. Visible Area per Linear Unit (percentage)

In Figure 4-6, the front 20 percent of a vehicle is blocked, so the blocked area will be 1-P (0.8), which is 1 - 0.89063 = 0.11. This means that 11 percent of the vehicle is blocked. This can be compared to a middle 20 percent of blockage, which could be from 40 to 60 percent marks on the vehicle profile line in Figure 4-6. This gives P(0.6) - P(0.4) or 0.71 - 0.455 = 0.25. This result follows from the differences in visible area along the vehicle length (visible area linear density).

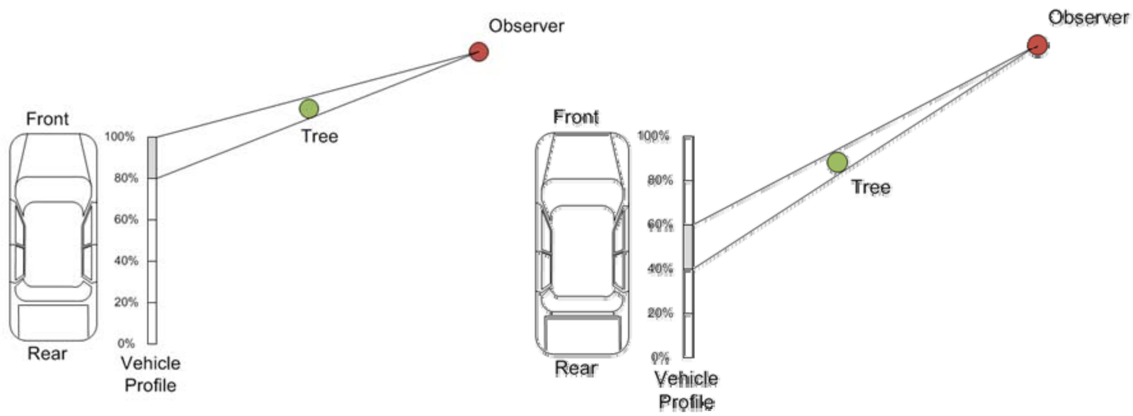


Figure 4-6. Vehicle Visibility Examples

Trajectory

The trajectory is represented by a MS Visio line object. It could be a straight line, poly line, or any curve. The underlying program segmentizes the trajectory to the desired resolution and speed. The position of the moving vehicle (observer or vehicle profile) is iterated over the segmented trajectory based on the desired resolution and speed. A resolution value could be 1/10 of a second. This value will generate a finer trajectory segmentation (more trajectory points) than 1/2 of a second.

Moving vehicle

In this case, only one vehicle is moving at a time (e.g., major approach has the right-of-way with stop control on the side approach). The type of moving vehicle could be the observer or the vehicle profile. If the observer is moving, the results will reflect the point of view of the vehicle on the major approach looking at the stopped vehicle on the side street. If the moving vehicle is the vehicle profile, then the analysis is from the perspective of the side street vehicle looking at the moving vehicle on the major approach.

Tree

A tree is represented by a circle. Since the drawing is made to scale, the tree diameter and spacing can be measured or input directly into the simulator screen as a regular MS Visio object.

Threshold distance

Threshold distance is a feature added to the simulator to setup an initial distance from the beginning of the vehicle trajectory for performance measure data collection. It generally can be set at the beginning of the vehicle stopping sight distance (SSD). For instance, if SSD is 250 ft., the distance from the beginning of the vehicle trajectory to the intersection is 510 ft. The threshold distance can be set at 510 – 250 = 260 ft. to collect performance measures.

Resolution

The resolution is related to the number of points of the discretization of the vehicle trajectory. This represents how often the visibility is evaluated. A coarse trajectory of one second will give a few points where visibility is evaluated, and some critical points may be missed. For instance, if the reaction time is assumed to be 2.5 seconds, then the resolution should be set so that this quantity can be achieved. The recommended (default value) for resolution is 1/10 of a second.

Performance Measures and Output Files

The on-screen performance measures are listed in Table 4-1. In addition to these measures, the tool saves the simulation results in a comma-separated file (*.csv). The simulation results contain a log of the run with simulation time, distance from the beginning of the trajectory, and visibility. All of the on-screen results can be derived from the simulation output file.

Table 4-1. Simulation Performance Measures

Performance Measure	Description
Average Visibility	Average visible or unobstructed area of a vehicle
Total Time of Unobstructed Visibility	Sum of time intervals when observed vehicle (vehicle profile) has 100% visibility
Maximum Time of Unobstructed Visibility	Maximum length of a time interval in which observed vehicle was viewed without obstruction

The same performance measures are collected at an intermediate point of the vehicle trajectory and the end of the simulation for the whole trajectory of the moving vehicle. The intermediate point where statistics are collected is referred to as the threshold distance. This can represent a point of interest such as the beginning of the stopping sight distance or the beginning of the breaking distance. Custom performance measures can be derived from the simulation output file. The simulation output file is saved in the same directory as the simulator.

Applications of the Simulator

The simulation was applied to a design on a 40 mph road following SI-546 for tree diameters and spacing from the point of view of the moving vehicle. The base scenario was a configuration of 18 in. diameter trees separated by 126 ft. The median width for the example was 22 ft. wide. The limits of the clear sight window according to SI-546 are presented in Figure 4-7. The sight distance, d, in Figure 4-7 is 520 ft. The minimum stopping sight distance for 40 mph (AASHTO 2004) is 267 ft. Therefore, the trajectory could be set to 520 ft., and the threshold distance could be set to 520 – 267 = 253 ft. from the intersection. The base scenario configuration is presented in Figure 4-8.

MEDIAN 22' OR LESS				
Design Speed	d	d_L	d_r	d_m
30	390	280	90	320
35	460	330	100	380
40	520	370	110	430
45	590	420	130	480
50	650	460	140	530
55	720	510	160	590
60	780	550	170	640
65	850	600	190	700

Figure 4-7. Parameters for Application Example

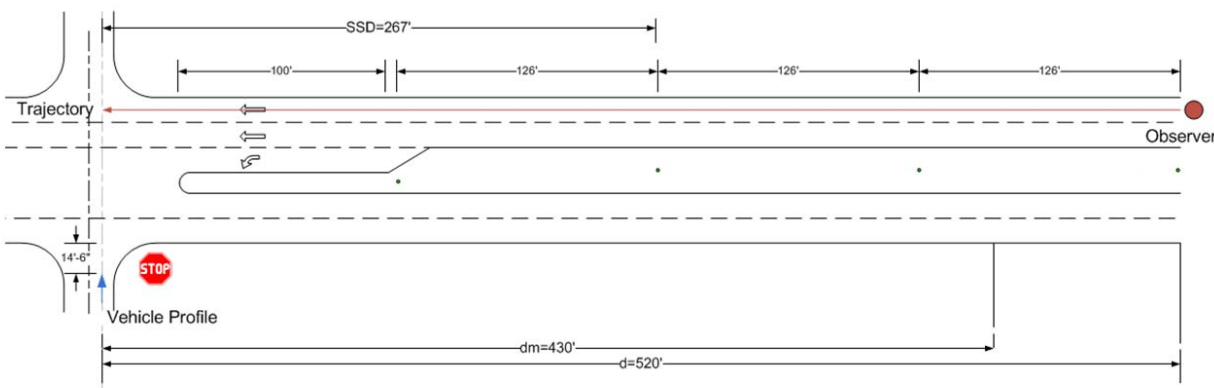
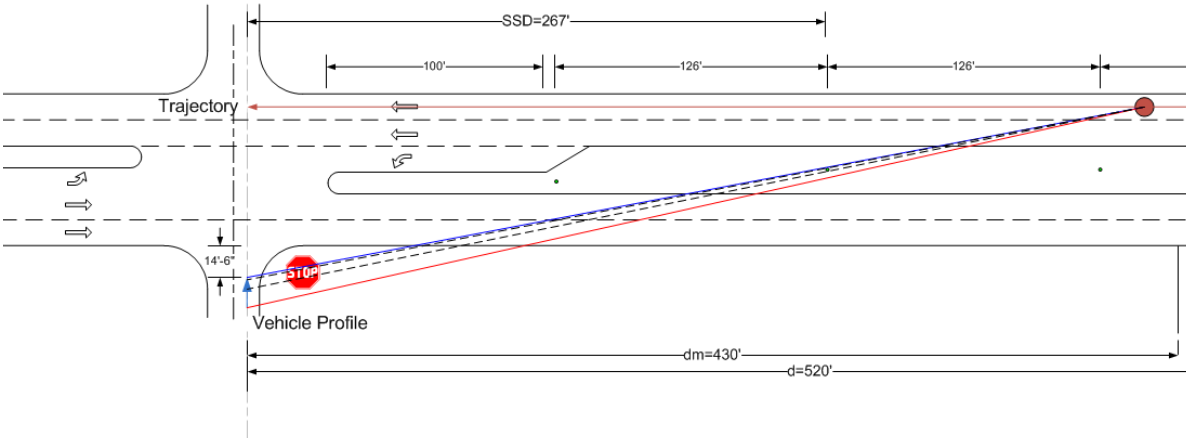


Figure 4-8. Base Scenario in Visibility Simulator

Tree spacing on the median

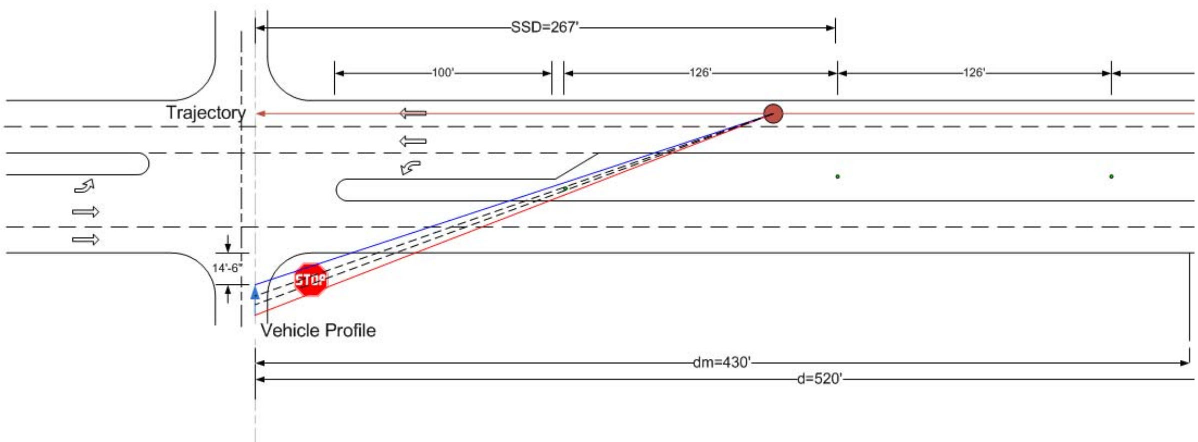
The first application of the simulator consists on evaluating tree configurations on the median. Figure 4-9 presents a screenshot of the simulation run at t=1.7 seconds. At that point in time, the trajectory distance was 99.73 ft. The on-screen performance measures showed a maximum unobstructed visibility time of 1.5 seconds. Since the moving vehicle (observer) has not reached the threshold distance, both performance measures—total and before-threshold distance—present the same numerical values. A screenshot of the simulator at time t=4.8 seconds is presented in Figure 4-10. Since the moving vehicle passed the threshold distance, the corresponding performance measures are fixed and overall performance measures are kept updated.



Time	Distance	Visibility
1.7	99.73	86.5%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	98.93%	1.5	1.5
Before Threshold Distance	98.93%	1.5	1.5

Figure 4-9. Screenshot of Simulator Run at t=1.7 s



Time	Distance	Visibility
4.8	281.6	64.94%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	94.66%	3.6	2.1
Before Threshold Distance	95.81%	3.5	2

Figure 4-10. Screenshot of Simulator Run at t=4.8 s

The results of the simulation are presented in Figure 4-11. The average visibility was 96.51 percent. The total time of unobstructed visibility was 7.8 seconds, and the maximum interval time with unobstructed visibility was 3.7 seconds. In addition, the baseline tree configuration provides two seconds of sustained unobstructed visibility before the stopping sight distance (threshold distance).

Time	Distance	Visibility
8.7	510.4	100%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	96.51%	7.3	3.7
Before Threshold Distance	95.81%	3.5	2

Figure 4-11. Simulation Results for Baseline Scenario (major street view point)

The visibility profile of the simulation run is presented in Figure 4-12. It can be observed that the two-second unobstructed visibility window is achieved in conformance with the tree spacing specifications established in SI-546.

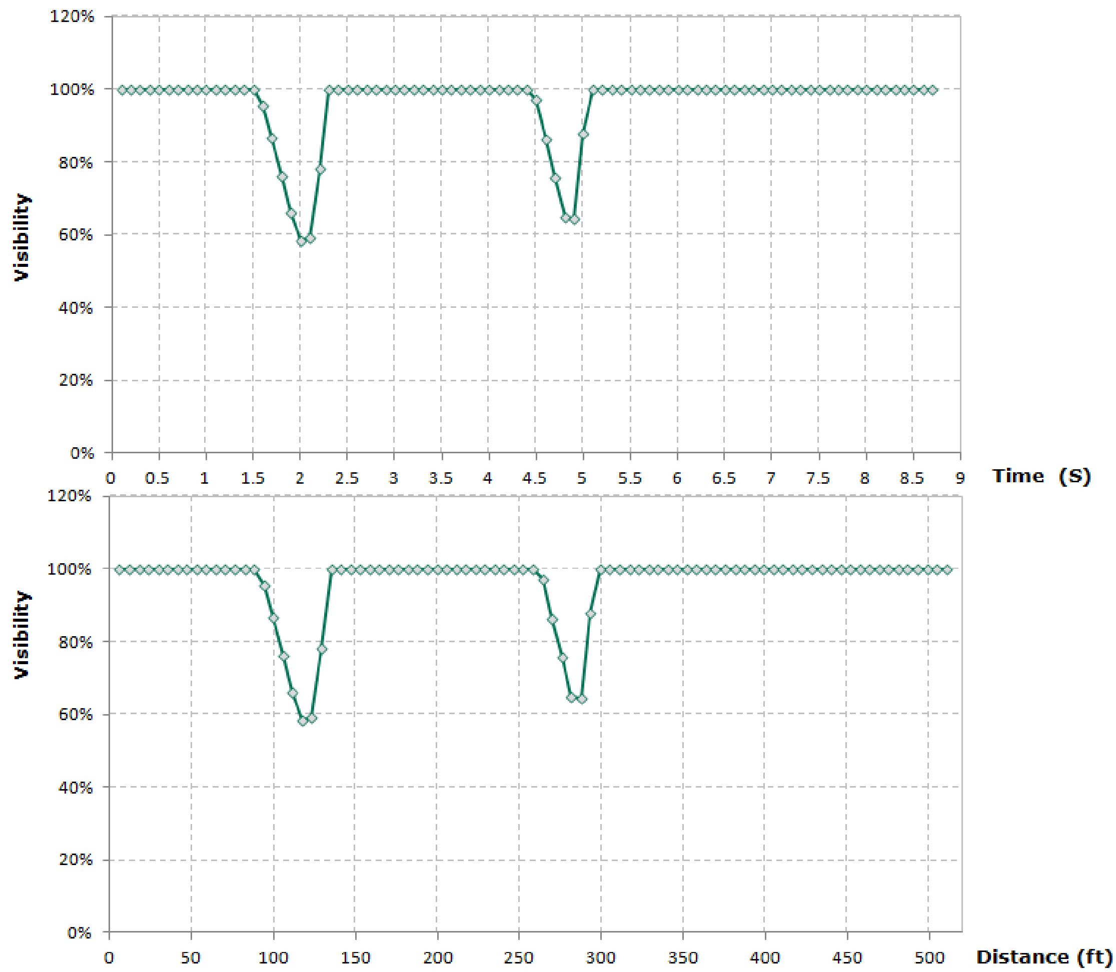
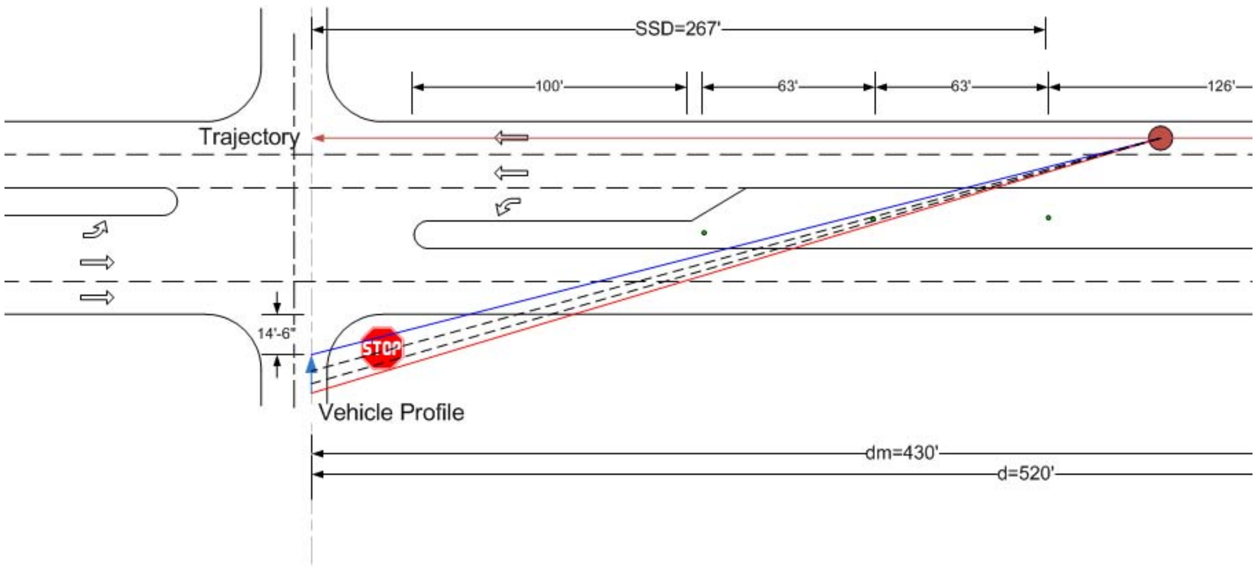


