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# Systemic Low-Cost Countermeasures for an Unsignalized Intersection Safety Improvement Plan for Virginia

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Abstract:

With more than 80,000 unsignalized intersections in Virginia, determining how and where to focus limited highway safety resources through deployment of low-cost, high-benefit systemic countermeasures is paramount to beginning to reduce the number of fatal and injury crashes at unsignalized intersections in Virginia. The purpose of this study was to develop a safety improvement plan for unsignalized intersections using systemic low-cost countermeasures. The scope of the study focused on unsignalized intersections with stop sign control on the minor approaches. Virginia's unsignalized intersection crashes over a 5-year period were assessed to determine predominant crash trends and crash types to target for treatment. Three Virginia Department of Transportation (VDOT) databases (crashes, roadway inventory, and traffic counts) were combined for unsignalized intersections. Four focus collision types with the highest frequency of crashes and the greatest potential reduction in crashes were identified from the data: 3-leg angle, 3-leg fixed object off road, 4-leg angle, and 4-leg rear-end. Chi-square automatic interaction detection (CHAID) was used to perform a systemic analysis to identify a group of intersections based on independent variables (roadway inventory and traffic count variables) that were most strongly related to the focus collision types.

After the crash assessment was performed, case studies of selected intersections in each group were reviewed to assess the factors that might influence the four focus collision types. A tiered list of countermeasures to deploy was developed based on the literature and input from VDOT staff. The countermeasures were intended to warn of the stop ahead, to make the stop sign and stop location more visible on the minor street, and to warn of the intersection ahead on the major street. The potential for safety improvement measure was used to prioritize the candidate treatment intersections. Before deployment, a study of the intersections conducted by district traffic engineering staff is planned in order to finalize the safety improvement plan. The output of the study is a safety improvement plan to deploy treatments to unsignalized intersections systemically as part of the safety program. The plan can be adjusted based on available funding.

**FINAL REPORT**

# SYSTEMIC LOW-COST COUNTERMEASURES FOR AN UNSIGNALIZED INTERSECTION SAFETY IMPROVEMENT PLAN FOR VIRGINIA

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**ABSTRACT**

With more than 80,000 unsignalized intersections in Virginia, determining how and where to focus limited highway safety resources through deployment of low-cost, high-benefit systemic countermeasures is paramount to beginning to reduce the number of fatal and injury crashes at unsignalized intersections in Virginia. The purpose of this study was to develop a safety improvement plan for unsignalized intersections using systemic low-cost countermeasures. The scope of the study focused on unsignalized intersections with stop sign control on the minor approaches. Virginia's unsignalized intersection crashes over a 5-year period were assessed to determine predominant crash trends and crash types to target for treatment. Three Virginia Department of Transportation (VDOT) databases (crashes, roadway inventory, and traffic counts) were combined for unsignalized intersections. Four focus collision types with the highest frequency of crashes and the greatest potential reduction in crashes were identified from the data: 3-leg angle, 3-leg fixed object off road, 4-leg angle, and 4-leg rear-end. Chi-square automatic interaction detection (CHAID) was used to perform a systemic analysis to identify a group of intersections based on independent variables (roadway inventory and traffic count variables) that were most strongly related to the focus collision types.

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## FINAL REPORT

## SYSTEMIC LOW-COST COUNTERMEASURES FOR AN UNSIGNALIZED INTERSECTION SAFETY IMPROVEMENT PLAN FOR VIRGINIA

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# INTRODUCTION

## Overview

In recent years, the Virginia Department of Transportation (VDOT) has made significant progress in deploying systemic safety countermeasures at signalized intersections across the state, including flashing yellow arrow projects and retroreflective back plate projects, among others. Even so, approximately 25 percent of highway fatalities and 40 percent of highway injuries in Virginia occur at intersections, with a majority of those occurring at unsignalized intersections. With more than 80,000 unsignalized intersections in Virginia, determining how and where to focus limited highway safety resources through deployment of low-cost, high-benefit systemic countermeasures is paramount to reducing the number of fatal and injury (FI) crashes at unsignalized intersections in Virginia.

## Background: Systemic Countermeasures and Their Benefits[1]

The traditional "spot location" approach to addressing safety is focused on treating a specific problem location based on its crash history. The "systemic approach" reflects the fact that the spot location approach is not the best choice when a comprehensive safety improvement strategy is needed to address similar crash characteristics that are widely distributed on homogeneous roadway facilities. Therefore, systemic implementation of safety countermeasures helps address the primary crash types over the area and/or road system, not just at specific high-crash spot locations.

The systemic safety approach is a two-pronged effort to reduce crashes and serious injuries on the roadways. This approach offers a means to do the following:

1. identify crash types (e.g., intersection, roadway departure, pedestrians) and the location-related factors that contribute to the highest number of fatal and serious injury crashes of each type based on a system-wide data-driven analysis

2. implement low-cost countermeasures widely over several locations with similar risk factors, such as crash characteristics and roadway features.

Typically, systemic safety improvements are low cost, require little maintenance, are associated with documented crash reductions, and address specific crash types or crash risk factors (e.g., narrow shoulders).

The systemic approach looks at crash history on an aggregate basis to identify high-risk roadway characteristics and considers multiple locations with similar risk characteristics. When the system is examined as a whole, a particular roadway element may have a high crash rate. If that is the case, it may be more cost-effective to correct the problem on a system-wide basis rather than by individual high-crash location. In other words, with a systemic approach, one would make improvements at intersections that may not have a demonstrated crash problem but have characteristics similar to those of intersections that do have a crash problem.

The application of the systemic safety approach offers the following benefits[1]:

- Systemic safety improvements can reduce overall fatal and severe injury crashes of certain types within a district/jurisdiction more effectively than application of safety improvements at a small number of spot locations.

- The approach allows an agency to adapt for all levels of data availability and can help prioritize data collection needs.

- Countermeasures implemented systemically are typically low-cost improvements.

- Systemic safety improvements help agencies broaden their safety efforts and consider risk factors in addition to crash history when identifying locations for potential safety improvement.

- Systemic safety improvements can be incorporated into planning, design, and maintenance policies; defended in tort liability cases; and used to develop a multiyear program of projects.

- The approach can bolster public confidence because it allows the agency to implement a proactive safety program.

## PURPOSE AND SCOPE

The purpose of this study was to develop a safety improvement plan for unsignalized intersections in Virginia using systemic low-cost countermeasures. The first objective was to assess Virginia's unsignalized intersection crashes over a 5-year period to determine predominant crash trends and crash types. The second objective was to develop a list of systemic countermeasures that could be deployed to target specific collision types and patterns that were determined during the assessment. This portion of the study included a review of the

*Unsignalized Intersection Improvement Guide* (UIIG)[2] and other available guidance on the topic to assist in the development of Virginia-specific recommendations.

Of the 80,000 unsignalized intersections in Virginia, approximately 700 were controlled by all-way stop signs. These intersections were not included in the crash analysis; based on a review of VDOT crash data, they tended to have a low number of crashes. Therefore, the scope of the study focused on unsignalized intersections with stop control (hereinafter stop-controlled intersections) on only the minor approaches.

# METHODS

Six tasks were conducted to achieve the study objectives.

1. Review the literature related to the systemic safety approach and unsignalized intersections.

2. Prepare the data.

3. Analyze the data.

4. Review case studies.

5. Identify low-cost ($10,000 to $15,000 or less) countermeasures for unsignalized intersections.

6. Develop a plan to deploy the treatments systemically.

## Review of the Literature

A literature search was conducted using available search tools such as Transport Research International Documentation (TRID) and other internet databases to identify literature that was relevant to the research effort. The literature search focused on unsignalized intersections, safety, crash analysis, and countermeasures.

## Preparation of Data

### Overview

VDOT has developed and maintained a comprehensive Oracle-based roadway management system called the Roadway Network System (RNS). The RNS is designed to be the repository and/or universal enterprise to access and connect internal and external VDOT business data, including the Crash (RNS-Crash), Roadway Inventory (RNS-RDI), and Traffic Monitoring System (RNS-TMS) modules.

RNS-Crash maintains a copy of the official source of automobile crash records, the Traffic Record Electronic Data System, which resides at the Virginia Department of Motor Vehicles. RNS-Crash locates and displays crashes along roadways. RNS-RDI integrates the geo-spatial representation of the roadway network with cross-sectional inventory attributes and serves as a source of record for linear referencing information at VDOT. RNS-TMS contains historical traffic count data (the annual average daily traffic [AADT]) and the locations of the traffic counters.

RNS-RDI contains more than 80,000 unsignalized (stop controlled) intersections in Virginia. Among those, only intersections with a 3-leg or 4-leg configuration that had at least one crash during the 5 years of the study period (2011-2015) were identified and collected. An intersection-related crash is defined as a crash that occurred at or within 250 ft from the center of the intersection; these were extracted by merging the RNS-RDI and RNS-Crash modules.

Intersection entering volumes on major and minor approaches were extracted through the merging of RNS-TMS and RNS-RDI. As defined in the *Highway Safety Manual*[3] approaches with the highest and lowest AADTs were classified as the major and minor approach, respectively. Structured Query Language (SQL) was used to extract and develop the study data.

## Identification of Focus Collision Types

The first step in the systemic analysis was to identify and understand focus collision types that represented the greatest potential reduction in crashes throughout the facility. Therefore, 5 years (2011-2015) of total and FI crash data at the 3- and 4-leg unsignalized intersections were extracted and disaggregated from RNS-Crash based on RNS-RDI. The crash data preparation procedures to identify the focus collision types are depicted in Figure 1.

The steps shown in Figure 1 are described as follows:

*Step 1.* Access RNS-RDI.

*Step 2.* Select and extract only intersections that consist of 3-leg and 4-leg configurations.

*Step 3.* Join the lists of extracted intersections to the records of the intersection traffic control device (TCD).

*Step 4.* Remove intersections controlled by traffic signals, roundabouts, yield control, and all-way stop control and select only unsignalized stop-controlled intersections from the result of Step 3.

*Step 5.* Join the extracted 2011-2015 intersection crashes from RNS-Crash using a 250-ft radius offset to the result of Step 4.

*Step 6.* Select only unsignalized intersections with at least one crash between 2011-2015.

*Step 7.* Disaggregate crashes by severity and collision type.

*Step 8.* Complete analysis to identify the focus collision type database.