Figure 4-12. Visibility Profile for Baseline Scenario

A SI-546 noncompliant or substandard landscaping configuration was tested using the simulator. A new tree was placed between the first and second median trees (from the median nose) in the previous configuration, as illustrated in Figure 4-13.



Time	Distance	Visibility
3.6	211.2	57.96%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	92.16%	2.4	1.5
Before Threshold Distance	92.16%	2.4	1.5

Figure 4-13. Substandard Tree Configuration Evaluation

The results of the simulation run with the substandard configuration are presented in Figure 4-14. The total unobstructed visibility time was reduced from 7.3 to 6.7 seconds. The maximum unobstructed visibility before the stopping sight distance (SSD) was reduced from 2 seconds to 1.5 seconds. This constitutes a 25 percent reduction in the unobstructed visibility time before SSD. This highlights the importance of different performance measures for evaluating landscaping visibility.

Time	Distance	Visibility
8.7	510.4	100%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	94.84%	6.7	3.7
Before Threshold Distance	92.43%	2.9	1.5

Figure 4-14. Results of Substandard Landscaping Configuration

The visibility profiles for the substandard landscaping example are presented in Figure 4-15. It can be observed that the effect of the additional tree causes an additional drop in the visibility line or profile.

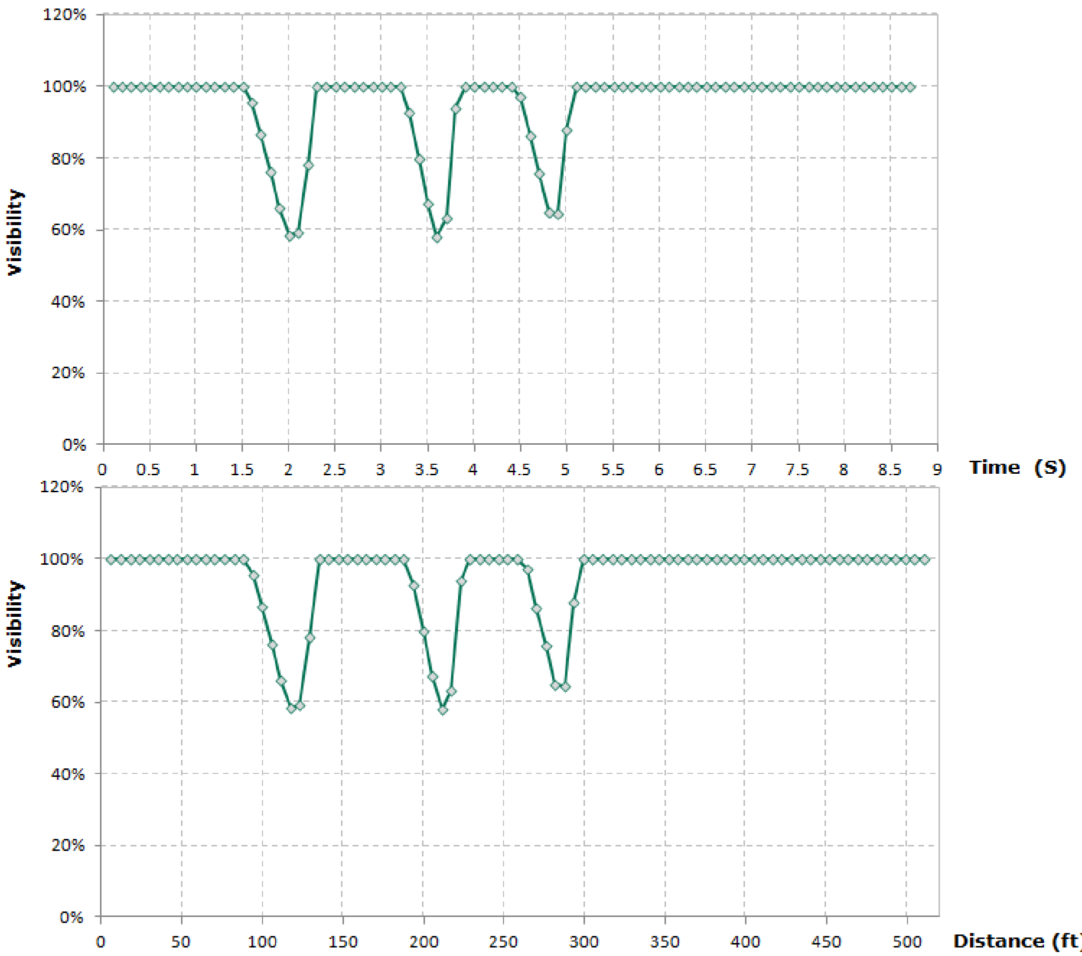


Figure 4-15. Visibility Profile of Substandard Landscaping Configuration Example

The previous examples are based on the point of view of the vehicle on the major road looking at the stopped vehicle on the side street. To change the viewpoint of the analysis, the observer is placed on the side street. The observer is now fixed, and the vehicle profile will act as the moving vehicle (see Figure 4-16).

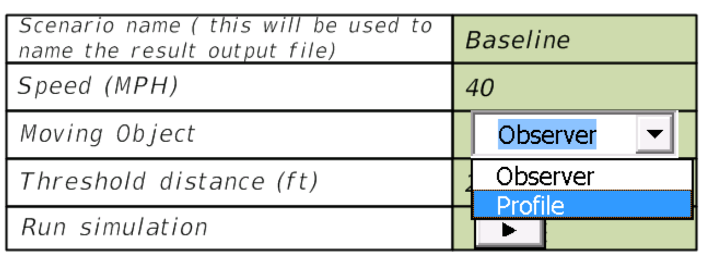


Figure 4-16. Moving Object Setup in the Simulator

The new setting where the observer is placed at the stop line on the side street and the vehicle profile is moving along the trajectory on the major road is presented in Figure 4-17.

A screenshot of the simulation running at 4.4 seconds is presented in Figure 4-18. It can be observed that the instantaneous blockage is 32 percent. This is a more severe blockage when compared to the analysis from the view point of the vehicle on the major approach.

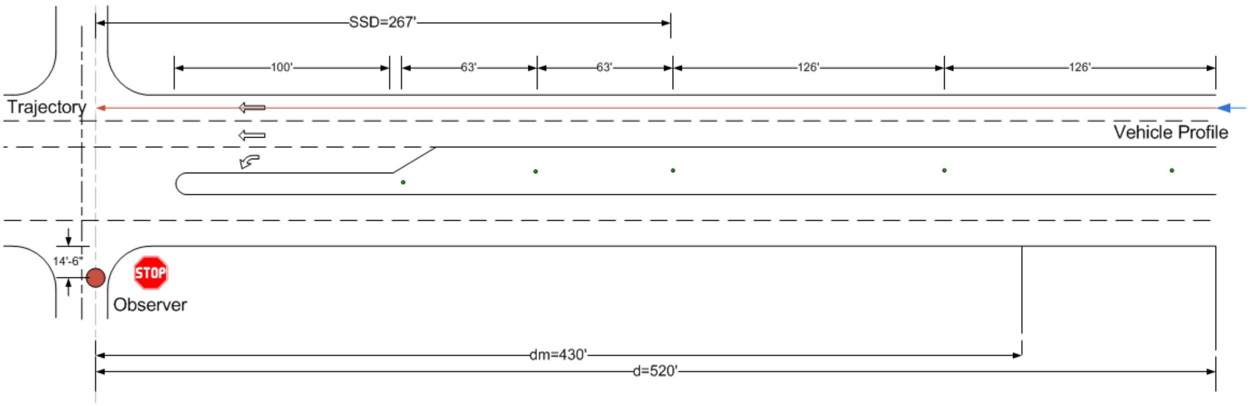


Figure 4-17. Simulator Setting for Side Street View Point Analysis

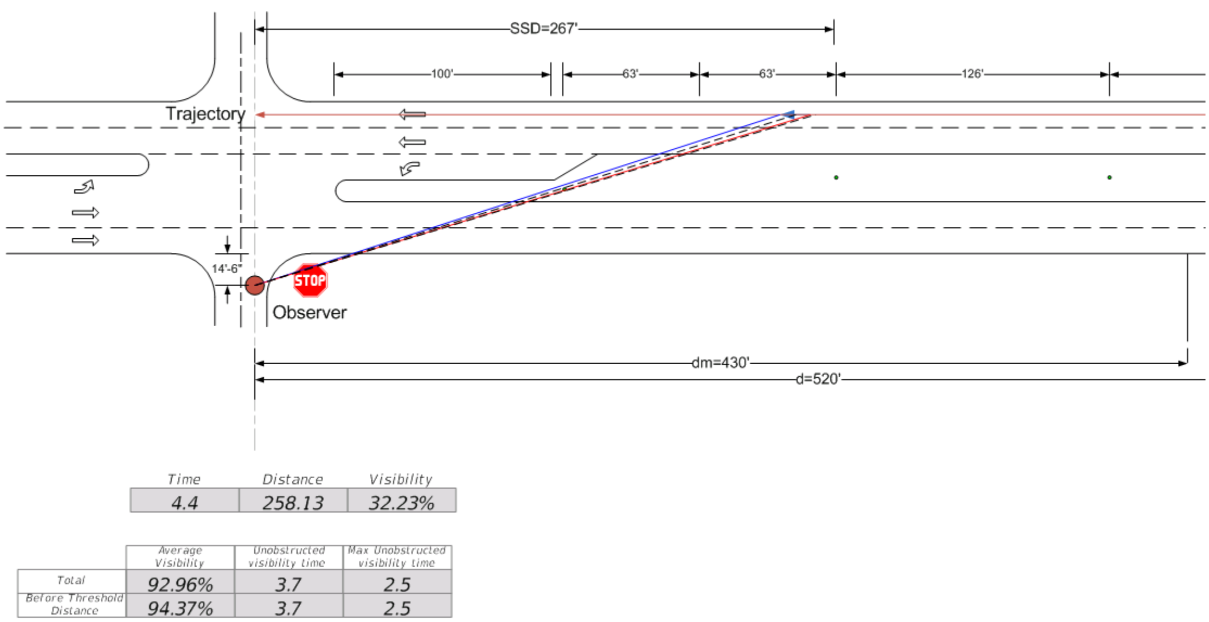


Figure 4-18. Screenshot of Simulation at Time t=4.4 s (side street view point)

The results of the simulation run for the baseline scenario from the viewpoint of the side street are presented in Figure 4-19. The visibility profiles for the same scenario are presented in Figure 4-20. It can be observed that the overall visibility is slightly better than in the case of the major approach view point. However, the drops in the visibility profile are more severe in the case of the side street view point. This is due to the proximity of the occluding object to the observer.

Time	Distance	Visibility
8.7	510.4	100%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	95.75%	7.8	4.1
Before Threshold Distance	94.37%	3.7	2.5

Figure 4-19. Simulation Results for Baseline Scenario (side street view point)

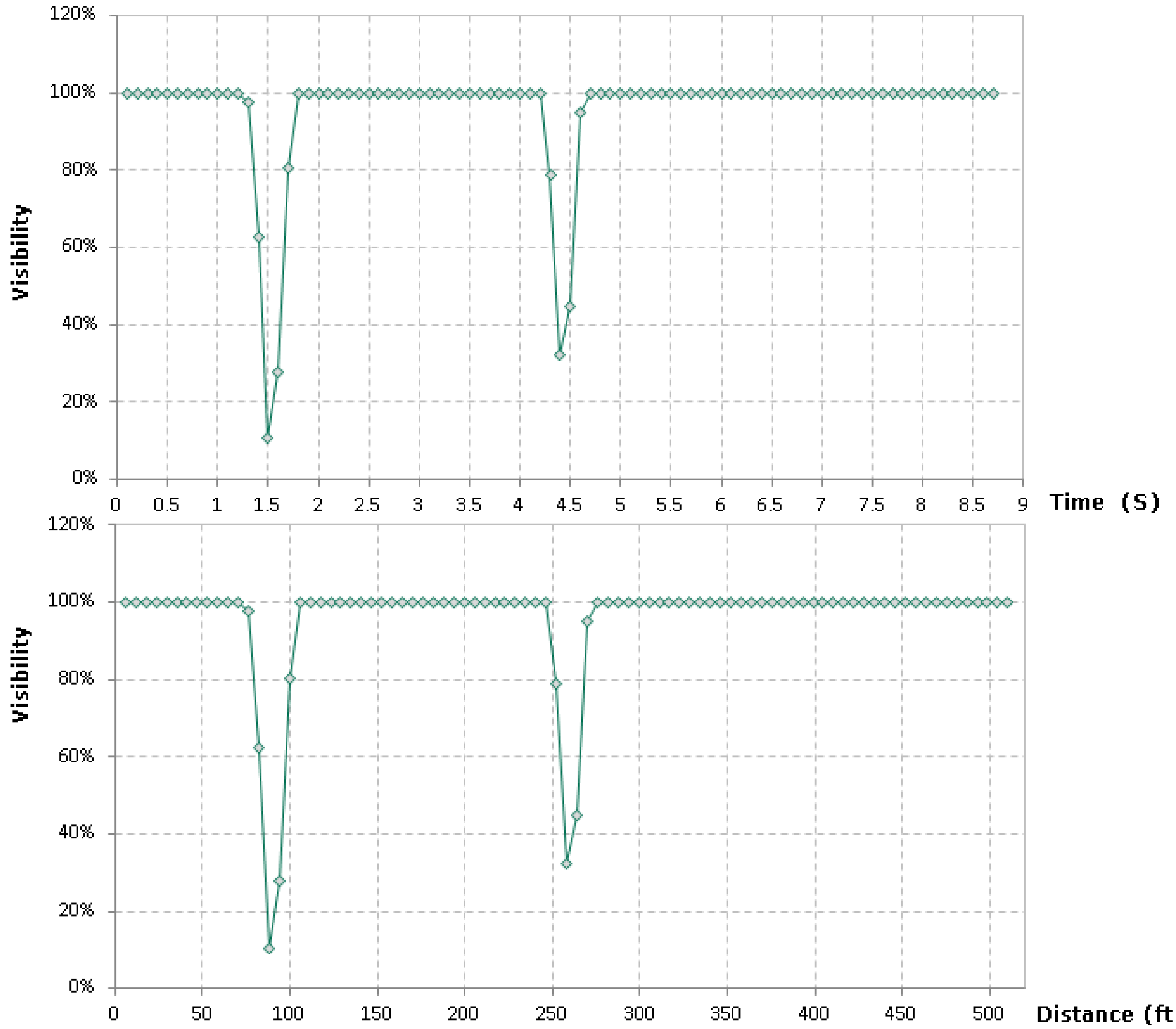


Figure 4-20. Visibility Profile for Baseline Scenario (side street view point)

The simulation results and the visibility profile for the substandard landscaping configuration example are presented in Figure 4-21 and Figure 4-22, respectively. It can be observed that the reduction in the continuous visibility time before SSD went from 2.5 to 1.2 seconds, constituting a 52 percent reduction in the unobstructed visibility.

Time	Distance	Visibility
8.7	510.4	100%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	93.75%	7.3	4.1
Before Threshold Distance	90.34%	3.2	1.2

Figure 4-21. Simulation Results for Substandard Landscaping Configuration (side street view point)

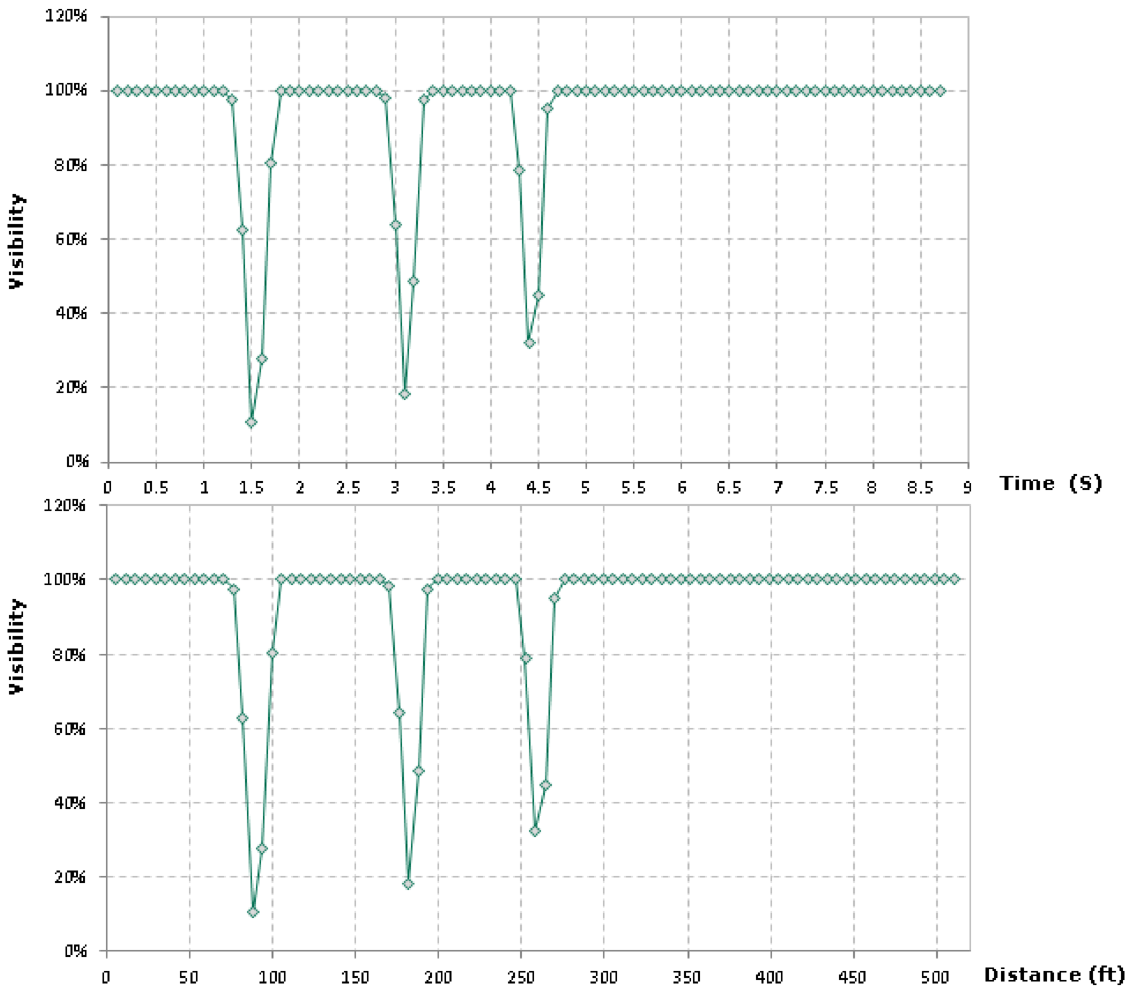


Figure 4-22. Visibility Profile for the Substandard Landscaping (side street view point)

Roadside objects

One of the advantages of the simulation tool is that it can be easily adapted to accommodate a variety of situations—for example, a roadside object such as a trash can that can cause significant blockage. Figure 4-23 presents the example of a roadside object with an 18 in. diameter located 100 ft. from the intersection and 6 ft. from the edge of the travel lane. The visibility profile for the example is presented in Figure 4-24.

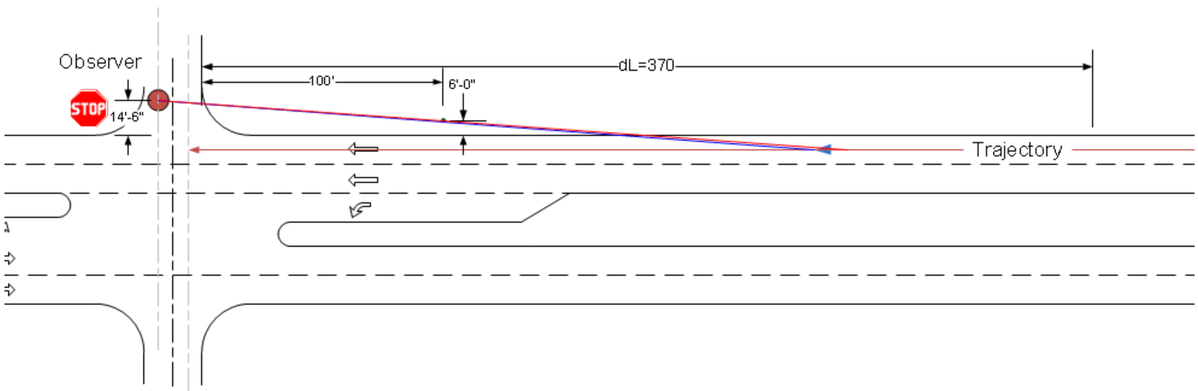


Figure 4-23. Example of Visibility Obstructions Due to Roadside Objects

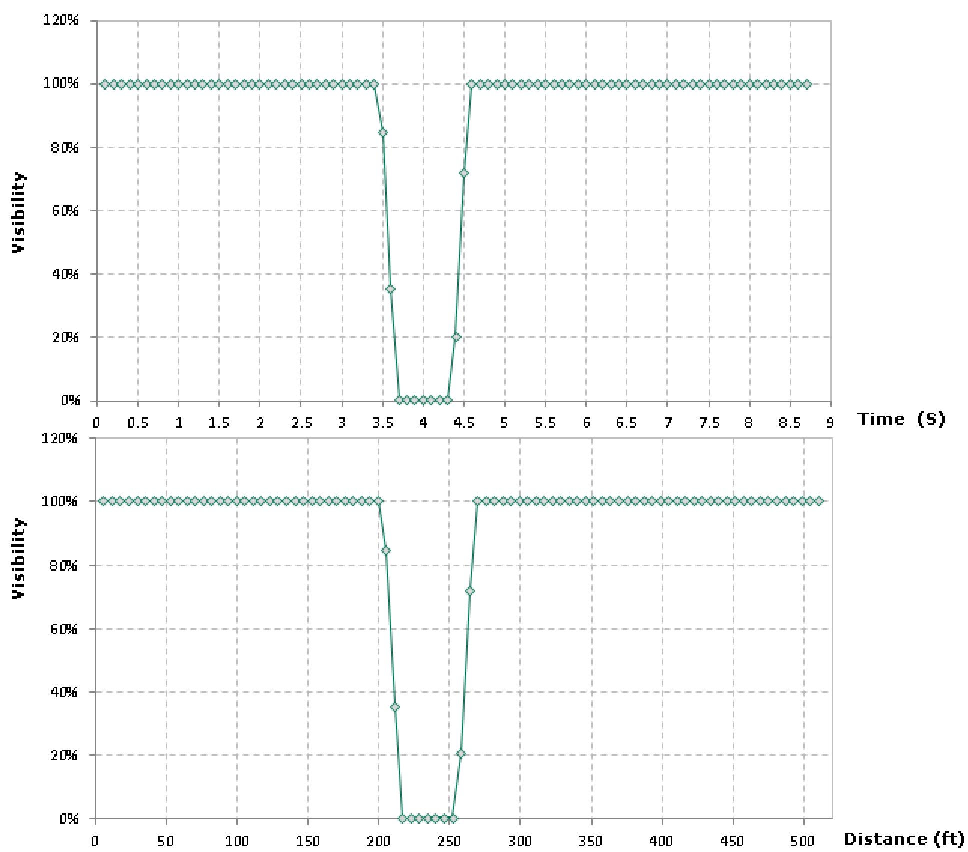


Figure 4-24. Visibility Profile Due to Roadside Objects

It can be observed that the visibility drops to zero for a sustained period of time. This is due to the proximity between the observer and the occluding object. Figure 4-25 shows the simulation results for the roadside object example. The average visibility is lower than in the cases of median trees. However, visibility requirements such as the two-second unobstructed views are met.

Time	Distance	Visibility
8.7	510.4	100%

	Average Visibility	Unobstructed visibility time	Max Unobstructed visibility time
Total	89.83%	7.6	4.2
Before Threshold Distance	81.92%	3.4	3.4

Figure 4-25. Simulation Results for Roadside Object Blockage Example

Speed and visibility

The simulation tool was used to measure the total time of unobstructed visibility for different speed values; the results are presented in Figure 4-26 (major approach viewpoint). It can be observed that the total visibility time before SSD is reduced on average 0.38 seconds per unit of increase in speed. Figure 4-27 presents the comparison of the maximum unobstructed view time before threshold distance from the major and side street viewpoints.

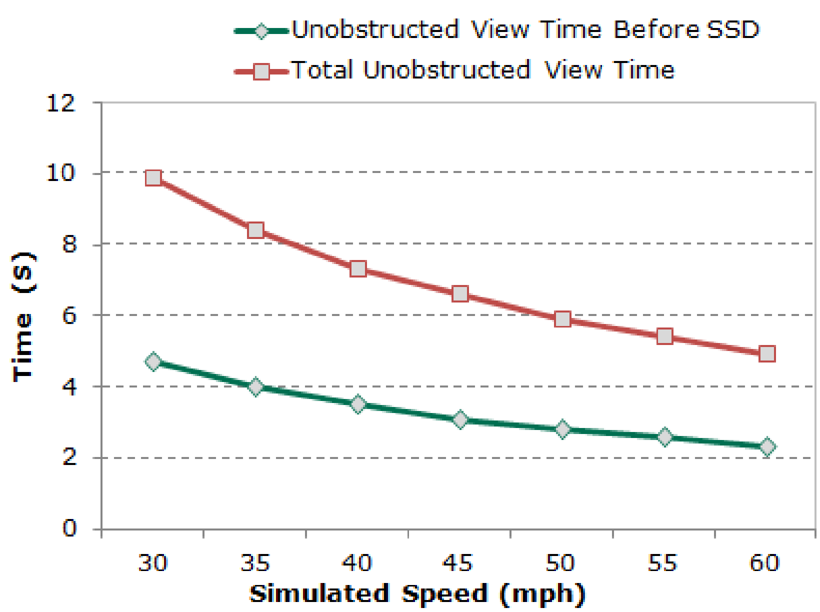


Figure 4-26. Total Unobstructed View Time vs. Simulated Speed

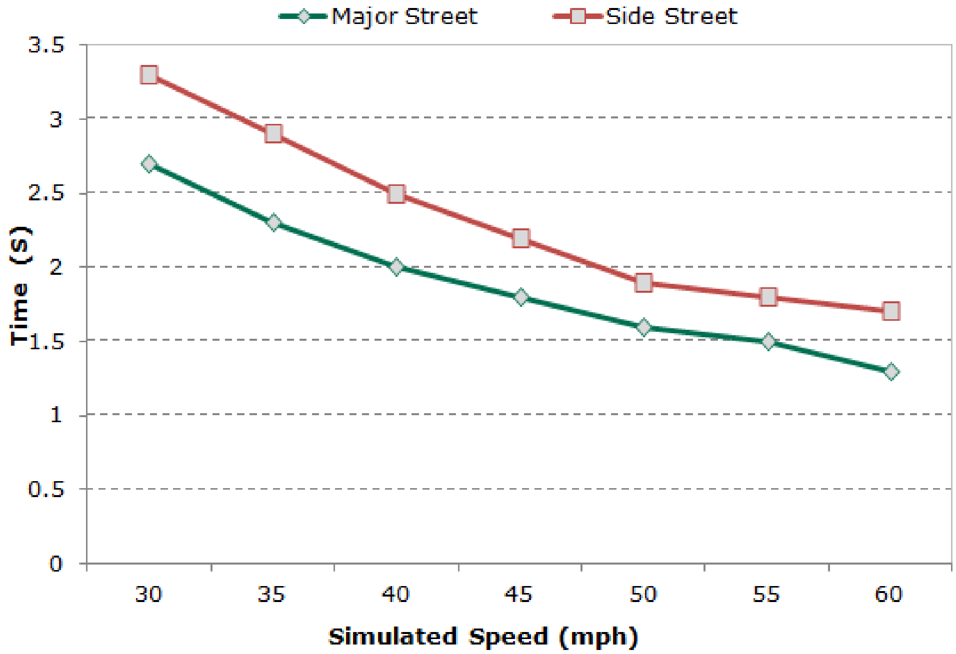


Figure 4-27. Comparison Maximum Unobstructed View Time before Threshold Distance with Respect to View Point

Chapter 5 Methodology and Data Collection

To support the evaluation of the safety aspects of landscaping of highway medians at intersections on divided highways through analyzing crash information and landscaping field data, this chapter presents three methodologies and associated data collections.

The first methodology presented is to identify crashes involving median fixed objects near intersections, synthesize the locations of crashes relative to the median noses, and provide the quantitative safety assessment of median tree setback settings on divided highways in SI-546 on both two-way stop-controlled and signalized intersections. The procedure for the collection of crash data involving median fixed objects is provided in this chapter. The results of the analysis can help in establishing setbacks for median trees as mitigation for fixed median object crashes (e.g., direct impact to a median object such as a tree). This analysis was processed based on the posted speed limit of the facility and its traffic control type. The methodology intended to produce the following outcome:

- Suggested setback based on the posted speed limit of the facility
- Suggested setback based on traffic control type

To evaluate whether compliance of landscaping of highway medians at intersections with SI-546 has a significant effect on crash rates, the second methodology focuses on collecting and analyzing median landscaping-related data at selected intersections and associated crash data. The study intersections were divided into three groups: (1) those with median trees near the intersections, compliant with SI-546; (2) those without median trees near the intersections; and (3) those with median trees near the intersections noncompliant with SI-546. The methodology intends to assess the effectiveness of the compliance of landscaping of highway medians at intersections with current SI-546 criteria on roadway safety.

The third methodology details the development of the landscaping-based crash predictive models. These models can be used as an effective tool to evaluate the relationship between crashes and highway median landscaping.