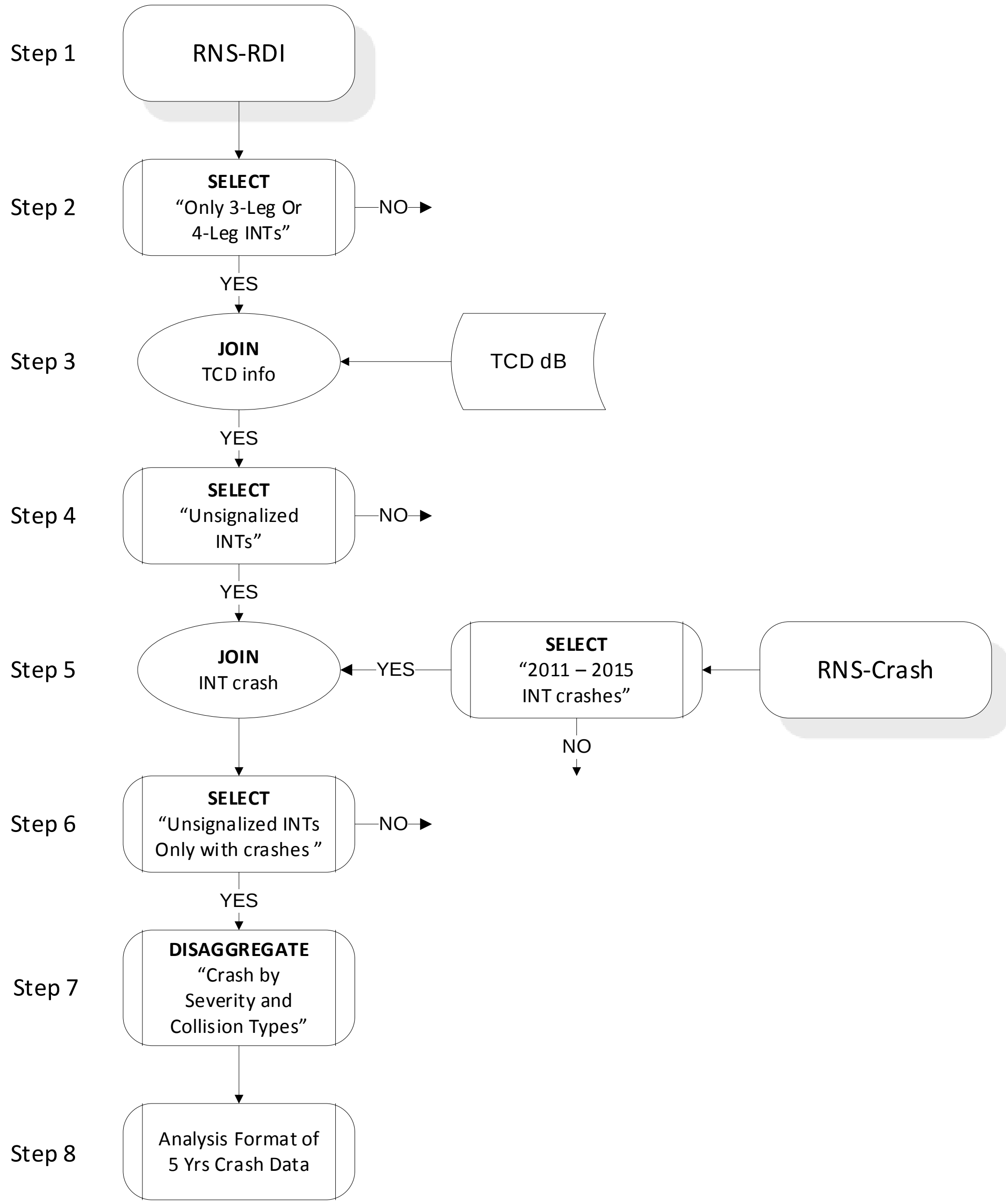



**Figure 1. Procedure for Identifying Focus Collision Types at Unsignalized Intersections**

## Identification of Features at Unsignalized Intersections for Risk Assessment

This task identified location-specific factors such as urban vs. rural, 3- vs. 4-leg intersections; intersection geometrics (such as number of lanes, presence of median); etc., that may be risk factors for crashes at unsignalized intersections. The following are examples of the types of location-related factors considered.

- *Administrative classification:* primary or secondary with rural or urban
- *Functional classification:* rural principal arterial, rural minor arterial, rural major collector, rural minor collector, rural local, urban principal arterial, urban minor arterial, urban collector, urban local
- *Number of approach lanes (through lanes)*
- *Traffic volume (AADT) groups*
- *Speed limit*
- *Facility type:* two-way, non-divided, divided, no control of access
- *Type of intersection.*

Examples of other possible groups include combinations of these factors, e.g., 4-leg / cross intersections with primary arterials. The Oregon Department of Transportation (ODOT) used four groups: state stop controlled and local stop controlled for both rural and urban areas.[4] The output of this task was used in the next task.

## Analysis of Data

This task identified groups of intersections based on specific collision types, patterns, and location-specific factors that are associated with a higher than average crash rate at unsignalized intersections. For this purpose, decision tree analysis[5] was used to perform a systemic analysis. Decision tree analysis is a simple but powerful form of multiple variable analysis. It is performed by algorithms that combine a dataset and successive splitting of the dataset into subgroups based on relationships between independent variables and a dependent (target) variable to improve the prediction or classification. When successful, the resulting tree indicates which independent variables are most strongly related to the target variable. It also displays subgroups that may have concentrations of cases with desired characteristics. Therefore, it is valuable to analysts faced with a large number of independent variables and not much theory or previous work to guide them.

A sample decision tree is shown in Figure 2. A decision tree typically starts with a single node that represents the entire sample and is known as a root node. When a new node is created by an additional split, the new nodes are called splitting nodes, which branch off into subgroups by outcome. The final type of node that is not split into further subgroups is called a terminal node and depicts the final outcome of the decision-making process. In the example of Figure 2, there are seven terminal nodes.

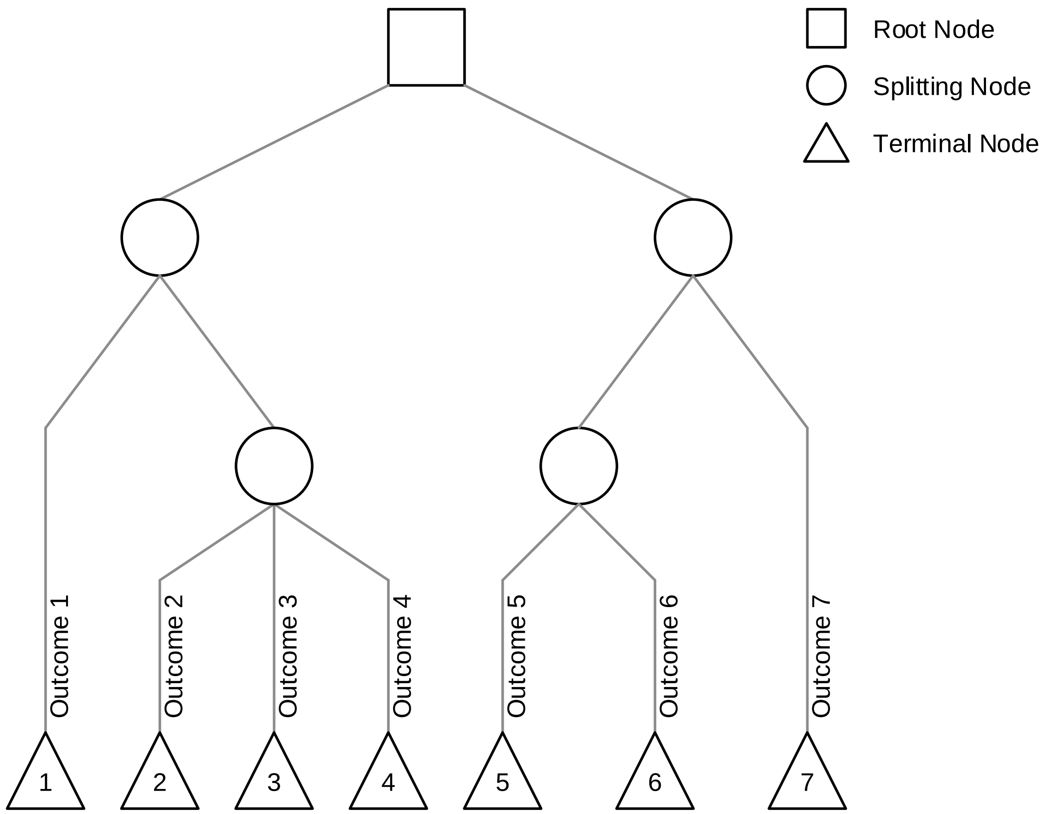



**Figure 2. Graphical Model of Decision Tree**

Chi-square automatic interaction detection (CHAID)[4] was chosen as the decision tree method because it produces (1) relationships between many categorical independent variables and a categorical dependent variable; (2) all possible cross tabulations for each categorical combination until the best outcome is achieved; and (3) more than two subcategories at any level in the tree (it is not limited to binary splits). The IBM-SPSS 24.0 Decision Tree[4] was used for CHAID. The option to limit the growth of the tree was set so that there were fewer than 100 cases when the tree was splitting from the parent node to the child node in this study.[6] The output of this analysis was groups of unsignalized intersections to target for treatment.

## Review of Case Studies

A review of select intersections within the groups that were selected in the previous step was performed to identify what types of crashes and location-specific factors might be present at the potential candidate sites for treatment. At least two intersections were chosen from each group. This was not intended to provide a representative sample for each group but rather simply a snapshot of what crash patterns and other factors might exist.

## Identification of Low-Cost Countermeasures for Unsignalized Intersections

This step included identifying low-cost countermeasures and available performance measures. Examples of low-cost countermeasures[3, 4] might include, but are not limited to, the following:

*Signing*

- signs on both sides of roadway
- larger or oversized signs
- retroreflective sign post panels
- solar-powered, sign-mounted beacons
- replacement of additional safety-related signs within 500 ft of the intersection
- advance street name signs on intersection warning signs.

*Pavement markings*

- properly placed stop bars
- dashed edgelines to delineate the mainline and turn bays
- lane arrows and word messages
- addition of crosswalks
- transverse rumble strips if applicable.

Countermeasures were selected based on those that seemed to be the most appropriate from the literature and input from VDOT staff. Select countermeasures were grouped into three tiers for possible implementation.

## Development of Plan to Deploy Treatments Systemically

Although CHAID effectively narrowed down the characteristics of unsignalized intersections for each focus collision type, there was a need to narrow down the lists of intersections to a manageable number of candidate sites for a systemic safety project. Therefore, the intersections were prioritized in accordance with a quantified safety performance measure, the potential for safety improvement (PSI).

VDOT completed development of Virginia-specific safety performance functions using local data and successfully implemented a statewide network screening for both intersections and segments beginning in 2014. The developed safety performance functions were applied at each site and the PSI was calculated by measuring differences between predicted crash frequency and expected crash frequency estimated from the empirical Bayes weighted crash frequency that used observed and predicted crash frequency. A positive PSI value indicates that there are excess crashes compared to what are predicted under given similar conditions. Therefore, a site with a positive PSI implies that it has a high potential for safety improvement. A zero or negative PSI value, however, indicates a typical or low level of crash occurrence, showing a lower potential for safety improvement.

The annual PSI was calculated for each year of the 5-year period at the intersections identified as focus collision groups through CHAID. The greater the number of years with a positive PSI, the greater the potential safety improvement. This measure was used to prioritize the candidate sites for treatment.

## RESULTS AND DISCUSSION

### Literature Review

Numerous reports related to unsignalized intersections, safety, crash analysis, and countermeasures were reviewed. Some relevant reports are briefly summarized here. The results are in two sections: (1) intersection safety and countermeasures, and (2) multiple countermeasures and related case studies.

#### Intersection Safety and Countermeasures

*Intersection Safety: A Manual for Local Rural Road Owners*[7]

According to Golembiewski and Chandler,[7] more than 6 million lane-miles of roadway in the United States are in rural areas and more than two-thirds of these rural roads are owned and operated by local entities. In 2008, 56 percent of the 37,261 fatalities on U.S. roadways occurred in rural areas. Rural areas face a number of highway safety challenges because of the nature of their facilities. More than 20 percent of all traffic fatalities in the United States occur at intersections, and more than 80 percent of intersection-related fatalities in rural areas occur at unsignalized intersections. This manual provided information on effectively identifying intersection safety issues in local areas, choosing the countermeasures that address them, and evaluating the benefits of those treatments. It is geared toward local road managers and other practitioners with responsibility for operating and maintaining roads. It offers information on the procedures and processes to improve the safety of local rural unsignalized intersections and to reduce the potential for future crashes. This included implementation approaches (systemic, spot, and comprehensive), safety analysis, and countermeasures.

*UIIG*[2]

The UIIG was developed to assist practitioners in selecting design, operational, maintenance, enforcement, and other types of treatments to improve safety, mobility, and accessibility at unsignalized intersections. Originally produced under National Cooperative Highway Research Program Project 03-104, the web-based UIIG is hosted by the Institute of Transportation Engineers under the sponsorship of the Federal Highway Administration’s Office of Safety.

The purpose of the UIIG is to assist and guide users through the process of evaluating unsignalized intersections and identifying opportunities to enhance their safety and operational performance. The contents of the UIIG are presented under two sections: Information, and Toolkit. The Information section provides important background material related to the types, users, common problems and treatments, and general considerations associated with unsignalized intersections. The Toolkit provides a number of resources to assist the user in (1) collecting data on the existing conditions and characteristics of the intersection, and (2) identifying potential treatments that may improve safety and mobility at the intersection. These tools include a sample citizen input form, a Microsoft Excel–based unsignalized intersection assessment and inventory form, and an unsignalized intersection treatment selection tool.

The UIIG provides an extensive list of potential countermeasures for use and a one-page description of each countermeasure.

*NCHRP Report 500, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*[8]

Unsignalized intersections represent potential hazards not present at signalized intersections because of the priority of movement on the main road. Vehicles stopping or slowing to turn create speed differentials between vehicles traveling in the same direction. This is particularly problematic on two-lane highways. The intersections along low- to moderate-volume roads in rural and suburban areas are usually unsignalized. These roadways are generally associated with high-speed travel and relatively lower geometrics than those in more developed suburban and urban areas.

This report focuses primarily on the physical improvement of unsignalized intersections and their approaches, as well as methods to improve driver compliance. The strategies considered cover the full range of engineering, enforcement, and education alternatives. The physical improvements considered include both geometric design modifications and changes to traffic control devices in nine categories.

1. Improve management of access near unsignalized intersections.

2. Reduce the frequency and severity of intersection conflicts through geometric design improvements.

3. Improve sight distance at unsignalized intersections.

4. Improve availability of gaps in traffic, and assist drivers in judging gap sizes at unsignalized intersections.

5. Improve driver awareness of intersections as viewed from the intersection approach.

6. Choose appropriate intersection traffic control to minimize crash frequency and severity.

7. Improve driver compliance with traffic control devices and traffic laws at intersections.

8. Reduce operating speeds on specific intersection approaches.

9. Guide motorists more effectively through complex intersections.

*Safety Evaluation of Flashing Beacons at Stop-Controlled Intersections*[9]

The Federal Highway Administration organized a pooled fund study of 26 states to evaluate low-cost safety strategies as part of its strategic highway safety effort. One of the strategies chosen for evaluation was flashing beacons. Three types of flashing beacons—intersection control beacons, beacons mounted on stop signs, and actuated beacons—were considered collectively at stop-controlled intersections. This strategy is intended to reduce the frequency of crashes related to driver unawareness of stop control at unsignalized intersections. Geometric, traffic, and crash data were obtained at stop-controlled intersections for 64 sites in North Carolina and 42 sites in South Carolina. Empirical Bayes methods were incorporated in a before-after analysis to determine the safety effectiveness of installing flashing beacons while accounting for potential selection bias and regression-to-the-mean effects. Overall, the installation of flashing beacons in North Carolina resulted in statistically significant reductions in total, angle, and FI crashes. The crash rates for the intersections in South Carolina changed very little following the introduction of the flashing beacons. The combined results from both states support the conclusion that an angle crash reduction of 13 percent and an FI crash reduction of 10 percent can be expected. The economic analysis based on the combined results for angle and non-angle crashes from both states indicates that standard flashing beacons and some of the actuated beacons (i.e., the less expensive beacons) are economically justified but that a benefit-cost (B/C) ratio of 2:1 may not be achievable for the more expensive actuated beacon types.

**Multiple Countermeasures and Related Case Studies**

*Low-Cost Safety Enhancements for Stop-Controlled and Signalized Intersections*[10]

The set of low-cost countermeasures presented in this report for stop-controlled intersections is designed to increase drivers' alertness to the presence of the intersection and reduce potential conflicts with other entering vehicles. These countermeasures are primarily intended for deployment at stop-controlled intersections with either a single through lane or multiple undivided through lanes. Countermeasures were classified as basic or supplemental. Basic countermeasures are those that typically have a very low unit cost, are effective in reducing future crash potential, and should be considered at all intersections having crashes above a defined crash threshold (10 crashes in 5 years for urban areas and 4 to 5 crashes in 5 years for rural areas). Supplemental countermeasures are targeted to intersections with crash levels considerably above the defined crash threshold or to intersections that have the specific types of crashes that the countermeasure can address.

The basic countermeasures should be considered as a package of minor improvements consisting of all of the following:

*Low-cost countermeasure for the through approach*

- doubled up (left and right) oversized advance intersection warning signs with street name sign plaques.

*Low-cost countermeasures for the stop approach*

- doubled up (left and right) oversized advance “Stop Ahead” intersection warning signs
- doubled up (left and right) oversized stop signs
- installation of a minimum 6-ft-wide raised splitter island on the stop approach (if no pavement widening is required)
- properly placed stop bar
- removal of any foliage or parking that limits sight distance
- double-arrow warning sign at stem of T-intersections.

Supplemental countermeasures can be considered when the frequencies of crashes are higher than the crash threshold for basic countermeasures or when intersections have crash types that the countermeasure can address. Examples of supplemental countermeasures include the following:

- installation of a minimum 6-ft-wide raised splitter island on stop approaches, which may require pavement widening
- either (1) flashing solar-powered LED beacons on advance intersection warning signs and stop signs or (2) flashing overhead intersection beacons
- dynamic warning signs to advise through traffic that a stopped vehicle is present and may enter the intersection
- transverse rumble strips across the stop approach lanes in rural areas where noise is not a concern and running stop signs is a problem; “Stop Ahead” pavement markings if noise is a concern
- dynamic warning signs to advise high-speed approach traffic that a stopped condition is ahead (when drivers running the stop sign is a problem)
- extension of the through edgeline using a short skip pattern to assist drivers in stopping at an optimum point (used for intersections with very wide throats in which stopped drivers have difficulty stopping at the correct location)
- retroreflective stripes on sign posts for signs with degraded conspicuity because of sign clutter or competing background features to increase attention to the sign, particularly at night.

*Oregon Intersection Safety Implementation Plan*[4]

Oregon's Transportation Safety Action Plan includes an overall goal of reducing the fatality rate in 2020. The plan lists intersection crashes as a "Priority 2 Emphasis Area," focusing on the following objectives:

- Focus on key infrastructure safety emphasis areas.

- Investigate the usefulness of advanced signing, roundabouts, access management techniques, advanced technology and features, and improvements to signal timing.

- Implement effective solutions.

ODOT personnel, local transportation partners, and other stakeholder representatives identified safety initiatives in the intersection emphasis area that could help achieve the desired reduction in statewide intersection fatalities. The traditional approach of relying primarily on pursuing major improvements at high-crash intersections was complemented with (1) an expansion of the systematic approach that involves deploying large numbers of relatively low-cost, cost-effective countermeasures at many targeted high-crash intersections, and (2) a comprehensive approach that coordinates an engineering, education, and enforcement initiative on corridors with high numbers of severe intersection crashes.

A broad comprehensive intersection safety plan including stop-controlled and signalized intersections, classified as either state or local roads, was developed. The countermeasure options for the two types of roads were the same except that J-turn modifications on high-speed divided arterials were an option for state roads.

A list of intersection safety countermeasures and approaches is shown in Table 1. The basic set considered for improvements includes the following:

*Through approach*

- doubled up (left and right) oversized advance intersection warning signs with street name plaques.

*Stop approach*

- doubled up (left and right) oversized advance "Stop Ahead" intersection warning signs

- "Stop Ahead" legend pavement marking

- doubled up (left and right) oversized stop signs

- installation of a minimum 6-ft-wide raised splitter island on the stop approach (optional: to be considered if no pavement widening is required)

- properly placed stop bar
- removal of any foliage or parking that limits sight distance
- double-arrow warning sign at stem of T-intersections.

The basic set of improvements was suggested for 567 state rural and urban intersections. An enhanced set was suggested for 43 intersections. The enhanced set includes the addition of a median stop sign and flashing LED beacons on warning signs on the through approach. ODOT also developed a basic intersection upgrades fact sheet.

**Table 1. Intersection Safety Countermeasures by Approach Type**

| Countermeasure | Approach |
|---|---|
| Sign and Marking Improvements: State Stop-Controlled Intersections<br>• Basic Set of Sign and Marking Improvements<br>• Flashing LED Beacons on Advance Intersection Warning Signs and Stop Signs or Actuated Flashing Overhead Intersection Beacons<br>• Optional Signing and Marking Improvements Based on the Characteristics of the Intersection | Systematic |
| J-Turn Modifications on High-Speed Divided Arterials: State Stop-Controlled Intersections | Systematic |
| Basic Set of Sign and Marking Improvements: Local Stop-Controlled Intersections | Systematic |
| Signal and Sign Improvements: State and Local Signalized Intersections<br>• Basic Set of Signal and Sign Improvements<br>• Optional Signal and Sign Improvements Based on the Characteristics of the Intersection<br>• Change of Permitted and Protected Left-Turn Phase to Protected Only or Conversion to Flashing Yellow Arrow<br>• Enforcement-Assisted Lights | Systematic |
| New or Upgraded Lighting: State and Local Rural Intersections | Systematic |
| High Friction Surfaces at Intersection Approaches: State Intersections | Systematic |
| Pedestrian Safety Enhancements | Systematic |
| Traffic Calming Improvements: State and Local Intersections | Systematic |
| Corridor 3E Improvements on High-Speed Arterials With Very High Frequencies of Severe Intersection Crashes | Comprehensive |
| Citywide Pilot Improvements (Flashing Yellow Arrow, Clearance Intervals, Enforcement-Assisted Lights) | Systematic/ Comprehensive |
| Spot Location Improvements / Roundabouts | Traditional |

*Source:* Oregon Department of Transportation.[4]

*Intersections: Enhanced Signs and Markings, A Winston-Salem Success Story*[11]

This case study examined the application of four successful combinations of intersection treatment enhancements that reduced crashes at stop-controlled intersections:

1. larger (30-in) stop signs with “Stop Ahead” advance signs and added pavement markings (double-yellow centerline and stop bars) to help delineate traffic at the intersection

2. added pavement markings (double-yellow centerline and stop bars) to existing (24-in) stop signs

3. additional and larger (30-in) stop signs

4. additional and larger (30-in) stop signs and added pavement markings (double-yellow centerline and stop bars).

The safety enhancements discussed in this case study were added to reduce crashes. The combinations of enhanced countermeasures installed at these intersections reduced total crashes at the intersections by approximately 55 percent and total injuries by an average of 70 percent per year. These results are based on a simple before-after study. The findings also indicated that installing stop signs larger than 24 in helps increase driver awareness of the stop condition.

*South Carolina Case Study: Systematic Intersection Improvements*[12]

The systematic improvements by the South Carolina Department of Transportation (SCDOT) at stop-controlled and signalized intersections were primarily related to signing and pavement markings. The typical improvements applied for all intersections are listed here by treatment category.

*Signing*

- doubled up (left and right) signing
- oversized signing with high-intensity fluorescent sheeting
- advance street name signs on intersection warning signs
- retroreflective sign post panels
- solar-powered, sign-mounted beacons
- replacement of additional safety-related signs (e.g., “Do Not Enter,” “One Way,” etc.) within 500 ft of the intersection.