Assessment of Median Tree Setback Setting via Median Fixed-Object Crash Analysis

Based on the existing data, crashes directly with median trees in the proximity of the intersection and under conditions where sight distances were clearly cited as a contributing factor in the crash report were scarce for the study period. Fixed median objects were used in the CARS for crashes impacting fixed median objects, including trees; therefore, fixed median object was used as a surrogate for trees to increase the sample size. The underlying assumption is that the procedure estimates the distribution of the distance from median nose of all crashes impacting fixed median objects with trees being a subgroup of such objects.

The CARS contains general crash information related to the crash, the vehicle, and person levels and constitutes a valuable source of crash data for research. For this part of the analysis, it was necessary to first identify reports on crashes that involved median fixed objects and then obtain the distance from the crash point to the median nose. Since that information is not collected directly in the police reports that form the basis of crash records in the CARS, other data elements were used to screen the records to identify a set of crashes involving median fixed objects. The detailed screening process is described below. The screening criteria included:

- Crashes occurring on multi-lane roadways with a divided median
- Primary or secondary crashes involving trees or other fixed objects
- Crash location at or close to the median
- Crashes involving and/or including automobiles, vans, pick-up trucks and SUVs

A database from the CARS was extracted to an SQL server database to perform advanced data querying operations. First, crashes along divided highways were extracted as the superset for the rest of the analysis. From the initial dataset, a refinement procedure was applied to select crashes in which a vehicle hit a median object as either a primary or secondary event. The crashes were further refined using criteria to increase the chance of locating median objects involved in the crash based on the crash narrative. A random sample of 300 crash reports was selected for analysis. From the sample, a combination of GIS maps was created. The objective of the GIS mix was to obtain aerial views and roadside pictures of the most likely location of the object impacted during the crash. For each crash, the center of the intersection, the median nose, and the median object position were located on a map. With additional GIS processing and the help of the crash report narrative, the distance to the median nose was extracted for the sample intersections. This process followed the procedure outlined in the diagram shown in Figure 5-1. At the end of the procedure, the traffic control type (e.g., signalized vs. stop) was incorporated into the dataset for analysis.

Evaluation of Landscaping Types of Highway Medians at Intersections on Safety

To capture contextual data and the complexity of landscaping elements along highway medians at intersections, it was essential to perform a careful site selection procedure. In this research project, the final locations for the empirical study consisted of intersections with similar physical and operational conditions as shown and noted in the following three groups:

1) those with median trees near the intersection and compliant with SI-546
2) those without median trees near the intersection
3) those with median trees near the intersection and noncompliant with SI-546

The definition of "trees near the intersection" is set by clear sight distances according to AASHTO guidelines, which are based on different speed posted limits and the number of lanes on the major approach (AASHTO 2004). The selection of study sites included an assessment of physical and operational conditions with median landscaping in relation to tree size, spacing and offset, design speed, and median width. The selected sites met the following criteria:

1. Multi-lane roadways with a divided median
2. No large skew angles at selected intersections
3. 4-way intersections or T-intersections
4. Posted speed limit along major approach ranging from 30 mph to 50 mph (based on AASHTO guidelines)
5. Intersections have stop signs for minor streets and do not have traffic signals on major roadway, where traffic on minor roadway is required to stop prior to entering major roadway
6. Vehicles on minor street can turn left, turn right, or go straight through major roadway

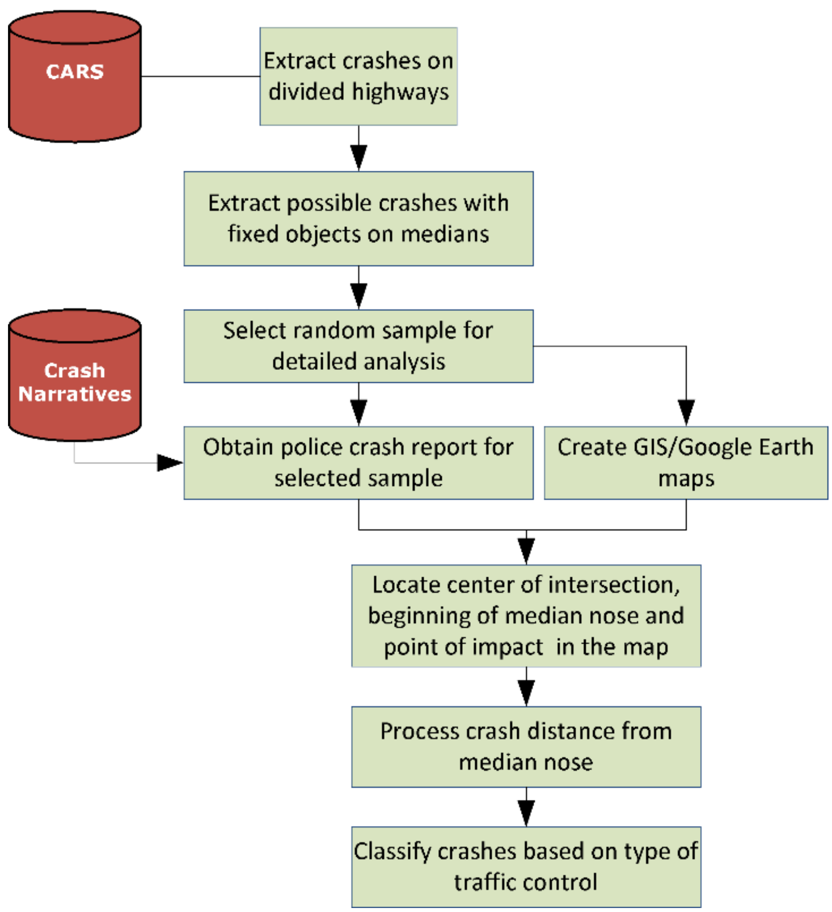


Figure 5-1. Process to Obtain Distance from Median Nose to Crash Location

Notice that #5 above restricts the study sites to two-way stop-controlled intersections. The purpose of this restriction is to study the cases where the importance of sight triangles is most relevant. Site selections were based on discussions with district landscaping architects, traffic operations engineers, and through a statewide search covering the northern, central, and southern Florida regions. Figure 5-2 presents the distribution of data collection sites in Florida.

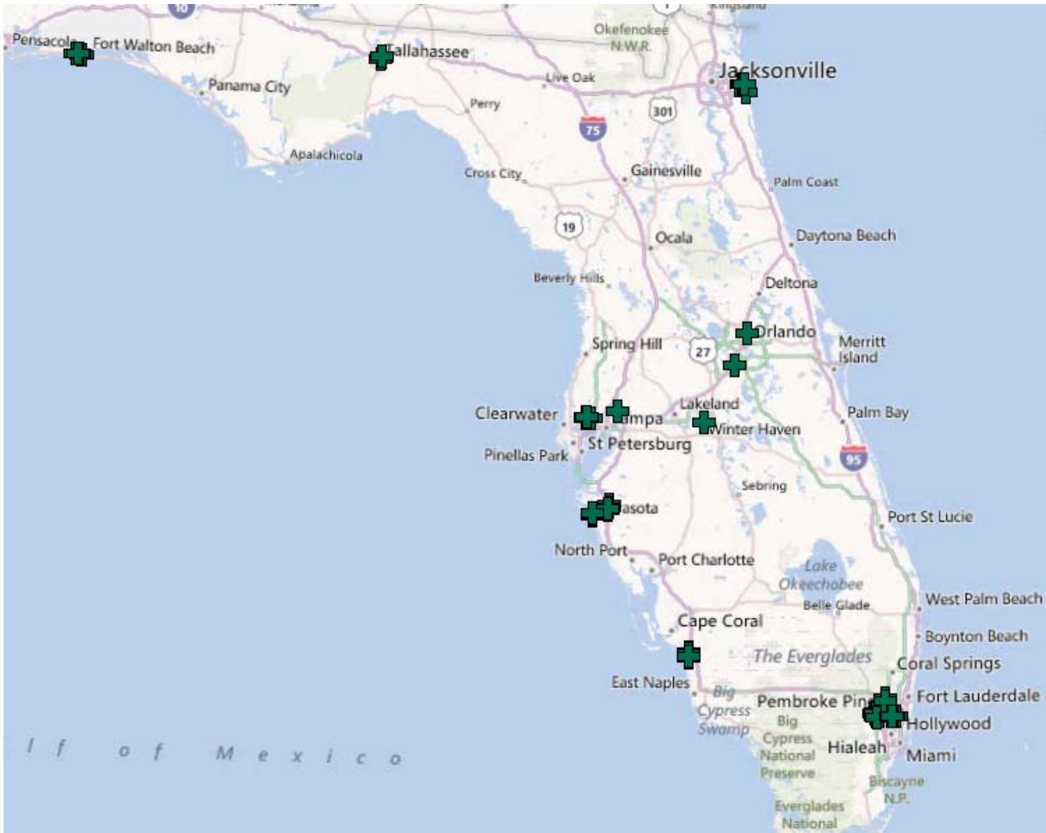


Figure 5-2. Distribution of Data Collection Sites

A field data collection process was implemented by the research team after candidate sites were identified. The relevant geometric data, such as tree diameters, multiple trunk plants (y/n), tree spacing, offsets, etc., were collected and included in the database. Next, all selected sites were organized into the three previously mentioned groups.

Considering the available project budget and the project objective to effectively evaluate and validate the current SI-546 median landscaping criteria on roadway safety, the empirical study focused on stop-controlled intersections, which are very crucial to SI-546. The analysis from evaluation of landscaping types of highway medians at unsignalized intersections on safety can also provide some insight for signalized intersections with permitted left-turns.

In this empirical study, 72 unsignalized intersections considering both 4-way and T-intersections, 3 landscaping types, and various posted speed limits across Florida were studied and analyzed, which far exceeded the originally-proposed 24 intersections in the technical proposal.

For historical safety and performance analysis, the latest two years of crash data (2009 and 2010) within 300 ft. from the centerline of those 72 intersections were collected. The Annual Average Daily Traffic (AADT) data for associated roadways were also collected for crash rate analysis.

Development of Landscaping-based Crash Predictive Model

To address the research questions in this study, landscaping-based crash predictive models were developed to inspect the contributing factors and how these factors affect the crash occurrences at these intersections. A negative binomial model was used to quantify the effects of various factors such as the following:

- Intersection Control Types (Signalized/Stop Sign/Median Opening)
- Geometric Design Features
- Traffic Data (average annual daily traffic of major/minor streets)
- Driver Characteristics (age, gender)

The link function and the linear predictor determine the functional forms of the landscaping-based crash predictive model. If the linear predictor is a linear function of the explanatory variables, the fitted landscaping-based crash predictive model takes the functional form as follows:

$$\mu_i = \exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ... + \beta_k x_{ik}) \quad i = 1, 2, 3...$$

In the preceding equation μ_i is the expected number of crashes at the site *i.* The symbols $\beta_0, \beta_1,...,\beta_k$ are coefficients and $x_{i1}, x_{i2},...,x_{ik}$ are explanatory variables. If the linear predictor is a linear function of the logarithm of the explanatory variables, the functional form is:

$$\mu_i = \beta_0 x_{i1}^{\beta_1} x_{i2}^{\beta_2} ... x_{ik}^{\beta_k}$$

The models are evaluated to the goodness-of-fit by the scaled deviance (SD) and the Pearson's χ^2 statistic. For an adequate model, the two statistics dividing the degrees of freedom (*N*-*p*) should be close to 1.0, where *N* is the number of observations and *p* is the number of variables in the model.

Chapter 6 Data Analyses and Discussion

This chapter presents the results and discussion of 1) the assessment of median tree setback setting via median fixed-object crash analysis, 2) landscaping field data and associated crash data collection, 3) an evaluation of landscaping types of highway medians at intersections on safety, and 4) landscaping-based crash predictive models based on the methodologies, crash data and landscaping data collections described in Chapter 5.

Outcome of Assessment of Median Tree Setback Setting via Median Fixed-Object Crash Analysis

Inconsistent application of tree setback requirements was a recent issue that prompted revision of SI-546. Tree setback can be verified from two points of view: median fixed-object crashes and crashes associate with median landscaping compliance with SI-546. From the median fixed-object crash point of view, crash narratives and aerial imagery were used to obtain an approximation of the crash distance with respect to the median nose. From the point of view of crashes associate with median landscaping compliance with SI-546, landscaping field data were used with crash reports to obtain evidence of the potential effect of landscaping types and compliance with SI-546 on crash frequency, which is presented in the second section of this chapter.

To cope with limited tree crash data, all crashes with fixed objects within the median were considered as the population of interest for the analysis. The first analysis was carried out using data tagged at intersections or influenced by intersections. From the CARS, a series of filtering and sorting produced a list of the most likely crash candidates to be inspected in detail. A total of 300 sample crash reports were found to contain verifiable information to determine distance from the median nose. The distribution of fixed-object crashes for facilities with speeds less than 50 mph is presented in Figure 6-1.

In Figure 6-1, it can be observed that 87 percent of all crashes with median fixed objects occur at 100 ft. or less from the median nose for facilities with speed limits less than 50 mph. The current median tree setback of 100 ft. in SI-546 provides a good protection level and does not allow tree planting in the zone where nearly 90 percent of median crashes tend to occur. It also offers sufficient median space for context-sensitive design and tree plantings. At 120 ft., 91 percent of the crashes with median object are covered. The distance values, which cover about 94 percent of all crashes with fixed objects, are between 160 ft. and 180 ft. This can be interpreted that any increase in the setback has the possibility to offer more coverage in terms of crashes with fixed median objects which include trees. Increasing the median tree setback may provide a higher level of protection or coverage for less likely crash scenarios, but it will also reduce more median space for context-sensitive design and tree plantings.

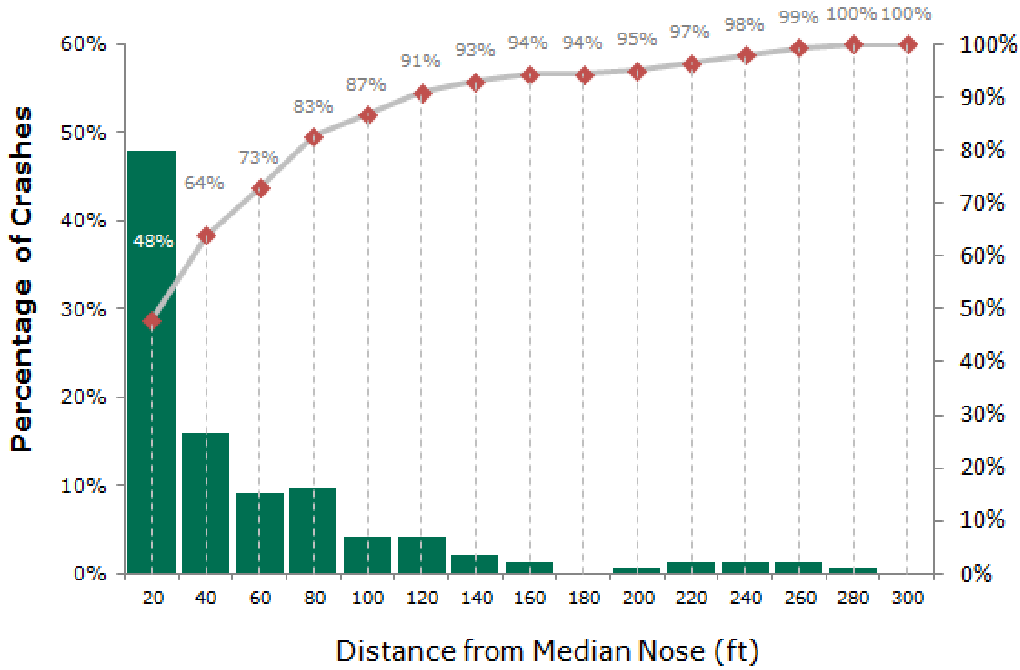


Figure 6-1. Distance from Median Nose for Sample Fixed-Objected Crashes at Intersections or Influenced by the Intersection for Speed Limit <50 mph

For high-speed facilities, the distribution of crashes with respect to the median nose is presented in Figure 6-2. The current median tree setback of 200 ft. in SI-546 for facilities with posted speed limit of 50 mph or greater can potentially avoid at least 94% of median fixed-object crashes. The current standard provides a very high level of protection and does not allow tree planting in the zone where nearly 95 percent of the median crashes tend to occur.

As shown in Figure 6-1, the reduction of median tree setback from 200 ft. to 100 ft. can still potentially avoid 94 percent of median fixed-object crashes and offers more median space for context-sensitive design and tree plantings.

It is necessary to note this analysis was based a smaller sample of size of 52 due to less available data for high-speed facilities. The data in Figure 6-2 appear to be skewed. More sample size may be needed for further analysis.

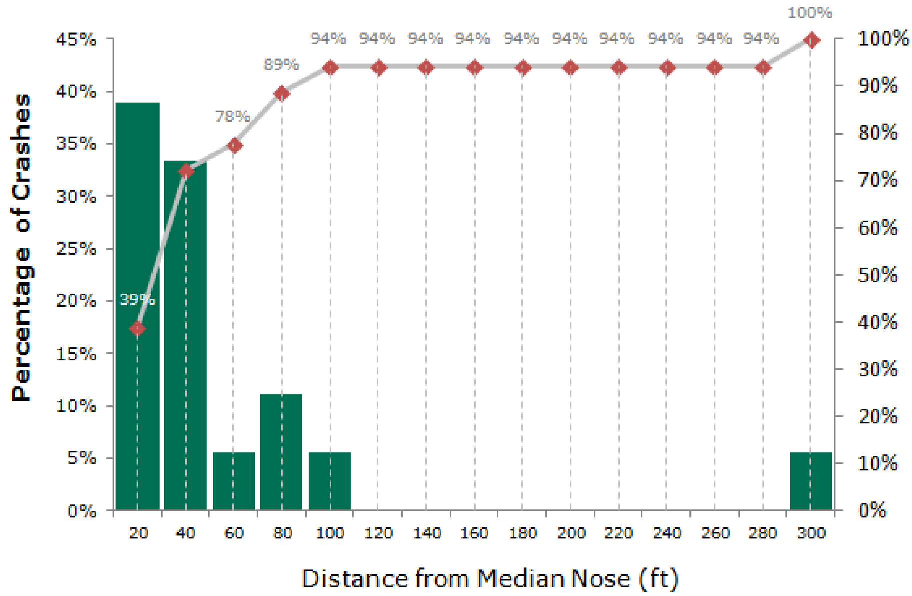


Figure 6-2. Distance from Median Nose for Sample Fixed-Object Crashes at Intersections or Influenced by the Intersection for Speed Limit ≥50 mph

Effect of Control Type on Crash Distance from Median Nose

The same crash data set was summarized by intersection traffic control types, as shown in Table 6-1. This analysis was performed to determine whether different setbacks may need to be considered for signalized or stop-controlled intersections from the point of view of crashes with median objects. The summary got the distance between crash locations and median nose by traffic control type is shown in Table 6-1.

Table 6-1. Summary for Distance between Crash Location and Median Nose by Traffic Control Type

Signalized	Sample Size	Mean Distance (ft)	Standard Deviation (ft)
N	156	74.1	83.1
Y	144	57.7	81.3

A two-sample, two-sided (equality) T-test was performed on the collected data. The p-value of the test was 0.086. For a significance level of 0.05, the mean of the two distributions is statistically equivalent for the selected significance level. In the context of this research, the equality test means that the distance from the median nose to the point of collision with a fixed median object is statistically equivalent for both signalized and unsignalized intersections.

It is important to note that the test will not result in equality for most of the common values of alpha, which range from 0.01 to 0.1. For example, for a significance level of 0.1, the test would support the assumption that there is a significant difference in the distance of crash occurrence between signalized and unsignalized intersections. As it can be observed in

Figure 6-2, the distance for median crashes tends to be greater for unsignalized intersections than for signalized intersections. This will lead to a second hypothesis test to evaluate whether the crash distance from median nose is greater for unsignalized than for signalized intersections.

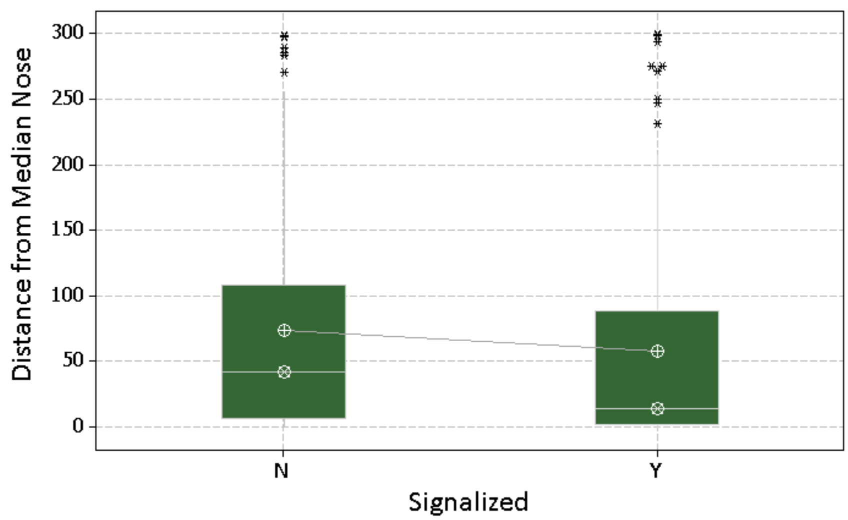


Figure 6-3. Box Plot of Distance from Median Nose by Control Type

The one-sided t-test resulted in a p-value of 0.043. This indicates that there is statistical evidence to support the assumption that crashes occur at greater distances from the median nose on unsignalized intersections than on signalized ones. The overall conclusion of the above tests in the context of the application of SI-546 is that, regardless of the presence of landscaping, the same tree setback guidelines should be applicable to both signalized and unsignalized intersections (from fixed object crash point of view) since crashes occur at an equivalent distance from the median nose or tend to be somewhat closer for signalized intersections. The possible explanation for a potentially closer distance from the median nose for crashes at signalized intersection is that more vehicles make permitted left turns from full stops or lower speeds.

Results of Landscaping Field Data and Associated Crash Data Collection

A total of 72 intersections were included in the final analysis. Figure 6-4 shows the number of sites selected for the three groups, with respect to intersection types and posted speed limits along the major roadway. For 4-way intersections, there were 11 sites without trees, 12 sites compliant with SI-546, and 20 sites not compliant with SI-546. For T-intersections, there were 8 sites without trees, 6 sites compliant with SI-546, and 15 sites not compliant with SI-546. Since tree diameters, spacing, and offsets varied from year to year, the research team decided to use the latest two years of crash data (2009 and 2010) to control the accuracy of these parameters. Considering that sight distance varies from 290 to 620 ft. and some intersections are relatively close to one another, the research team used 300 ft. as the segment length within which to associate relevant crashes with the intersections. Therefore, crashes that occurred within 300 ft. from the center of the study intersections were included in the analysis.

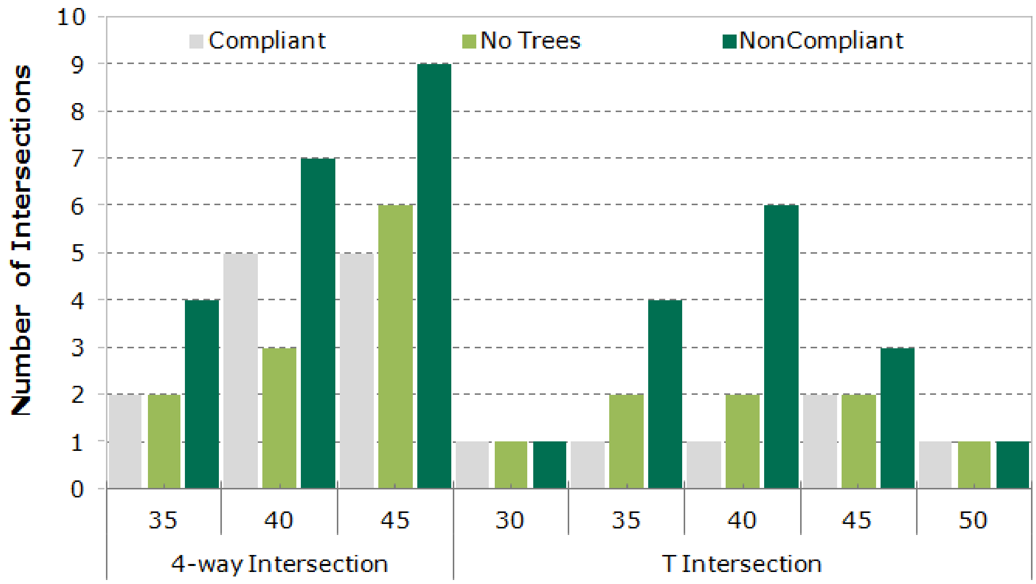


Figure 6-4. Number of Intersections for Empirical Study

Figure 6-5 represents scatter plots of tree diameters measured at 6 inches from the ground line, as required by SI-546. For each speed, SI-546 defines threshold values of 11 and 18 inches for tree spacing requirements. The maximum allowable tree diameter is 18 inches and is represented by the upper horizontal limit line in red. Trees with diameter greater than 18 inches are considered non-compliant.

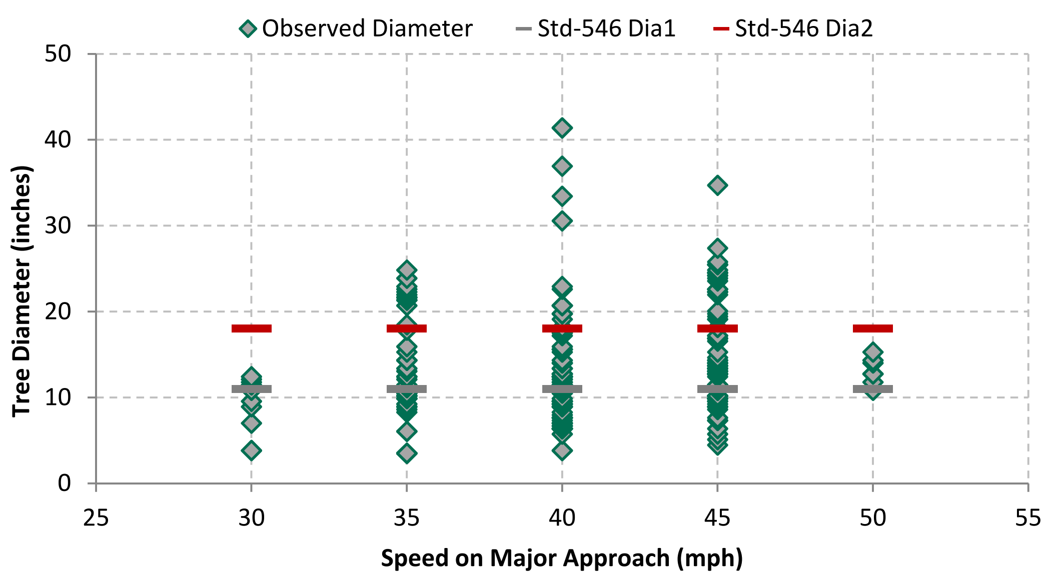


Figure 6-5. Tree Diameters Measured at 6 In. from Base by Speed

In Figure 6-5, it can be observed that for the case speed limits of 30 mph and 50 mph, all the trees surveyed had diameter at or below 18 inches. Intersections with 35, 40, and 45 mph speed limits presented several cases of trees with diameters above 18 inches; the intersections are, therefore, non-compliant with SI-546. The maximum tree diameters were encountered on intersections with 40 mph speed limits.

Figure 6-6 represents tree spacing by speed for trees with diameters of 11 inches or less. Similarly, Figure 6-7 represents tree spacing by speed for trees with diameters between 11 and 18 inches. The minimum spacing for each speed limit category is represented by a horizontal bar in red. Any tree spacing below the corresponding minimum spacing is considered non-compliant. Approaches with only one tree were not included in the spacing compliance calculations.

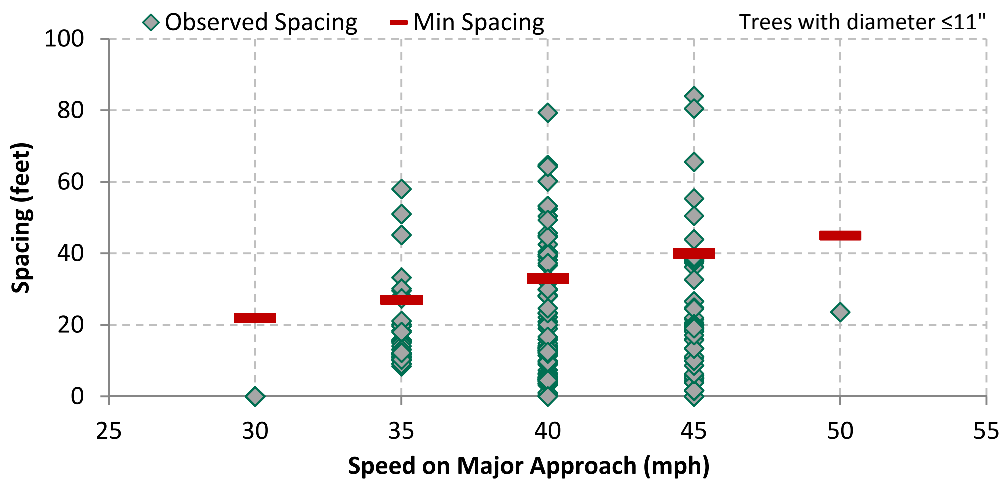


Figure 6-6. Tree Spacing for Trees with Diameter under 11"

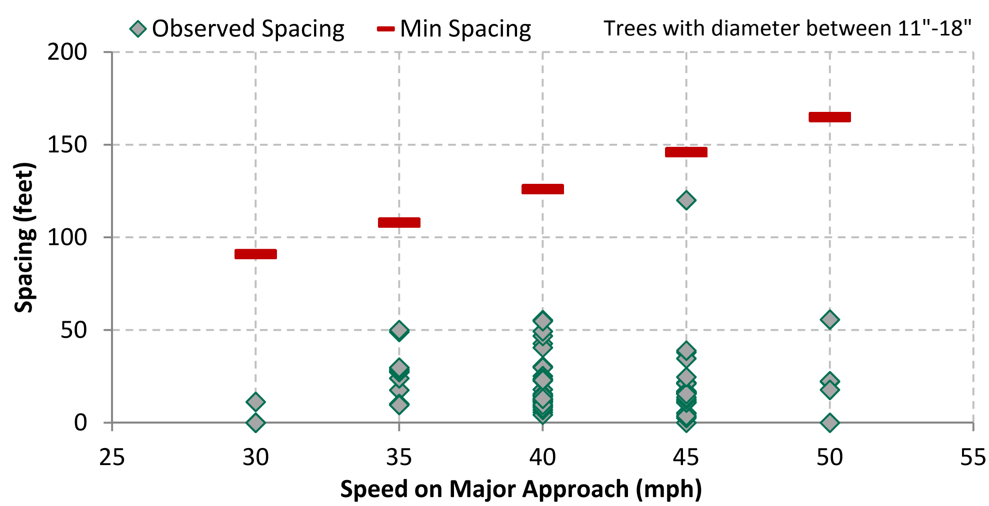


Figure 6-7. Tree Spacing for Trees with Diameter between 11"and 18"

Spacing was found as the major source of noncompliance with SI-546 for many study intersections. Compliance with spacing requirements was observed in several cases for trees with diameter at or under 11 inches. For trees of 11 to 18 inches, it was observed that compliance with the standard was rarely achieved, as shown in Figure 6-7. The observed spacing for trees larger than 11 inches is completely inadequate for median landscaping safety purposes.

Figure 6-8 represents observed tree setbacks by speed. The required setbacks are 100 ft. for approaches with speed limits under 50 mph and 200 ft. for 50 mph or more. The required values are represented by horizontal lines in red. It can be observed that there is fair compliance with the 100 ft. or more setback distance with respect to speed.