*Pavement markings*

- properly placed stop bars (4 to 8 ft offset and perpendicular to the mainline)
- dashed edgelines to delineate the mainline and turn bays and establish points of conflicting traffic
- lane arrows and word messages
- addition of crosswalks.

SCDOT provided one general template drawing for each of the four intersection types (signalized, four-way stop-controlled, two-way stop-controlled, and T-type stop-controlled) in the bid documents.

### *Safety Evaluation of Multiple Strategies at Stop-Controlled Intersections*[13, 14]

This study[13, 14] evaluated a combined application of multiple low-cost treatments at stop-controlled intersections. Improvements included basic signing and pavement markings. No prior study (before 2017) had conducted a rigorous evaluation of the effectiveness of installing packages of these strategies in combination across many intersections.

In recent years, agencies have shown increased interest in the widespread installation of low-cost safety treatments throughout an entire jurisdiction. SCDOT embraced this approach in its intersection safety improvement plan. Each intersection received a unique package of improvements suited for implementation at that site. The possible improvements included the following (the list is slightly different than the one for the South Carolina case study described previously):

*Signing improvements*

- double-up 36-in x 36-in intersection warning signs on fluorescent yellow sheeting on the left and right sides of the street
- addition of an advance street name plaque (W16-8) on fluorescent yellow sheeting accompanying each right-side intersection warning sign
- double-up 48-in x 48-in stop and yield signs on the left and right sides
- use of retroreflective sign post panels for the signs.

*Pavement marking improvements*

- Place stop lines within 4 to 10 ft of the nearest through lane along the major road.
- Install yield lines at all lanes having yield conditions.
- Add a dashed white edgeline through the intersection along the major road.
- Re-mark all existing stop lines, crosswalks, arrows, and word messages unless certain criteria proved that they were in very good condition.

The study examined the safety impacts of multiple low-cost signing and pavement marking treatments at stop-controlled intersections in South Carolina on total, FI, rear-end, right-angle, and nighttime crash frequency. The data sample included 434 treatment sites and 568 reference sites of all intersection types. The research team categorized intersections for evaluation using the following configuration types:

1. *3 x 22:* 3-leg intersections with two lanes on the main line and two lanes on the cross street

2. *4 x 22:* 4-leg intersections with two lanes on the main line and two lanes on the cross street

3. *3 x 42:* 3-leg intersections with four lanes on the main line and two lanes on the cross street

4. *4 x 42:* 4-leg intersections with four lanes on the main line and two lanes on the cross street.

The evaluation made use of the empirical Bayes method for observational before-after studies.

The crash reductions were statistically significant at the 95 percent confidence level for all crash types. For all crash types combined, the crash modification factors (CMFs) were 0.917 for all severities and 0.899 for FI crashes. The crash type with the smallest CMF, which indicates the greatest crash reduction, was nighttime crashes, with a CMF of 0.853. The CMFs for rear-end and right-angle crashes were 0.933 and 0.941, respectively. The B/C ratio, estimated with conservative cost and service life assumptions and consideration of the benefits for total crashes, was 12.4:1. With the sensitivity analysis, these values could range from 7.1:1 to 17.5:1. These results suggest that the multiple low-cost treatments, even with conservative assumptions on cost, service life, and the value of a statistical life, can be cost-effective in reducing crashes at stop-controlled intersections.

### Summary

Much literature is available on unsignalized intersection safety and related countermeasures. The recent trend for systemic intersection improvements has incorporated multiple low-cost countermeasures for treatment, often using basic and enhanced combinations or tiers.

## Data Preparation

Based on the criteria defined in the “Methods” section, there were 25,420 unsignalized intersections that had at least one crash during the study period (2011-2015) (Table 2). Table 3 shows that these sites had 68,691 total crashes and 25,825 FI crashes. Of the 25,420 intersections, 21,753 were 3-leg (85.6%) and 3,667 were 4-leg (14.4%). Table 3 also shows the characteristics of data elements that were collected and manipulated based on RNS-Crash, RNS-RDI, and RNS-TMS.

**Table 2. Descriptive Statistical Summary of Unsignalized Intersection Study Data**

| No. of Unsignalized Intersections | Variable | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|---|
| 25,420 | Total Crashes | 1 | 58 | 2.7 | 3.3 |
| | FI Crashes | 0 | 28 | 1.0 | 1.6 |
| | $AADT_{Major}$ | 11 | 34,893 | 4,774.2 | 5,902.1 |
| | $AADT_{Minor}$ | 1 | 9,995 | 360.1 | 568.1 |

**Table 3. Summary of Collision Types at Unsignalized Intersections**

| Intersection Configuration | Collision Type | Total Crash Frequency | Percent | Fatal and Injury Crash Frequency | Percent |
|---|---|---|---|---|---|
| All (3- and 4-Legs) | Rear-End | 14,732 | 21.4 | 5,462 | 21.2 |
| | Angle | 22,109 | 32.2 | 9,124 | 35.3 |
| | Fixed Object Off Road | 16,068 | 23.4 | 6,299 | 24.4 |
| | Others | 15,782 | 23.0 | 4,940 | 19.1 |
| | Total | 68,691 | 100.0 | 25,825 | 100.0 |
| 3-Leg | Rear-End | 12,582 | 22.7 | 4,702 | 22.9 |
| | Angle | 15,491 | 27.9 | 6,129 | 29.8 |
| | Fixed Object Off Road | 14,209 | 25.6 | 5,574 | 27.1 |
| | Others | 13,214 | 23.8 | 4,147 | 20.2 |
| | Total | 55,496 | 100.0 | 20,552 | 100.0 |
| 4-Leg | Rear-End | 2,150 | 16.3 | 760 | 14.4 |
| | Angle | 6,618 | 50.2 | 2,995 | 56.8 |
| | Fixed Object Off Road | 1,859 | 14.1 | 725 | 13.7 |
| | Others | 2,568 | 19.4 | 793 | 15.1 |
| | Total | 13,195 | 100.0 | 5,273 | 100.0 |

## Focus Collision Types

Table 3 shows a summary of the collision types for all, 3-leg, and 4-leg intersections that were identified. Angle crashes accounted for the highest frequency and percentage of collision types and were also the most common FI crash type across all unsignalized intersections. The second highest collision type (excluding "others") was different for 3-leg and 4-leg unsignalized intersections. Fixed object off road (FOOR) crashes were the second highest at 3-leg intersections, and rear-end crashes were the second highest at 4-leg intersections. These most common crash types were used to define focus collision types for the 3- and 4-leg intersections. In order to avoid skewness that selects only intersections with higher volumes, mean percentage of crashes was used in the analysis instead of crash frequency for this threshold.

After the focus collision types were identified, the percentage of the focus collision types at individual unsignalized intersections was measured, and Table 4 shows descriptive statistics for the percentage of the focus collision types. As shown in the table, the mean percentage of angle and FOOR collision types at 3-leg intersections was 22.5 and 33.1, respectively, with standard deviations of 34.9 and 41.5, respectively. The mean percentage of angle and rear-end collision types at 4-leg unsignalized intersections was 13.7 and 43.7, respectively, with standard deviations of 26.0 and 39.3, respectively. In addition, when the percentages of unsignalized intersections that had greater than the mean percentage of the focus collision types were examined, it was determined that 33.2 percent (7,212) and 40.2 percent (8,754) of 3-leg unsignalized intersections were identified with greater than the mean of angle and FOOR collision types, respectively (Table 5). Similarly, 50.7 percent (1,858) and 28.0 percent (1,027) of 4-leg unsignalized intersections were identified with greater than the mean of angle and rear-end collision types, respectively.

**Table 4. Summary of Collision Types at Unsignalized Intersections: Descriptive Statistics of the Identified Target Collision Types by Intersection Configurations**

| Configuration Type | No. of Unsignalized Intersections | Variable | Minimum % | Maximum % | Mean % | Standard Deviation |
|---|---|---|---|---|---|---|
| 3-Leg | 21,753 | % of angle crashes | 0 | 100.0 | 22.5 | 34.9 |
| | | % of FOOR crashes | 0 | 100.0 | 33.1 | 41.5 |
| 4-Leg | 3,667 | % of angle crashes | 0 | 100.0 | 13.7 | 26.0 |
| | | % of rear-end crashes | 0 | 100.0 | 43.7 | 39.3 |

FOOR = fixed object off road.

**Table 5. Summary of Collision Types at Unsignalized Intersections: Number and Percent of Intersections With Greater Than the Mean of Target Collision Types**

| Configuration Type | No. of Unsignalized Intersections | Variable | No. of Intersections > Mean % Crashes | Percent Intersections > Mean % Crashes |
|---|---|---|---|---|
| 3-Leg | 21,753 | % of angle crashes | 7,212 | 33.2 |
| | | % of FOOR crashes | 8,754 | 40.2 |
| 4-Leg | 3,667 | % of angle crashes | 1,858 | 50.7 |
| | | % of rear-end crashes | 1,027 | 28.0 |

FOOR = fixed object off road.

## Identification of Features at Unsignalized Intersection for Risk Assessment

To identify the potential risks of the unsignalized intersection features where the target collision types most frequently occurred, eight unsignalized intersection features were extracted and defined at each intersection using RNS-RDI and RNS-TMS.

1. Intersection configuration

   - 3-Leg
   - 4-Leg.

2. Interchange area

   - Urban
   - Rural.

3. Intersection approach administrative system definition for major and minor road

   - Primary–Primary
   - Primary–Secondary
   - Secondary–Secondary.

4. Intersection approach lane configuration for major and minor road

   - 2 Lanes–2 Lanes
   - 4 Lanes–2 Lanes
   - 4 Lanes–4 Lanes.

5. Intersection approach median configuration for major and minor road

    - Undivided–Undivided
    - Divided–Undivided
    - Divided–Divided.

6. Intersection approach functional classification for major and minor road

    - Primary Arterial–Primary Arterial
    - Primary Arterial–Minor Arterial
    - Primary Arterial–Collector
    - Primary Arterial–Local
    - Minor Arterial–Minor Arterial
    - Minor Arterial–Collector
    - Minor Arterial–Local
    - Collector–Collector
    - Collector–Local
    - Local–Local.

7. Intersection entering volume (AADT) ratio of major and minor road

    - 50 percent–50 percent
    - 60 percent–40 percent
    - 70 percent–30 percent
    - 80 percent–20 percent
    - 90 percent–10 percent.

8. Intersection entering volume (AADT) band

    - <= 5,000
    - 5,001–10,000
    - 10,001–15,000
    - 15,001–20,000
    - 20,001–25,000
    - 25,001–30,000
    - 30,001–35,000.

## Data Analysis

CHAID was performed on each of the four collision types described here and in Table 4.

### Angle Collisions at 3-Leg Unsignalized Intersections

Figure 3 shows the CHAID tree constructed for angle collisions at 3-leg unsignalized intersections. In total, the dataset included 21,753 3-leg unsignalized intersections, and each intersection is classified as being either above or below the mean percentage of angle collisions based on all intersection configurations. This categorization is placed at the top of the tree and is termed the root node. At the root node (Node 0), it is shown that 7,212 unsignalized intersections (33.2%) of the 3-leg unsignalized intersections have more than the mean percentage of angle collisions (22.5%). The remaining 14,541 (66.8%) intersections have less than the mean percentage of angle collisions.