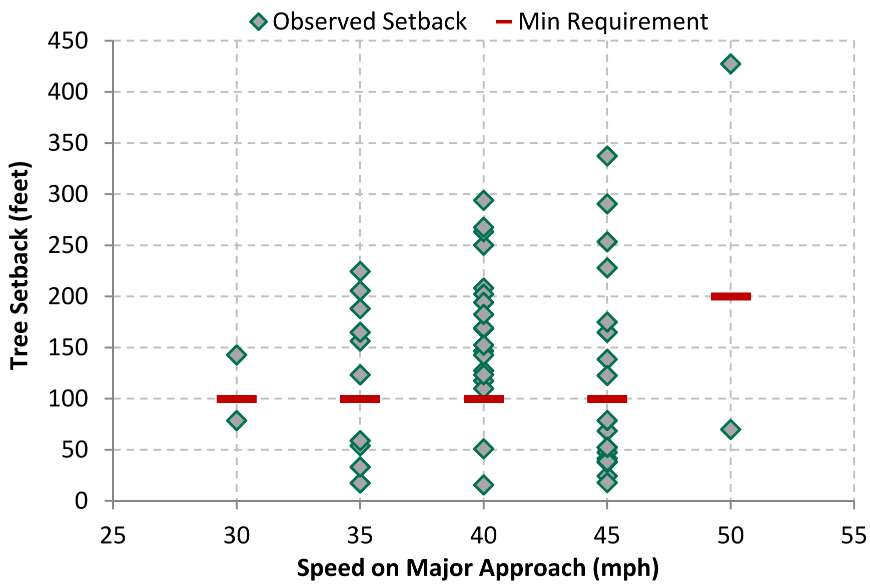


Figure 6-8. Tree Setback by Speed

Sources of Noncompliance with SI-546

An overall descriptive analysis of compliance with respect to the different landscaping design elements of SI-546 is represented in Figure 6-9. It was observed that in 65 percent of the cases, the first tree observed at any approach was compliant with the required setback in SI-546. In general, tree diameter ranked at the most compliant landscaping design element, with 86 percent of the observed trees being within the limits of compliance.

Tree spacing was found as the major source of noncompliance. The spacing criterion was applied giving priority to large trees. For example, a combination of consecutive trees with diameters 10, 15, and 10 inches will follow the requirements for trees with diameters greater than 11 inches. In this way, trees with larger diameters can be properly spaced with respect to other trees. For trees with diameter at or under 11 inches, only 12 percent of approaches had compliant tree spacing. For trees with diameters over 11 inches, none of the study intersections had tree spacing that was compliant with the recommended spacing in SI-546.

It was found that 66 and 84 percent of observed trees were compliant with respect to tree canopy height and ground cover height, respectively, at the time of data collection. These two landscaping elements constitute the viewing window for drivers on divided highways. Tree canopy height and ground cover height degree of compliance can be increased through landscape maintenance.

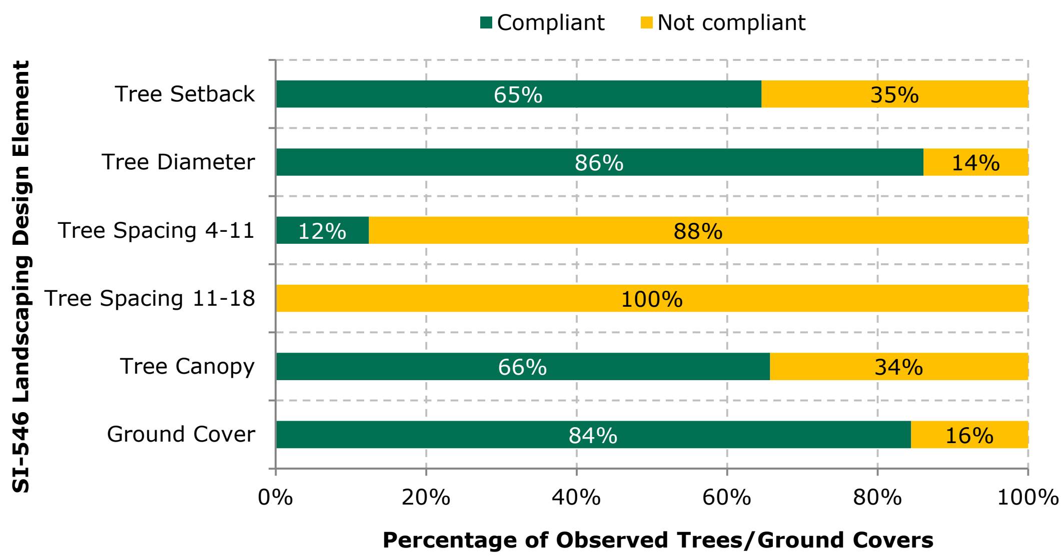


Figure 6-9. Compliance of Observed Landscaping Features with Respect to SI-546 Design Elements

Analysis of Evaluation of Landscaping Types of Highway Medians at Intersections on Safety

A total of 174 crashes were observed at the 72 selected intersections between 2009 and 2010. Figure 6-10 presents the average number of crashes per site for the three intersection groups. For landscaped intersections compliant with SI-546, the number of crashes per year per intersection for 4-way intersection category was 1.08, and for the T-intersection category it was 0.58. On landscaped intersections non-compliant with SI-546, the number of crashes per year per intersection was 1.35 and 1.57 for 4-way and T intersection categories respectively. The average number of crashes per year per intersection for sites without trees is 1.27 for 4-way intersection category and 0.75 for T-intersection category. Intersections compliant with SI-546 showed the best safety performance measures in terms of crash rates per year. Compared to intersections with no trees, intersections compliant with SI-546 presented 15 percent fewer crashes per year for 4-way intersections and 22 percent fewer crashes per year for T intersections. Intersections non-compliant with SI-546 presented 25 percent more crashes per year for 4-way and 169 percent more (almost twice as many) for T-intersections than intersections in compliance with SI-546.

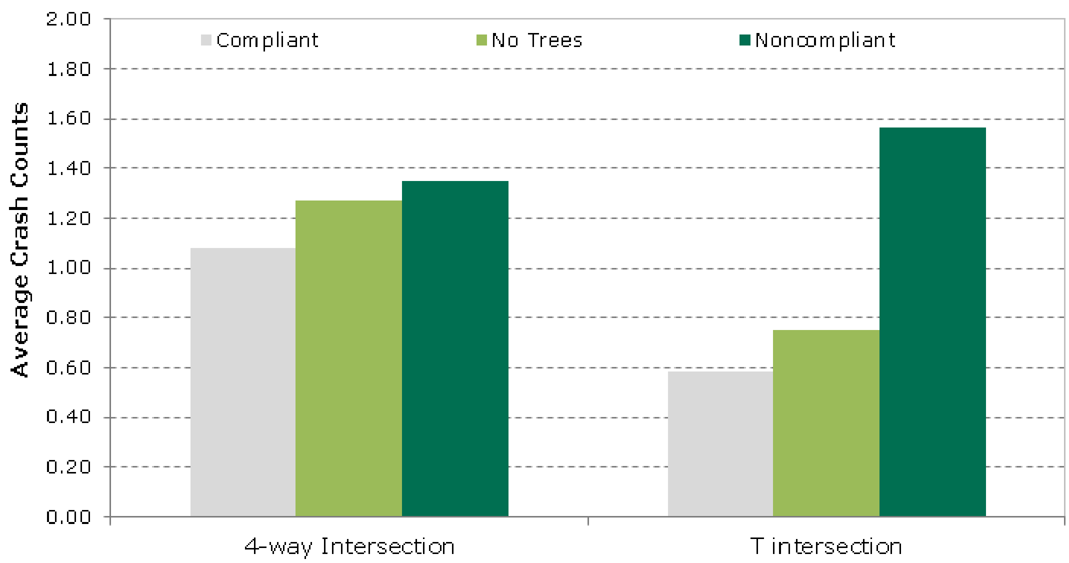


Figure 6-10. Comparison of Average Crash Counts per Year per Intersection for Three Groups at 4-way Intersections and T Intersections

The average number of crashes per year per intersection is presented in Figure 6-11 by intersection type and posted speed limits. In general, the sites with trees not compliant with SI-546 showed a greater number of crashes at each posted speed limit than the other groups regardless of the presence of landscaping. Facilities with speed limits of 40 mph presented the highest crash frequencies, with 1.38 crashes per year per intersection, followed by the 35 mph with 1.27 and the 45 mph sites with 1.24 crashes per year per intersection. When the speed limit is low (30 mph) or high (50 mph), fewer crashes were observed.

The highest number of crashes was observed on facilities having a 40 mph speed limit with trees not compliant with SI-546. The average number of crashes per year per intersection at these non-compliant sites was 1.81. For sites with landscaping compliant with SI-546, the average number of crashes per year per intersection was 0.67. This is more than double that of compliant sites for facilities with 40 mph speed limit. For facilities with no trees with the same speed limit, the number of crashes per year per intersection was 1.10. For facilities with a speed limit of 45 mph, the differences in crash counts among the three groups was very similar—1.21 crashes for sites with trees compliant to SI-546, 1.25 crashes for sites without trees, and 1.28 crashes with trees not compliant to SI-546.

An Analysis of Variance (ANOVA) was performed on the crash rates with respect to the presence of landscaping and compliance with SI-546. The results are presented in Table 6-2. The ANOVA test indicated that there is no statistical significance in terms of crash rates among the intersection groups.

Figure 6-11. Comparison of Average Number of Crashes per Year per Intersection for Three Groups from 30 mph to 50 mph at Major Streets

Table 6-2. ANOVA Results for Crash Rates among Three Intersection Groups

Source	Degrees of Freedom	Sum of Squares	Mean Square Error	Fishers' Ratio	p-value
Comp SI-546	2	0.01346	0.00673	2.05	0.137
Error	69	0.2269	0.00329		
Total	71	0.24035			

The p-value of 0.137 indicates that there is not enough evidence to assume that compliance or the presence of trees have an effect on crash rates. However, the p-value is close to the boundary of acceptance/rejection for the test. To illustrate this, an Analysis of Means (ANOM) test was performed. The ANOM illustrates how different a group is from the rest based on the difference with respect to the overall mean. Figure 6-11 shows the result of an ANOM test using a significance level of 0.1. Intersections with trees compliant with SI-546 and intersections with no trees are both below the overall mean and belong to the same group (within the upper and lower level limits). It can be observed that in the case of intersections with median landscaping noncompliant with SI-546 are at the boundary of constituting a different group.

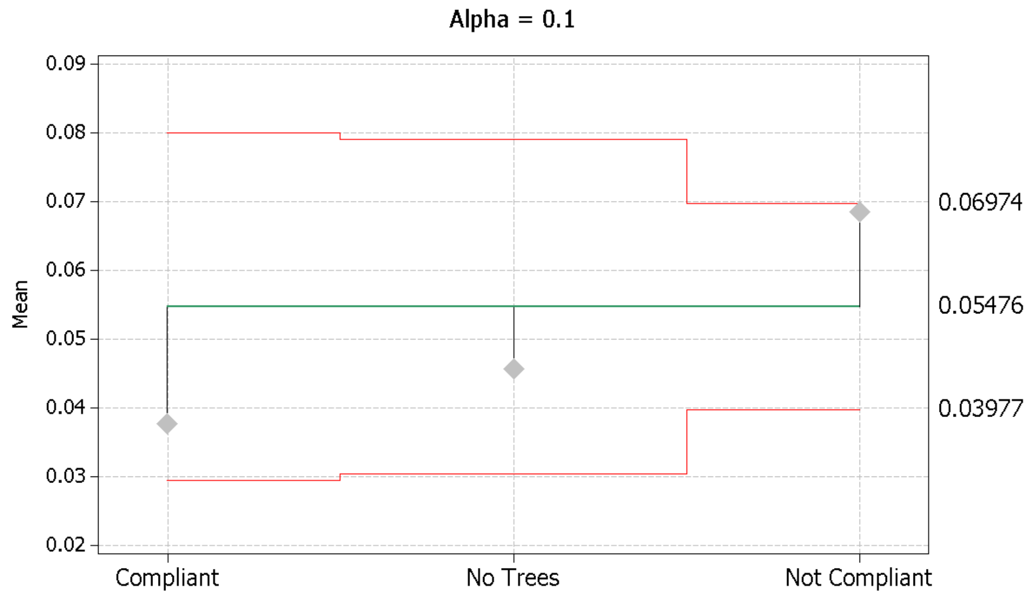


Figure 6-12. Analysis of Means for Crash Rate among Three Intersection Groups at 0.1 Significance Level

The statistical summary indicates that median trees at highways near the intersections can reduce the number of crashes and even the injury severity levels of crashes if the trees are located where they meet the size and spacing requirements of SI-546. Sites compliant with the standard were observed to have 12 percent fewer crashes and 28 percent fewer crashes involving injuries than sites without median trees near the intersections. However, if the landscaping is not properly located or designed or is noncompliant with the design standards, nearly 37 percent more crashes could be observed than at the sites without trees.

Table 6-3 summarizes the average statistics of crash characteristics at the selected sites for all three groups in terms of overall crash features, crash severity, and crash types. It can be observed that sites compliant with SI-546 have the lowest average crash counts and crash rates for overall crash features. The average crash rate is 0.038 for sites with trees compliant with SI-546, 0.046 for sites without trees, and 0.069 for sites with trees noncompliant with SI-546. When comparing crash severity, nearly 61 percent of all crash counts for sites with trees compliant with SI-546 were Property Damage Only (PDO), while 54 percent of crash counts for sites not compliant with SI-546 involved both minor and incapacitating injuries. The crash counts of crash types for intersections compliant with SI-546 were the lowest among rear-end crashes (8 counts), angle crashes (4 counts), left-turn crashes (1 count), and crashes with fixed objects (5 counts) for all three groups. The crash count of side swipe crashes was the same for compliant intersections and intersection without trees (3 counts).

Table 6-3. Summary Statistics of Crash Characteristics at Selected Sites for Three Groups

Group	Compliant		No Trees		Not Compliant	
No. of Sites	18		19		35	
Overall Crash Features	**Average**	**Std.**	**Average**	**Std.**	**Average**	**Std.**
Crash count	0.92	0.67	1.05	1.17	1.44	1.59
Crash rate (crashes per year per site per thousand vehicles)	0.038	0.031	0.046	0.052	0.069	0.069
Severity	**Count**	**Percentage**	**Count**	**Percentage**	**Count**	**Percentage**
PDO crash	20	60.61%	19	47.50%	44	43.56%
Minor injury	10	30.30%	14	35.00%	47	46.53%
Incapacitating injury	3	9.09%	5	12.50%	7	6.93%
Sum	**33**	**100.00%**	**38**	**95.00%**	**98**	**97.03%**
Crash Types	**Count**	**Percentage**	**Count**	**Percentage**	**Count**	**Percentage**
Rear-end	8	24.24%	12	30.00%	27	26.73%
Angle	4	12.12%	9	22.50%	18	17.82%
Left-turn	1	3.03%	4	10.00%	9	8.91%
Side swipe	3	9.09%	3	7.50%	6	5.94%
Hit fixed object	5	15.15%	7	17.50%	26	25.74%
Others	12	36.36%	5	12.50%	15	14.85%
Sum		**100.00%**		**100.00%**		**100.00%**

According to the statistical analyses shown in Table 6-3, for the severity of crashes there is a significant difference in the crash counts for PDO crashes (20 counts), minor injury crashes (10 counts), and incapacitating injury crashes (3 counts) for compliant and noncompliant sites with a 90% confidence level. These results indicate that median landscape plantings must adhere to SI-546 to not only provide a better roadway environment, but also to improve roadway safety. SI-546 provides sufficient intersection visibility and allows proper judgment for spacing trees at different speeds along major roadways. Sites near intersections with stop sign controls for minor roadways should strictly follow SI-546 within the clear sight triangle area.