The first split of the tree (at the root node) is the variable "INT entering volume," which is clustered by four different entering volume bands. The four splitting nodes are then split by intersection functional classification configuration (Nodes 1 and 4) and intersection entering volume ratio (Nodes 2 and 3), and intersections are assigned to subgroups defined by these splits. These nodes are then split, and the process is recursively repeated. When the tree construction is completed, 18 terminal nodes (i.e., nodes that do not get split into further subgroups) are generated (Nodes 5, 8, 9, 11, 13, 16-28), each of which has a proportion of angle collisions greater than the overall mean. Of these 18 terminal nodes, Node 13 has the highest percentage of unsignalized intersections with a greater than mean percentage of angle collisions (76.1%, or 197 of 259 intersections). This indicates that intersections matching the conditions in this node might be more likely to benefit from treatments addressing angle collisions.

An index percentage was created to represent the relative probability of identifying intersections with a higher than average angle collision percentage versus a random sample [(Percent yes for Node x/Percent yes for Node 0)*100]. If the index percentage is greater than 100 percent, the desired target category of the node has a better chance of finding characteristics of the intersection group that contain more intersections with values greater than the threshold of the target collision type. The node does not offer strong classification power when it has an index value below 100 percent. For Node 13, the index percentage is 229.2 percent (76.1%/33.2%*100). Therefore, the identified group of Node 13 has more than twice the number of unsignalized intersections with greater than the mean proportion of angle collisions than the random sample. Consideration was given to choosing multiple nodes with high classification power. However, only the best terminal node was chosen to control the number of intersections. As a result of the tree analysis, the characteristics of a 3-leg unsignalized intersection with a high percentage of angle collision type are as follows:

- *Intersection entering volume*

    —>15,000.

- *Functional classification of major and minor roads*

    —Primary Arterial–Collector
    —Minor Arterial–Minor Arterial
    —Minor Arterial–Collector
    —Local–Local.

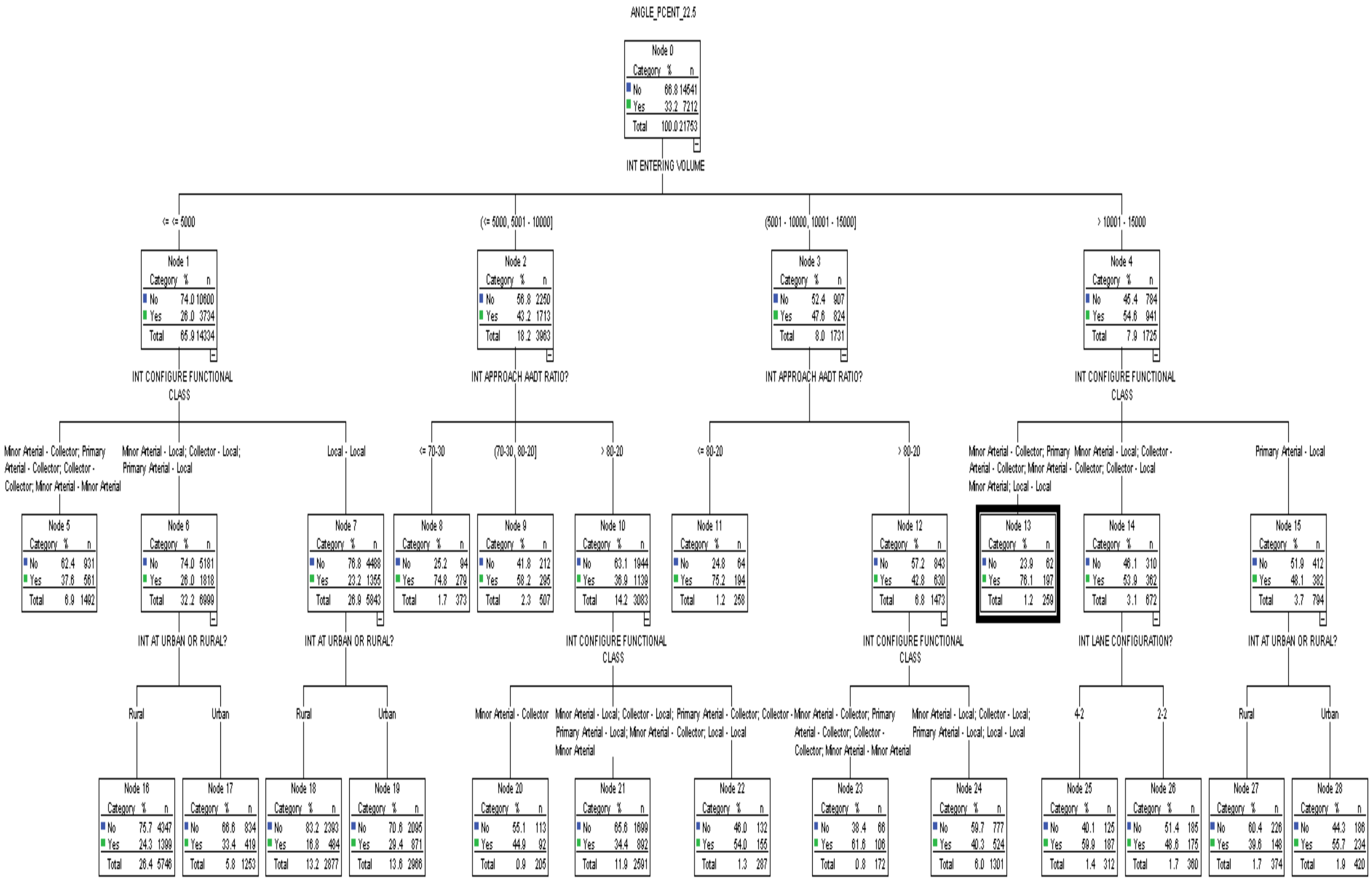



**Figure 3. Classification Tree for Angle Collisions at 3-Leg Unsignalized Intersections**

## FOOR Collisions at 3-Leg Unsignalized Intersections

The same tree analysis process was performed for FOOR collisions at 3-leg unsignalized intersections, as shown in Figure 4. Approximately 40 percent of the intersections at the root node have greater than the mean percentage of the FOOR collisions. Through recursive tree splitting using the eight feature variables, a tree consisting of 11 terminal nodes was constructed. Among those, the index percentage of Node 10 was the highest: 142.3 percent (57.3%/40.2%*100). Therefore, the characteristics of a 3-leg unsignalized intersection with a high percentage of FOOR collisions are as follows:

- *Intersection area:* Rural
- *Intersection entering volume:* <=5,000
- *Administrative system definition at major and minor roads*

  — Primary–Primary
  — Secondary–Secondary.

## Angle Collisions at 4-Leg Unsignalized Intersections

From the root node in Figure 5, 1,858 4-leg unsignalized intersections have greater than the mean percentage of angle collisions (43.7%). Terminal Node 6 was identified as having the highest index percentage (135.5%) as compared to all six terminal nodes. The intersection features that satisfy the group of Node 6 categories are as follows:

- *Entering volume (AADT) ratio at major and minor roads*

  — 50–50
  — 60–40
  — 70–30
  — 80–20.

- *Intersection entering volume: >5,000.*

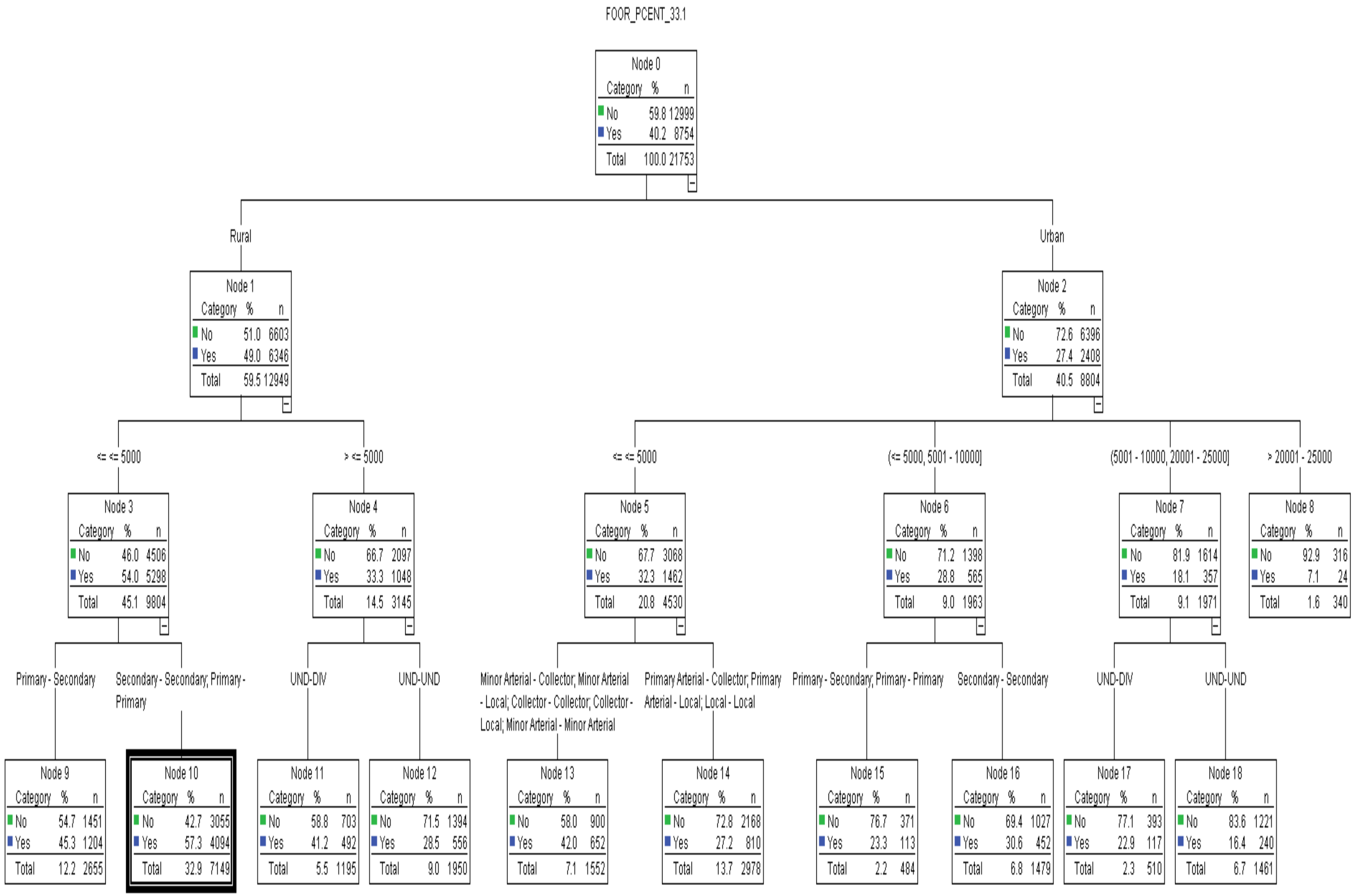



**Figure 4. Classification Tree for FOOR Collisions at 3-Leg Unsignalized Intersections. FOOR = fixed object off road.**

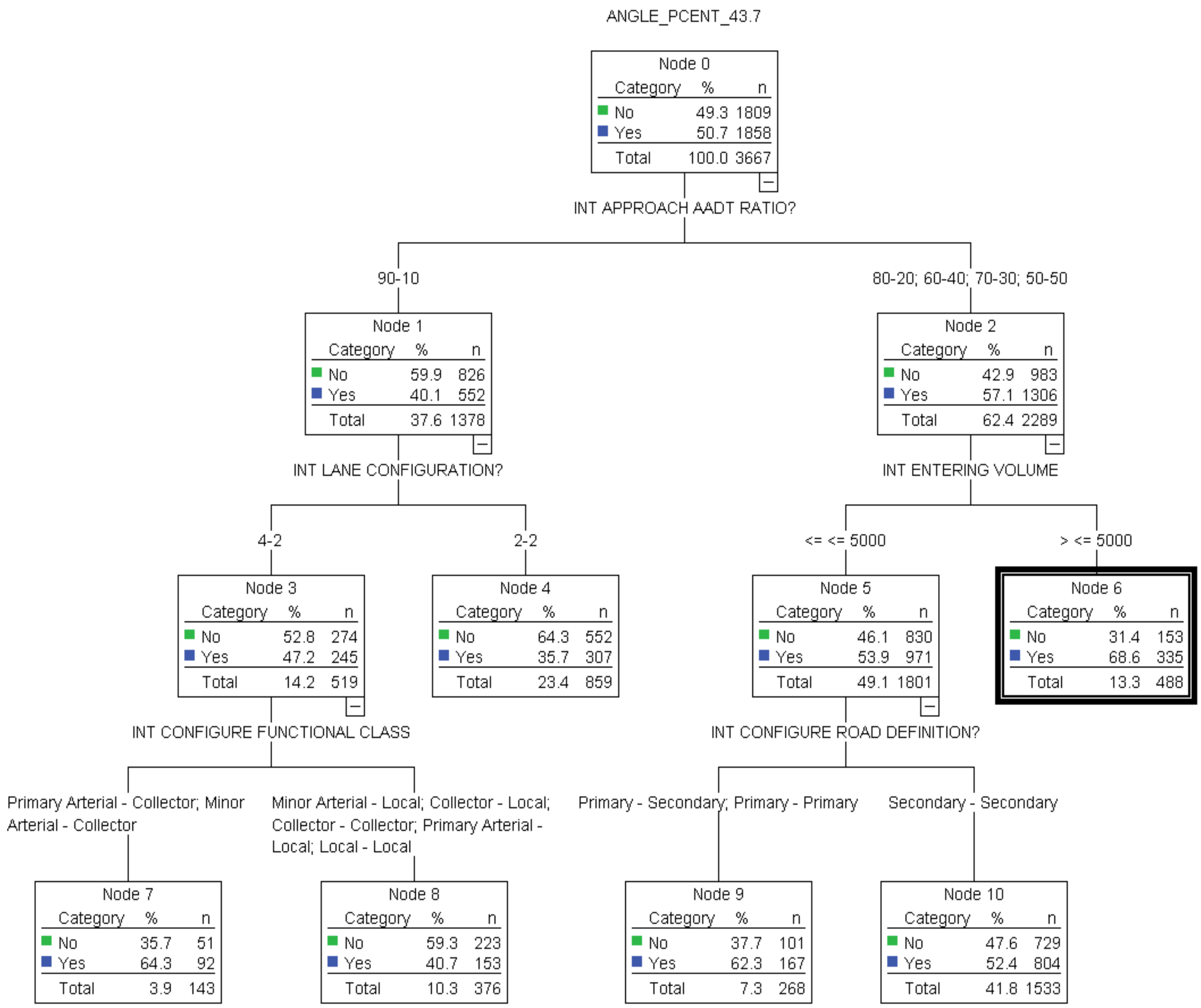



**Figure 5. Classification Tree for Angle Collision at 4-Leg Unsignalized Intersections**

## Rear-End Collisions at 4-Leg Unsignalized Intersections

According to the results shown in Table 4, the mean percentage of rear-end collisions at 4-leg unsignalized intersections was 13.7 percent. Of the total of 3,667 4-leg unsignalized intersections, 28 percent (1,027) had a percentage of rear-end collisions greater than this value. The CHAID tree analysis shown in Figure 6 indicates that Terminal Node 15 had the highest index percentage (246.8%) compared to that of the remaining eight terminal nodes.

The intersection features that describe Node 15 are as follows:

- *Intersection entering volume:* >10,000
- *Intersection area:* Urban
- *Intersection median configuration at major and minor roads:* Undivided–Undivided.

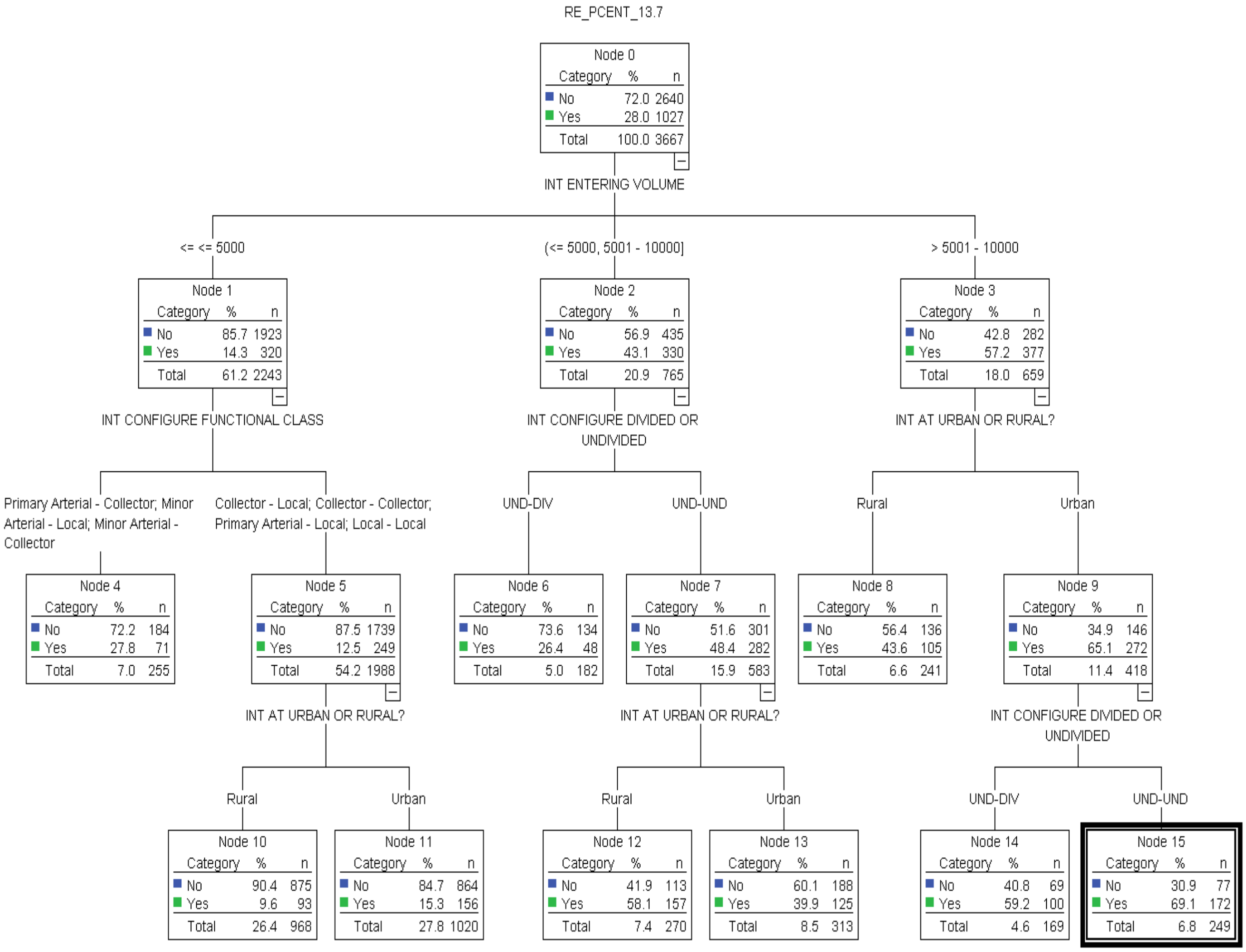



**Figure 6. Classification Tree for Rear-End Collisions at 4-Leg Unsignalized Intersections**

## Summary

CHAID identified specific features of unsignalized intersections where the focus collision types are predominant. Table 6 summarizes the identified features for each focus collision type, number of intersections for the chosen node, target threshold for that node, and number of crashes at those intersections.

## Case Study Review

The crash histories of at least two intersections in each of the four targeted groups identified in the crash analysis were reviewed to gain insight into typical crash patterns and other factors such as driver characteristics, time of day, weather, etc., at these types of intersections. A description of the case studies is provided in Appendix A.

From these case studies, it was observed that crash frequency and patterns; geometrics; traffic control, especially markings; and road conditions varied among sites in the same group. Although the four target groups are each based on one collision type, there are other types of crashes at the intersections that may be considered for treatment. Moreover, the value of a study of each intersection before any treatment is deployed to identify site-specific issues is evident.

**Table 6. Summary of the Identified Intersection Features for the Focus Collision Types**

| Collision Type | Feature | Threshold of Target Collision Type |
|---|---|---|
| **3-Leg Angle Collision** | | |
| | • INT Entering Volume: >15,000<br>• INT Functional Classification<br>— Primary Arterial–Collector<br>— Minor Arterial–Minor Arterial<br>— Minor Arterial–Collector<br>— Local–Local | $INT_{Angle} > 22.5\%$ |
| No. of Intersections | 259 | 197 |
| No. of Crashes | 1,189 | 1,112 |
| **3-Leg Fixed Object Off Road (FOOR) Collision** | | |
| | • INT Area: Rural<br>• INT Entering Volume: ≤5,000<br>• INT Administrative Definition<br>— Primary–Primary<br>— Secondary–Secondary | $INT_{FOOR} > 33.1\%$ |
| No. of Intersections | 7,149 | 4,094 |
| No. of Crashes | 5,324 | 5,238 |
| **4-Leg Angle Collision** | | |
| | • INT Entering Volume Ratio<br>— 50–50<br>— 60–40<br>— 70–30<br>— 80–20<br>• INT Entering Volume: >5,000 | $INT_{Angle} > 43.7\%$ |
| No. of Intersections | 488 | 335 |
| No. of Crashes | 2,269 | 2,062 |
| **4-Leg Rear-End Collision** | | |
| | • INT Entering Volume: >10,000<br>• INT Area: Urban<br>• INT Median Configuration: Undivided–Undivided | $INT_{Rear\text{-}End} > 13.7\%$ |
| No. of Intersections | 249 | 172 |
| No. of Crashes | 535 | 500 |

INT = intersection.

Therefore, instead of potential countermeasures being selected for each collision type group, countermeasures are presented in a tier structure in the next section.

## Low-Cost Countermeasures

An extensive list of countermeasures was reviewed, with the UIIG being the primary source. The CMF Clearinghouse[15] was searched to identify CMFs for each countermeasure (see Appendix B). Unfortunately, the majority of countermeasures did not have CMFs.