Landscaping-based Crash Predictive Models

Two landscaping-based crash predictive models, one for total crash counts and another for injury crashes, were developed by applying the Negative Binomial model. A total of 17 variables were originally selected as input variables for different models, including 7 dummy variables, 2 count variables, and 8 continuous variables, as listed in Table 6-4. “No Trees” and “Not Compliant” are two dummy variables indicating the site groups. Geometric variables include intersection types (T or 4-way), left-turns present at the minor approach, number of lanes on the major and minor approach, posted speed limits on the major or minor approach, median types on the minor approach, right shoulder width on the major approach, and median width. Traffic features include the AADT on the major roadway. However, the number of lanes and the presence of left-turn lanes on minor side streets were used as indicators for traffic volumes on intersecting side streets. Also, variables relevant to landscaping criteria were included: multi-trunk, ground cover, average tree spacing, tree setbacks from the median nose, and tree diameter. Sites without trees do not have the variables associated with landscaping criteria. To be consistent with the models, the sight distance defined by AASHTO was used as the tree offset and average spacing, indicating that any obstructions are far enough away from the beginning of the median nose.

Table 6-4. Collected Model Variables and Values at Selected Sites to Model Crashes

Variables	Type	Codes/Range	Frequency
No Trees	Dummy	1 (No Trees)	19
		0 (Otherwise)	53
Not Compliant		1 (Trees not Complied with Standard 546)	35
		0 (Otherwise)	37
Intersection Type		0 (T Intersection)	29
		1 (4-way Intersection)	43
Left Turn Lane Present at Minor Approach		0 (No Left-turn Lane)	58
		1(Left-turn Lane present)	14
Median Type at Minor Approach		0 (Not Divided)	57
		1(Divided)	15
Multi-trunk		0 (no)	60
		1 (yes)	12
Ground Cover		0 (no)	39
		1 (yes)	33
Number of Lane(s) of Major Approach	Count	1, 2, 3	72
Number of Lane(s) of Minor Approach		1, 2	72
Major Street AADT	Continuous	4,900 ~ 49,500	72
Post Speed on Major Approach (mph)		30 ~ 50	72
Post Speed on Minor Approach (mph)		15 ~ 30	72
Right Should Width (ft)		0 ~ 9	72
Median width (ft)		14 ~ 46	72
Tree Offset from Median Nose (ft)		13.95 ~ 296.00 (Trees Present)	53
		100 (No Trees)	19
Average Tree Spacing (ft)		9.87 ~ 262.00 (Trees Present)	53
		*290.00 ~ 650.00 ((No Trees)	19
Tree Trunk Diameter (ft)		0.504 ~ 3.581	53
		0	19

**Depending on Sight Distance Criteria in AASHTO 2004*

Different variable combinations and formats (Ln) were tested to derive the best fit models. Table 6-5 and Table 6-6 are the final best fit models for crash frequency and injury crashes, respectively. For the crash frequency model, eight variables are statistically significant at a 90% confidence level. The model indicates a 4-way intersection, increasing traffic volume, left-turn present on the minor approach, and increasing the tree diameters would increase the chances of crash occurrences. The presence of a left-turn on the minor approach may be associated with a high volume of left-turn vehicles on the minor approach to enter the major approach than these sites without the left-turn, thus increasing the chances of being involved in a crash with a vehicle on the major approach. Increasing the right shoulder width and/or providing a median on the minor approach and/or increasing the number of lanes on major approaches would reduce the chances of being involved in a crash. When traffic volume remains the same, increasing the number of lanes on major approaches can reduce the chance of crashes due to fewer conflicts between vehicles.

Table 6-5. Negative Binomial Model Result for Crash Frequency at Highway Intersections with Median and Landscaping

Criteria for Goodness of Fit			
Criteria	**DF**	**Value**	**Value/DF**
Deviance	60	59.2027	0.9867
Scaled Deviance	60	59.2027	0.9867
Pearson Chi-Square	60	61.9083	1.0318
Scaled Pearson	60	61.9083	1.0318
Log Likelihood	-44.0054		
Full Log Likelihood	-89.0986		

Analysis of Parameters				
Parameter	**Coefficient**	**Standard**	**χ^2**	**Pr > χ^2**
Intercept	-10.3975	2.7424	14.38	0.0001
No Trees	0.5217	0.4120	1.60	0.2055
Intersection Type	0.3966	0.2045	3.76	0.0524
Ln AADT in Thousands	1.5215	0.3072	24.53	<0.0001
Post Speed Limit on Major Approach	-0.0369	0.0187	3.89	0.0485
Left-turn On Minor Approach	0.7020	0.2895	5.88	0.0153
Median Type on Minor Approach	-0.8126	0.3210	6.41	0.0114
Right Shoulder Width on Major Approach	-0.1718	0.0576	8.91	0.0028
Ln Tree Offset	-0.1959	0.1352	2.10	0.1474
Ln Tree Spacing	-0.2185	0.1472	2.21	0.1375
Number of Lanes on Major Approach	-0.4406	0.2187	4.06	0.0440
Tree Trunk Diameter	0.0809	0.0464	3.04	0.0812
Dispersion	-0.1239	0.0393		

The other three variables are significant at the 85% and 80% confidence levels. The dummy variable No Tree had a positive sign, indicating that if other conditions remained the same, a site without trees would have 68 percent more crashes than a site with trees compliant with SI-546. Increasing the tree spacing and tree offset to the beginning of the median nose can reduce the chance of a crash at a 14% significance level. The dummy variable Trees Not Compliant with SI-546 is not included in the final model. However, for the injury crash model, only four variables—Ln AADT in Thousands, Ln Tree Offset, Ln Tree Spacing, and No Trees—are statistically significant at a 90% confidence level. For injury crashes, sites without trees tripled the number of injury crashes compared to the sites with trees compliant with SI-546. The model also indicates that when the tree setback increases from 100 ft. to 200 ft., an 18 percent crash reduction can be observed if other variables remain the same. The landscaping-based crash predictive models indicate the benefits of applying SI-546 to highway medians near intersections compared to no landscaping or landscaping not compliant with SI-546, which is a national and state goal to increase roadway environmental conditions and improve intersection safety.

Table 6-6. Negative Binomial Model Result for Injury Crashes at Highway Intersections with Median and Landscaping

Criteria for Goodness of Fit			
Criteria	**DF**	**Value**	**Value/DF**
Deviance	67	74.8721	1.1175
Scaled Deviance	67	74.8721	1.1175
Pearson Chi-Square	67	52.7386	0.7871
Scaled Pearson	67	52.7386	0.7871
Log Likelihood		-49.7453	
Full Log Likelihood		-60.9535	

Analysis of Parameter				
Parameters	**Coefficient**	**Standard**	χ^2	Pr > χ^2
Intercept	-7.0778	2.8925	5.99	0.0144
No Trees	1.1828	0.6362	3.46	0.0630
Ln AADT in Thousands	0.9126	0.2800	10.63	0.0011
Ln Tree Setback	-0.2762	0.1609	2.95	0.0860
Ln Tree Spacing	-0.3813	0.2261	2.84	0.0918
Dispersion	-0.3333	0.1536		

Chapter 7 Conclusions and Recommendations

Recent interest in road beautification initiatives as a way to help economic growth has led to a number of changes in landscaping policies in Florida. These changes raised the need to evaluate whether the design criteria contained in the current SI-546 remain valid for providing guidance on the installation of trees on medians at intersections. This research project validated SI-546 and evaluated its safety performance with respect to roadside landscaping on medians at intersections through the following objectives:

- Review the current roadside landscaping criteria.
- Develop a computational procedure to analyze landscaping configurations.
- Perform an empirical study of the safety performance of SI-546.

This research project has successfully accomplished the followings: 1) intensive literature review on landscaping criteria and policies, 2) development of a computational procedure to analyze landscaping configurations 3) thorough validation of SI-546 using the latest AASHTO standards in 2011 edition of the *Green Book*, 4) detailed analysis on median tree setback setting via median fixed-object crash analysis, 5) analysis of source of noncompliance with SI-546 from collected field landscaping data, 6) evaluation of landscaping types of highway medians at intersections, and 7) development of landscaping-based crash predictive models.

Conclusions

In the literature review, landscaping policies from 29 states were compiled and summarized, as shown in Chapter 2. The remaining 21 states did not have specific landscaping policies and standards. SI-546 was found to be the leading, critical standard to establish tree setbacks and detailed spacing requirements for highway medians near intersections. Tennessee and Ohio cited SI-546 and the *Florida Median Handbook* for their intersection sight distance requirements. It was found that trees of four inches in diameter or less were generally allowed on low speed facilities. For ground cover, a height of 24 inches from the ground was widely used in other states. Such values are consistent with SI-546.

SI-546 was presented in Chapter 3. This research project has thoroughly reviewed and validated the current SI-546 and provided recommendations for modifying this index in a separate document for safe placement of plant material to comply with intersection sight distance and vehicle recovery areas using the latest AASHTO standards in 2011 edition of the *Green Book*.

In this study, a computational tool to calculate visibility measures on landscaping configurations was developed, as presented in Chapter 4. The computational tool runs in MS Visio using VBA macros. With the addition of this tool, the following landscaping performance measures were introduced:

- Average vehicle visibility
- Total time of unobstructed view

- Maximum time of unobstructed view
- Visibility profile

The setting of tree setback from the median nose was one of the recent revisions to SI-546. Median tree setback was to be verified from two points of view: median fixed-object crashes and crashes associate with median landscaping compliance with SI-546. From the point of view of direct fixed-object impact crashes, crash narratives and aerial imagery were used to obtain an approximation of the crash distance with respect to the median nose by intersection control type. A total of 300 sample crash reports were analyzed to obtain an estimated distance distribution of median crashes from media nose, as provided in Chapter 6. The results of this analysis are as follows:

- For signalized intersections, the mean distance from median nose for crashes with fixed objects was 57.7 ft.; for stop-controlled intersections, this distance was 74.1 ft. The distance from the median nose to the point of collision with a fixed object tended to be somewhat closer for signalized intersections due to likely stopped conditions.

- According to the statistical analysis based on collected landscaping field data and associated crash data in Chapter 6, for a significance level of 0.05 (95% confidence level), the distance from the median nose to the point of collision with a fixed object in the median is statistically equivalent for both signalized and unsignalized intersections.

An empirical study was conducted to evaluate the current SI-546 median landscaping criteria with respect to roadway safety. For the empirical study, study intersections were divided into three groups: 1) those with median trees near the intersection compliant with SI-546, 2) those without median trees near the intersection, and 3) those with median trees near the intersection noncompliant with SI-546. A total of 72 intersections were selected for data collection. For historical safety performance analysis, the latest available two years of crashes (2009 and 2010) within 300 ft. from the centerline of the intersection were used. The main findings of the empirical analysis in Chapter 6 are as follows:

- From historical records, 174 crashes from the studied 72 intersections were obtained. The sites with landscaped medians compliant with SI-546 had the best overall safety performance. For 4-way intersections, the average number of crashes per year per intersection was 1.08; for T-intersections, it was 0.58.

- For intersections with landscaped medians non-compliant with SI-546, the average number of crashes per year per intersection was 1.35 for 4-way and 1.57 for T-intersections.

- Intersections with no landscaping presented an average number of crashes per year per intersection of 1.27 for 4-way intersections and 0.75 for T-intersections.

- Having non-landscaped intersections as the baseline, intersections with landscaped medians compliant with SI-546 presented 15 percent fewer crashes per year per intersection for 4-way intersections and 22 percent fewer crashes per year per intersection for T intersections.

- Intersections with landscaped medians non-compliant with SI-546 presented 25 percent more crashes per year per intersection for 4-way and 1.57 for T-intersections than intersections with landscaped medians in compliance with SI-546.

- At each posted speed limit, sites with landscaped medians non-compliant with SI-546 dominated all of the other sites in terms of the highest number of crashes per year per intersection.

- The effect of non-compliant landscaping was more pronounced on facilities with a 40 mph speed limit. On these facilities, the average number of crashes per year per intersection was 1.81 for non-compliant sites. For sites with landscaped medians compliant with SI-546, the number of crashes per year per intersection was 0.67. For facilities with no landscaping, the average number of crashes per year per intersection was 1.10.

- When analyzed based on crash rates in the number of crashes per year per intersection and per thousand vehicles, there was no statistically-significant difference between sites with landscaped medians compliant with SI-546, non-compliant medians, and sites with no trees. However, the significance level of the test was 0.13 (87% confidence level), which is sufficiently close to the significance level of 0.1, to draw definitive conclusions on the effectiveness of SI-546 in isolation from other variables.

- Sites with landscaped medians compliant with the standard were observed to have 12 percent fewer crashes per year per intersection and 28 percent fewer crashes per year per intersection involving injuries than sites without median trees near the intersection. However, if landscaping is not properly located or designed or does not comply with the design standards, 37 percent more crashes per year per intersection could be observed than at sites without trees.

- There were statistically-significant differences in average crash counts, PDO crashes, and minor injury crashes between the sites with landscaped medians compliant and noncompliant with SI-546 at significance level of 0.1 (90% confidence level).

Two landscaping-based crash predictive models were developed in this study and presented in Chapter 6, one for total crash frequency and one for injury crashes. The crash frequency model indicated for 4-way intersections that increased traffic volume, left-turn lane presence on the minor approach, and increased tree diameters would increase the chance of crash occurrences. The main findings of these two crash predictive models are as follows:

- The total crash frequency model indicated that when other conditions remain the same, 68 percent more crashes could occur at sites without trees compared to sites with trees compliant with SI-546. It was also found that the chance of crash occurrence decreases as tree setback and tree spacing increase (inverse relation). However, the significance level of these variables was 0.14 and did not reach the adopted standard level of significance of 0.1 (90% confidence level).

- For the injury crash model, sites without trees tripled the number of injury crashes as compared to sites with trees compliant with SI-546 when all other variables remain constant. In this model, SI-546 related variables such as tree setback and spacing were significant at a significance level of 0.1 (90% confidence level). These variables expressed the inverse relationship between setback, tree spacing, and diameter with injury crash occurrence. That means the increased setback and tree spacing may have the potential of reducing the occurrence of injury crashes.

- The results indicate that median trees at highways near intersections may have the potential to reduce the number of crashes and even the injury severity levels of crashes if the landscaping plan provides proper visibility.

Recommendations

The major recommendations from this research project are as follows:

- It is beneficial to apply FDOT SI-546 at highway medians near intersections as a national and state guideline to enhance the roadway environmental conditions and improve intersection safety.

- Landscaping in the median should follow SI-546 to provide not only a better roadway environment but also improve roadway safety. Sites with landscaping near intersections with stop sign controls at minor roadways should strictly follow SI-546 within the clear sight triangle area to incorporate a CSS approach.

- Based on the distribution of distance from median nose for crashes with fixed median object in this study, it was found that increasing the setback may have the potential to reduce the chances of a direct impact crash with the tree. However, with the increase of median tree setback, the potential benefit of context-sensitive design with median landscaping may be reduced. Therefore, the determination on the revision of median tree setback in SI-546 should consider the benefits from both crash reduction and context-sensitive design perspectives.

- According to the assessment of median tree setback setting via median fixed-object crash analysis in Chapter 6, It can be observed from Figure 6-1 that the current median tree setback of 100 ft. in SI-546 for facilities with posted speed limits under 50 mph can potentially avoid 87 percent of median fixed-object crashes. The current standard provides a good protection level and does not allow tree planting in the zone where nearly 90 percent of the median crashes tend to occur. It also offers sufficient median space for context-sensitive design and tree plantings. If a consideration is given to avoid at least 90 percent of median fixed-object crashes, it is suggested that the median tree setback in SI-546 increase from 100 ft. to 120 ft.

- According to the assessment of median tree setback setting via median fixed-object crash analysis in Chapter 6, the current median tree setback of 200 ft. in SI-546 for facilities with posted speed limit of 50 mph or greater can potentially avoid at least 94 percent of median fixed-object crashes. The current standard provides a very high level of protection and does not allow tree planting in the zone where nearly 95 percent of the median crashes tend to occur.

- As shown in Figure 6-2, for facilities with a posted speed limit of 50 mph or greater, the reduction of median tree setback from 200 ft. to 100 ft. can still potentially avoid 94 percent of median fixed-object crashes and offers more median space for context-sensitive design and tree plantings. The reduction of median setback in SI-546 can be considered. It is necessary to note that this analysis was based a smaller sample of size of 52 due to less available data for high-speed facilities. For facilities with a posted speed limit of 50 mph or greater, a median fixed-object crash analysis based on a larger sample size will be beneficial to further enhance the result. It is recommended to maintain a median tree setback of 200 ft. for facilities with a posted speed limit of 50 mph or greater and allow variance for the tree setback of between 120 ft. and 200 ft. if deemed adequate.