## Countermeasures and a Tier Structure

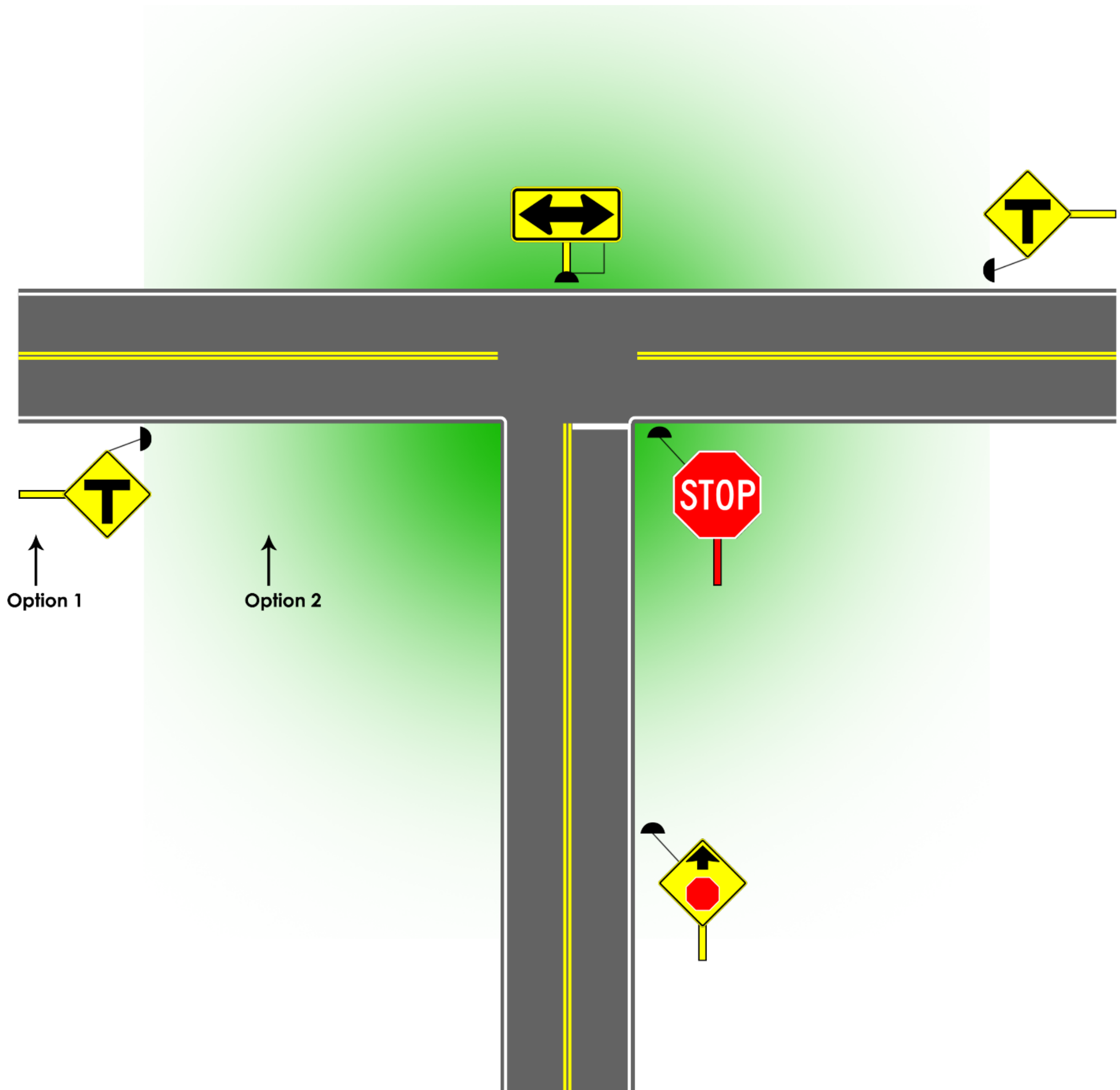
The potential low-cost ($10,000-$15,000 or less) countermeasures were arranged in a three-tier structure. The basic set of countermeasures should be considered a package of improvements consisting of the following:

*Tier 1 (Figure 7)*

- standard advance intersection ahead warning signs, advance “Stop Ahead” warning signs, and stop signs
- properly spaced stop bar and double-yellow centerline (up to 50 ft)
- for T-intersections, double-arrow warning sign
- yellow retroreflective strip on advanced warning sign posts
- red retroreflective strip on the stop sign post
- on the major approach where rear-end crashes are a concern, “Watch for Turning Vehicles” advance warning sign
- removal of any foliage or parking that limits sight distance.

*Tier 2 (Figure 8)*

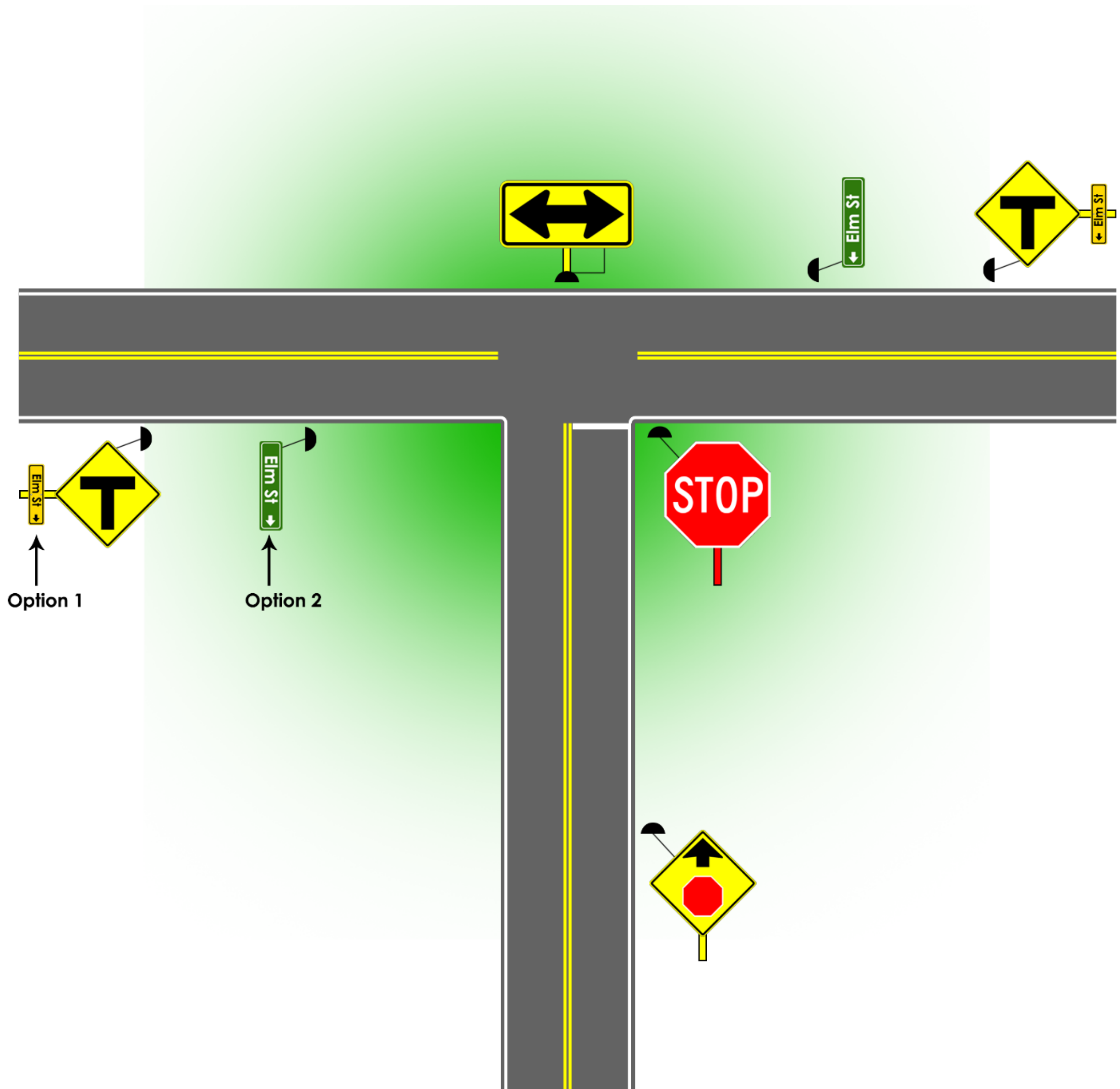
- properly spaced stop bar and double-yellow centerline (up to 50 ft)
- for T-intersections, large double-arrow warning sign
- yellow retroreflective strip on advance warning sign posts
- red retroreflective strip on the stop sign post
- oversized advance intersection warning signs on the through approach (or option: dual left and right oversized signs)
- options: (1) advance street name plaque with advance intersection warning sign (also where limited right of way exists), and (2) advance street name sign on the through approach
- oversized advance “Stop Ahead” intersection warning signs (option: dual left and right oversized signs)
- oversized stop signs (option: dual left and right oversized signs)




***Tier 1***

- Standard advance intersection ahead warning signs, advance "Stop Ahead" warning signs, and stop signs
- Properly spaced Stop bar and double yellow centerline (up to 50 ft)
- For T intersections, double arrow warning sign
- Yellow retroreflective strip on advanced warning sign posts
- Red retroreflective strip on the stop sign post
- On the major approach where rear end crashes are a concern, WATCH FOR TURNING VEHICLES advanced warning sign
- Removal of any foliage or parking that limits sight distance.

**Figure 7. Tier 1 Countermeasures for 3-Leg Intersections. (For 4-leg intersections, remove the double arrow and duplicate the stop sign approach on the opposite side.)**




***Tier 2***

- Properly spaced Stop bar and double yellow centerline (up to 50 ft)
- For T intersections, large double arrow warning sign
- Yellow retroreflective strip on advanced warning sign posts
- Red retroreflective strip on the stop sign post
- Oversize advance intersection warning signs on the through approach (or option: Dual (left and right) oversize signs)
- Options: 1) advance street name plaque with advance intersection warning sign (also where limited right of way exists) or 2) Advance street name sign on the through approach
- Oversize advance "Stop Ahead" intersection warning signs. (option: Dual (left and right), oversize signs)
- Oversize STOP signs (option: Dual (left and right), oversize signs)
- On the major approach where rear end crashes are a concern, WATCH FOR TURNING VEHICLES oversize advanced warning sign
- Optional: Installation of a minimum 6 ft. wide raised splitter island on the stop approach (if no pavement widening is required).
- Removal of any foliage or parking that limits sight distance.

**Figure 8. Tier 2 Countermeasures for 3-Leg Intersections. (For 4-leg intersections, remove the double arrow and duplicate the stop sign approach on the opposite side.) All signs are larger than in Tier 1.**

- on the major approach where rear-end crashes are a concern, “Watch for Turning Vehicles” oversized advance warning sign

- option: installation of a minimum 6-ft-wide raised splitter island on the stop approach (if no pavement widening is required)

- removal of any foliage or parking that limits sight distance.