- From the analysis of landscaping field data, an additional set back distance in the aforementioned range should be considered for landscaping designs that include trees with the potential of reaching an 18-inch diameter at maturity that.

- Because there is no statistically-significant difference between signalized intersections and unsignalized intersections with respect to the distance from median nose for crashes with fixed median objects, it is recommended that median tree setback standards be applied to both signalized intersections and stop-controlled intersections.

- Based on the analysis on the sources of noncompliance with SI-546, tree spacing was found as the major source of noncompliance. For trees with diameter at or under 11 inches, only12 percent of approaches had compliant tree spacing. For trees with diameters over 11 inches, none of the study intersections had tree spacing that was compliant with the recommended spacing in SI-546. Additionally, it was found that median trees at 35 percent of observed intersections were noncompliant with the required setback in SI-546. Therefore, it is recommended that priority be placed on tree spacing and median tree setbacks to improve the compliance of median landscaping with SI-546.

- It is recommended that a landscaping tracking tool be implemented statewide. This tool could contain location information, landscaping plans, installation date, etc., as well as other general information. This tool can be used to track maintenance and tree growth and serve as a valuable data source for safety analyses (e.g., before and after analyses).

- In this study, a fully functional computational tool was developed. This tool allows landscape architects and design engineers to obtain a variety of additional performance measures. It is recommended that the use of this tool be promoted. The tool can be upgraded to be an add-in for existing CAD packages and can incorporate effects such as grade and additional vehicle type.

- During the course of this study, more than 300 police crash reports were reviewed to find evidence of the distance of the crash from the median nose. Indication of the point of the median crossing was inferred from the narrative of the crash. It is recommended that, for crashes involving vehicles crossing through the median, a quantitative estimate of the crossing point is included in the crash narrative. This will provide valuable feedback for geometric roadway design.

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Appendix A

Literature Review Compilation on Landscaping Policies

Table A-1. General State Guidelines on Median Trees at Intersections – FHWA
Alabama, Alaska, Arkansas, and California

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
US DOT, FHWA	▪ No planting greater than 2′ in height in median near intersection ▪ No plantings having foliage between 2′ and 8′ in height should be present within sight distance triangles	50′ away from intersection	No obstruction within clear sight triangle /Design exemptions	Signalized Intersection Information Guidehttp://www.fhwa.dot.gov/publications/research/safety/04091/04091.pdf; AASHTO Green Book –A Policy on Geometric Design of Highways and Streets 2004
Alabama	Only limited plantings or shrubs inside clear zone and nothing larger than 4″ diameter within median	150′ from intersection	No obstruction within clear sight triangle /Design exemptions	State DOT Landscape Reviewer [1]
Alaska	No shrubs or trees planted in medians	Not specified	Not applicable	Alaska's Highway Preconstruction Manual, State Standards Engineer[1]
Arkansas	No guidelines/standards, on median planting	Not applicable	Not applicable	State DOT Division Admin[1]
California	▪ Barrier is required for speeds 45 mph or less ▪ Mature trees (4″ or greater in diameter) require an 11′ or more wide median	▪ Signalized intersections: 100′ from intersections ▪ Unsignalized intersections: o 25 mph - 150′ from intersections o 30 mph - 200′ from intersections o 35 mph - 250′ from intersections	No obstruction within clear sight triangle /Design exemptions	Caltrans Sight Distance Setback Criteria http://www.grandboulevard.net/toolbox/index.php?option=com_content&view=article&id=31:m-sight-distance-setback-trees-at-intersections&catid=13:matrix&Itemid=9

[1] Trees and Highway Safety, Preliminary Investigation by Caltrans Division Research and Innovation, March 18, 2010, http://www.dot.ca.gov/research/researchreports/preliminary_investigations/docs/tree_safety_pi_3-18-10.pdf

Table A-2. General State Guidelines on Median Trees at Intersections – Georgia, Hawaii, Idaho, Kansas, and Kentucky

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
Georgia	▪ Allow shrubs/trees not exceeding 30" in height within the clearance zone ▪ Trees should be limbed up a minimum of 7' in line	Regular checking no obstruction views within clear sight triangle areas	No obstruction within clear sight triangle/Design exemptions	Landscaping on DOT Right of Way http://www.dot.ga.gov/informationcenter/programs/environment/landscapes/Documents/6755-9.pdf, State DOT Landscaping Architect
Hawaii	Trees larger than 4" caliper should be planted in curbed median	Not specified	Not applicable	State DOT Landscape Architect [1]
Idaho	▪ Limited to flowers, shrubs and other low growing vegetation ▪ Not suggested to plant trees on medians unless safety barrier exists or width of median exceeds 80' and limited to 5' height in urban and 7' in rural areas	Not specified in design manual but generally 50' from pavement edge in practice	No obstruction within clear sight triangle/Design exemptions	Roadside Design Manual http://itd.idaho.gov/manuals/online_manuals/Current_Manuals/Design%20Manual/500.pdf, State DOT Roadside Programs Administrator
Kansas	No specified guidelines for trees at medians but must be 6' or more from the street gutter	Not specified	No obstruction within clear sight triangle/Design exemptions	State DOT Design Office
Kentucky	Do not plant trees with medians	Not applicable	Not Applicable	State DOT Landscape Architect [1]

[1] Trees and Highway Safety, Preliminary Investigation by Caltrans Division Research and Innovation, March 18, 2010, http://www.dot.ca.gov/research/researchreports/preliminary_investigations/docs/tree_safety_pi_3-18-10.pdf

Table A-3. General State Guidelines on Median Trees at Intersections – Louisiana, Massachusetts, and Maryland

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
Louisiana	▪ Only allow shrubbery and ground cover in clear sight triangle area with height less than 2.5' above roadway surface ▪ No trees allowed in the clear sight triangles	▪ 30 mph - 300' from median nose ▪ 40 mph - 400' from median nose ▪ 50 mph - 500' from median nose ▪ 55 mph - 550' from median nose	No obstruction within clear sight triangle/Design exemptions	Policy for Roadside Vegetation Management http://www.dotd.la.gov/highways/maintenance/Policy_For_Roadside_Vegetation_Management.pdf
Massachusetts	▪ Trees can be planted in the median width at least 66' or safety guardrail ▪ If the barrier exist, tree planting should be limited to medians at least 10' ▪ Shrubs require minimum width of 5' median	Not specified	Sight lines should be kept clear around intersections; trees with 3.28' or greater caliper size should not be planted in clear sight triangle	Massachusetts Highway Design Manual http://www.mhd.state.ma.us/downloads/manuals/design.pdf
Maryland	▪ Guidelines for planting in median currently under development ▪ Allow low growing shrubs and ground covers near intersection ▪ Medians should be 16' or wider to plant trees	Not specified but larger single stem street trees are preferred closer to intersections as they can be limbed up and spaced farther apart to reduce sight distance conflicts	No block view in clear sight triangle/Design exemptions	State DOT Landscape Architecture Division Chief

Table A-4. General State Guidelines on Median Trees at Intersections – Michigan, Minnesota, Missouri, Montana, and Nevada

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
Michigan	▪ Allow shrubs/trees with a mature diameter of 4" or less at 4'-6'' above the ground line ▪ Trees to plant at least 10' apart ▪ Center of trunk should be planted in planning zone limits	▪ 40' (opposite travel lane side) from median nose at median openings ▪ 70' (turn lane side) from median nose at median openings ▪ 300' from center point of intersections for all intersection ▪ 150' from centerline of crossroads	No obstruction within clear sight triangle zone (300' by 300' by 424' in each quadrant)	Typical Planting Procedures, Michigan Roadside Design Manual http://mdotwas1.mdot.state.mi.us/public/design/files/englishroadmanual/erdm07.pdf, State DOT Design Division Engineer
Minnesota	▪ Allow trees with or less than 4" in diameter when mature in median ▪ Placement is flexible as each site is unique depending on area and purpose ▪ Tree spacing ranging from 15'–75'	Not specified since each project varies but strict to clear sight triangle zones	Maintain adequate sight lines and clear zones follows AASHTO standards	Minnesota Rod Design Manual Chapter 5 http://dotapp7.dot.state.mn.us/edms/download?docId=1062358, State DOT Landscape Architecture Supervisor
Missouri	Generally no planting in medians	Not specified	Not specified	State DOT Landscape Architect [1]
Montana	Typically, no trees in rural medians and no plan to date in interstate median	Not specified	Not specified	State DOT Landscape Architect [1]
Nevada	▪ Allow trees 4" caliper in diameter or less from 35 mph to 45 mph ▪ No trees when speed limit above 45 mph	Not specified	Not specified	State DOT Landscape Architect [1]

[1] Trees and Highway Safety, Preliminary Investigation by Caltrans Division Research and Innovation, March 18, 2010, http://www.dot.ca.gov/research/researchreports/preliminary_investigations/docs/tree_safety_pi_3-18-10.pdf

Table A-5. General State Guidelines on Median Trees at Intersections – New Hampshire, New Jersey, and North Carolina

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
New Hampshire	▪ No design standard regarding the median trees ▪ Smaller ornament type trees can be planted in clear sight triangle area ▪ In practice, larger trees about 25'–35' apart ▪ Smaller ornamental trees 15'–20' apart	▪ 35' from edge of pavement or the nose for rural area ▪ A little bit closer to edge of pavement or nose for urban areas	Follow Federal Guidelines and no block views at clear sight triangle	State DOT Landscape Specialist Supervisor
New Jersey	▪ Only smaller trees not greater than 6" in diameter can be planted within median ▪ No required minimal tree spacing and generally are closer because of size trees	▪ Not allow trees to be planted within the sight triangle area for all intersections o 30 mph - 335' from decision point o 40 mph - 445' from decision point o 50 mph - 555' from decision point o 60 mph - 665' from decision point	Unobstructed clear sight triangle along roads at an intersections /Design exemptions	Roadway Design Manual http://www.state.nj.us/transportation/eng/documents/RDM/, State DOT Landscape Architect
North Carolina	▪ A minimal clearance of 16' above pavement ▪ Medians must be at wider enough for large trees to be planted: o ≤35 mph - 30' wide o >35 mph ≤ 45 mph – 44' wide o > 45 mph – 60' wide	Not specified but keep necessary sight distance which can be determined each site individually	All plantings are to be maintained in a condition which will not interfere with nor endanger either vehicular or pedestrian traffic	Guidelines for Trees, Shrub and Groundcover Planting on Highway at Right-Of-Way Other than Controlled Access or Interstate http://www.ncdot.org/doh/preconstruct/traffic/teppl/Topics/C-09/C-9_guide.pdf

Table A-6. General State Guidelines on Median Trees at Intersections – Ohio, Oregon, and South Carolina

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
Ohio	▪ No trees in medians within intersection sight triangles areas ▪ Low maintenance flowers, ground covers with 18" or less in height can be planted in sight triangle areas ▪ Minimum clearance of 16' above pavement should be maintained ▪ 4'–6' minimal distance from curb face to trees	▪ Not allow trees to be planted within the sight triangle area for all intersections o 15 mph - 170' from decision point o 20 mph - 225' from decision point o 25 mph - 280' from decision point o 30 mph - 335' from decision point o 35 mph - 390' from decision point o 40 mph - 445' from decision point o 45 mph - 500' from decision point o 50 mph - 555' from decision point o 55 mph - 610' from decision point o 60 mph - 665' from decision point	Clear of trees or any other obstructions	Location and Design Manual (Section 200) , Roadside Safety Landscaping Guidelines http://www.dot.state.oh.us/Divisions/Engineering/Roadway/roadwaystandards/Location%20and%20Design%20Manual/LandscapingGuidelines_2010-4-16.PDF, State DOT Roadway Standards Engineer
Oregon	▪ Trees can only be planted at those posted speed of 35 mph or less ▪ Curved/raised median with 8' or wider ▪ No planting higher than 24" above pavement surface within intersection functional area ▪ Minimum clear height of 10' from pavement to bottom of branches	▪ Not allow trees to be planted within the intersection functional areas o 19 mph – 215' to 315' o 22 mph - 270' to 370' o 25 mph - 335' to 490' o 28 mph - 405' to 595' o 31 mph - 485' to 710' o 34 mph - 565' to 835' o 37 mph - 605' to 960'	Follow FDOT *Median Handbook* ▪ At least 50% of the visual area of a vehicle ▪ 2 sec full view of entering vehicle	Highway Design Manual Chapter 5, State DOT Senior Standards Engineer
South Carolina	▪ No specific standard for spacing of trees in medians and set distance ▪ Usually vertical face curb & gutter in median does not allow a 4" or greater diameter tree to be planted	Typically ,ends of median noses are narrow and tree planting would not be allowed	No trees may interfere with traffic visibility and standard sight distance/ Design exemptions	Access and Roadside Management Manual http://www.scdot.org/community/pdfs/roadsidemanual.pdf, State DOT Landscape Architect

Table A-7. General State Guidelines on Median Trees at Intersections – South Dakota, Texas, and Tennessee

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
South Dakota	▪ Shrubs and flowers only ▪ Typically tree and shrub planting are outside the median	Not applicable	Not applicable	State DOT Landscape Architect[1]
Texas	▪ Only low-growing varieties can be planted in the intersection areas ▪ Most trees are within 2" – 3" inch caliper ▪ Trees with mature caliper of 4" or greater cannot be planted within clear sight triangle areas	Not allow trees larger than 4" caliper to be planted within sight triangle area for all intersections	No obstruction within clear sight triangle	Aesthetics Design Manual http://onlinemanuals.txdot.gov/txdotmanuals/lad/landscape_design.htm, State DOT Landscape Design Section Director
Tennessee	Same as Florida Design Standard Index 546	▪ 100' from pavement edge for design speeds < 50 mph ▪ 200' from pavement edge for design speeds ≥ 50 mph	▪ At least 50% of the visual area of a vehicle ▪ 2 sec full view of entering vehicle	Tennessee Intersection Sight Distance Standard Drawings http://www.tdot.state.tn.us/Chief_Engineer/engr_library/design/StdDrwgEng_PDFs/RD01SD2_000000.pdf

[1] Trees and Highway Safety, Preliminary Investigation by Caltrans Division Research and Innovation, March 18, 2010, http://www.dot.ca.gov/research/researchreports/preliminary_investigations/docs/tree_safety_pi_3-18-10.pdf

Table A-8. General State Guidelines on Median Trees at Intersections – Virginia, Washington, and Wyoming

State	Median Trees	Setback Restrictions from Intersections	Visibility Criteria	Source
Virginia	▪ No specific standards ▪ No trees could be planted inside clear sight triangle areas ▪ Minimum 8′ offset from median curb	No trees could be planted inside the clear sight triangle areas ▪ 25 mph - 280′ - 325′ from centerline of intersection ▪ 30 mph - 335′ - 390′ from centerline of intersection ▪ 35 mph - 390′ – 445′ from centerline of intersection ▪ 40 mph - 445′ - 520′ from centerline of intersection ▪ 45 mph - 500′ - 580′ from centerline of intersection ▪ 50 mph - 555′ - 645′ from centerline of intersection ▪ 55 mph - 610′ -710′ from centerline of intersection	Tall shrubs, groundcovers, trees should not block the driver's view	Guidelines for Planting Along Virginia Roadway, State DOT Location and Design Landscape Architect
Washington	▪ Only trees with 4" in diameter or less can be planted within the clear sight triangle areas ▪ Trees larger than 4" in diameter are allowed beyond clear sight triangle areas	Beyond clear sight triangle areas following AASHTO standards	Prohibition of vegetation interfering with a driver's opportunity to observe	Washington DOT Design Manual Chapter 1310 http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1310.pdf, State DOT Design Policy, Standards & Research Manager
Wyoming	▪ Rarely undertake median landscape due to climatic restrictions and winter maintenance salt ▪ Shrubs maintained at maximum 2.5′ tall within intersection sight-distance	Beyond clear sight triangle areas	No obstruction within clear sight triangle/Design exemptions	State DOT Environment Agronomist