*Tier 3 (Figure 9)*

- properly spaced stop bar and double-yellow centerline (up to 50 ft)

- for T-intersections, large double-arrow warning sign

- yellow retroreflective strip on advance warning sign posts

- red retroreflective strip on the stop sign post

- dual (left and right) oversized advance “Stop Ahead” intersection warning signs

- dual (left and right), oversized stop signs

- dual (left and right) oversized advance intersection warning signs on the through approach

- options: (1) advance street name plaque with advance intersection warning sign (also where limited right of way exists), and (2) advance street name sign on the through approach

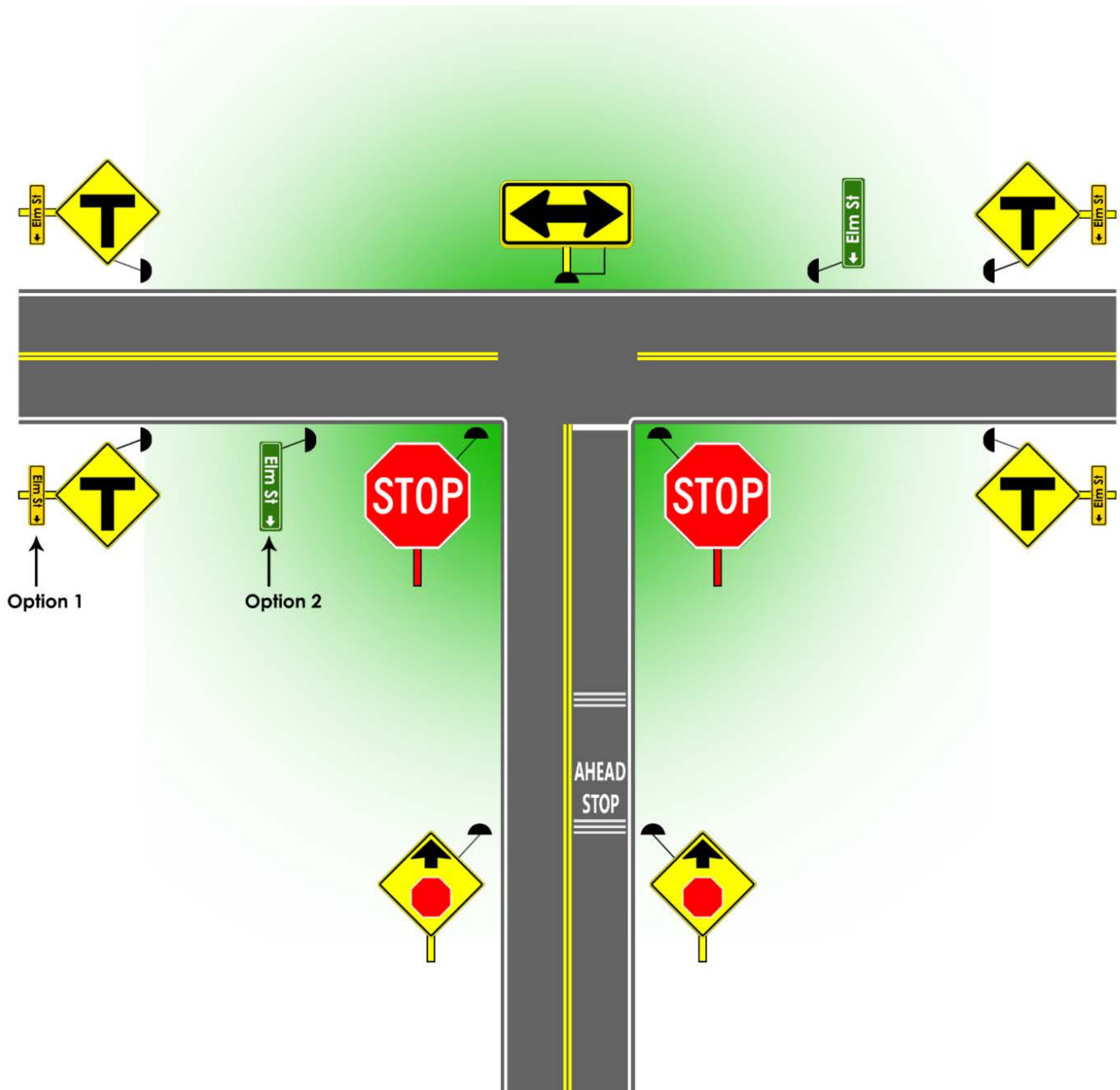
- pavement marking messages: “Stop Ahead”

- transverse rumble strips across the stop approach lanes in rural areas where noise is not a concern and running stop signs is a problem (use only “Stop Ahead” pavement markings if noise is a concern)

- on the major approach where rear-end crashes are a concern, “Watch for Turning Vehicles” oversized advance warning sign

- option: installation of a minimum 6-ft-wide raised splitter island on the stop approach (if no pavement widening is required)

- removal of any foliage or parking that limits sight distance.




***Tier 3***

- Properly spaced Stop bar and double yellow centerline (up to 50 ft)
- For T intersections, large double arrow warning sign
- Yellow retroreflective strip on advanced warning sign posts
- Red retroreflective strip on the stop sign post
- Dual (left and right), oversize advance "Stop Ahead" intersection warning signs.
- Dual (left and right), oversize STOP signs
- Dual (left and right) Oversize advance intersection warning signs on the through approach
- Options: 1) advance street name plaque with advance intersection warning sign (also where limited right of way exists) 2) Advance street name sign on the through approach
- Pavement marking messages: STOP AHEAD
- Transverse rumble strips across the stop approach lanes in rural areas where noise is not a concern and running STOP signs is a problem. (Use only "Stop Ahead" pavement markings if noise is a concern.).
- On the major approach where rear end crashes are a concern, WATCH FOR TURNING VEHICLES oversize advanced warning sign
- Optional: Installation of a minimum 6 ft. wide raised splitter island on the stop approach (if no pavement widening is required).
- Removal of any foliage or parking that limits sight distance.

**Figure 9. Tier 3 Countermeasures for 3-Leg Intersections. (For 4-leg intersections, remove the double arrow and duplicate the stop sign approach on the opposite side.)**

Additional individual countermeasures can be considered based on an engineering study. These include:

- flashing solar-powered LED beacons on advance intersection warning signs and stop signs
- flashing overhead intersection beacons
- extension of the through edgeline using a short skip pattern; this countermeasure is used on intersections with very wide throats in which stopped drivers have difficulty stopping at the correct location
- single luminaire intersection LED lighting to address night crashes
- delineation through the intersection if needed based on the degree of curvature
- intersection sight distance improvements through low-cost measures that may involve changes on private property.

Other measures are listed in Appendix B. Table 7 is a listing of the estimated costs of the countermeasures in the three tiers. Cost information was provided by VDOT's Culpeper District Traffic Engineering Section. Table 8 provides cost estimates for each tier for 3- and 4-leg intersections. These costs were rounded up to the nearest $500 increment to simplify estimates and provide a cushion.

**Table 7. Cost Estimates of Countermeasures**

| **Tier 1** | **Cost Installed** |
|---|---|
| Standard advance intersection ahead warning signs | $275.60 |
| Standard advance "Stop Ahead" warning sign | $230.60 |
| Standard stop sign | $230.98 |
| Properly spaced stop bar and double-yellow centerline (up to 50 ft) | $553.30 |
| W1-7 Double-Arrow 18 in x 36 in | $194.60 |
| Yellow/Red retroreflective strip on sign post per post | $40.00 |
| **Tier 2a Low-Cost Countermeasures for the Through Approach** | |
| Oversized advance intersection warning sign | $515.96 |
| Advance street name plaques with the advance intersection warning sign | $50 |
| Advance street name sign | $750.00 |
| **Tier 2b Low-Cost Countermeasures for the Stop Approach** | |
| Large W1-7 Double Arrow 24 in x 48 in | $238.60 |
| Oversized advance "Stop Ahead" intersection warning signs | $483.96 |
| Removal of any foliage or parking that limits sight distance (per hour) | $125.00 |
| Installation of a minimum 6-ft-wide raised splitter island on the stop approach (if no pavement widening is required) | NA |
| **Tier 3** | |
| Dual (left and right) oversized stop signs | $967.92 |
| Pavement marking messages: "Stop Ahead" | $796.11 |
| Pavement marking messages: "Slow" | $515.00 |
| Transverse rumble strips, 2 sets 1 direction | $1,228.70 |

*Source:* VDOT's Culpeper District Traffic Engineering Section.

**Table 8. Cost Estimates by Tier for 3- and 4-Leg Intersections**

| Tier | 3-Leg | 4-Leg |
|---|---|---|
| 1 | $2,000 | $3,000 |
| 2 | $3,000 | $4,500 |
| 3 | $5,500 | $8,500 |

The selection of a tier for an intersection depends on what traffic control devices are currently present and the results of the field/engineering study. Although this effort focuses on low-cost countermeasures, it is possible that the field/engineering study will result in higher cost countermeasures being the recommended treatment.

## Safety Improvement Plan

### Using the PSI for Scoping Systemic Projects

Although CHAID effectively narrowed down the high-risk characteristics of unsignalized intersections to the four focus collision types, the number of intersections filtered through the method was still relatively high, at almost 4,800. To narrow down the number of intersections to a manageable size for a systemic safety project, the intersections were prioritized using the PSI. From the “Methods” section, a positive PSI implies that the site has a high potential for safety improvement. A zero or negative PSI, however, indicates a typical or low level of crash occurrences, implying a lower potential for safety improvement.

Therefore, the annual PSI was calculated each year for the 5 years of crash data and then summed for each site. For example, a PSI (3) means that a positive PSI was measured for 3 of the 5 years. Table 9 shows the screening results of the annual PSI status over the past 5 years for each focus collision type at the intersections from CHAID. The four focus collision types were divided into six groups, from PSI (0 Yr) > 0 to PSI (5 Yr) > 0.

As stated previously, the selection of a tier for an intersection depends on what traffic control devices are currently present and the results of the field/engineering study. Although this effort focuses on low-cost countermeasures, it is possible that the field/engineering study will result in higher cost countermeasures being the recommended treatment.

**Table 9. PSI Values for Each Focus Group of Intersections**

| PSI Group | Angle at 3-Leg Unsignalized Intersections | FOOR at 3-Leg Unsignalized Intersections | Angle at 4-Leg Unsignalized Intersections | Rear-End at 4-Leg Unsignalized Intersections | Total |
|---|---|---|---|---|---|
| PSI (5 Yr) > 0 | 17 | 13 | 26 | 1 | 57 |
| PSI (4 Yr) > 0 | 28 | 63 | 31 | 16 | 138 |
| PSI (3 Yr) > 0 | 40 | 261 | 57 | 21 | 379 |
| PSI (2 Yr) > 0 | 40 | 969 | 62 | 40 | 1,111 |
| PSI (1 Yr) > 0 | 37 | 2,748 | 74 | 53 | 2,912 |
| PSI (0 Yr) > 0 | 35 | 40 | 85 | 41 | 201 |
| Total | 197 | 4,094 | 335 | 172 | 4,798 |

PSI = potential for safety improvement; FOOR = fixed object off road.

Because a PSI (0) implies a low potential for safety improvement, that group would not be considered for treatment. Moreover, the process of clustering intersections by the appearance of the annual PSI can be used as a control where there is a concern that the frequency of crashes is low. Next, PSI values were used to group sites beginning with the highest value PSI, PSI (5), and adding 1 year as one proceeds down the first column in Table 9. This was performed successively to yield five PSI groups for each collision type, as shown in Table 10.

The cost estimates in Table 11 were calculated for the total number of intersections in each PSI group. One option for implementation is a phased approach to begin by treating sites in the PSI (5) or PSI (4-5) categories and then treat sites in lower categories over time as funds are available. In Table 10, an estimate of the overall systemic program cost to implement countermeasures by tier group for intersections in the PSI (5) category is $394,500 for Tier 3; $211,500 for Tier 2; and $141,000 for Tier 1 (values from Table 8 were rounded up). The recommended list of projects will be a mix of the three tiers; therefore, the Tier 2 estimate may be more realistic as an average estimate of costs. An alternative option is to choose different PSI threshold values for different collision types.

**Table 10. Range of Number of Potential Treatment Intersections by Collision Type and PSI**

| Collision Type | No. of Intersections | | | | |
|---|---|---|---|---|---|
| | **PSI (5 yr)** | **PSI (4-5 yr)** | **PSI (3-5 yr)** | **PSI (2-5 yr)** | **PSI (1-5 yr)** |
| 3-leg Angle | 17 | 45 | 85 | 125 | 162 |
| 3-leg FOOR | 13 | 76 | 337 | 1306 | 4,054 |
| 4-leg Angle | 26 | 57 | 114 | 176 | 250 |
| 4-leg Rear-End | 1 | 17 | 38 | 78 | 131 |
| Total No. of Intersections | 57 | 195 | 574 | 1685 | 4597 |

PSI = potential for safety improvement. FOOR = fixed object off road.

**Table 11. Cost Estimates by Tier and PSI**

| Tier | PSI (5 yr) | PSI (4-5 yr) | PSI (3-5 yr) | PSI (2-5 yr) | PSI (1-5 yr) |
|---|---|---|---|---|---|
| 3 | $394,500 | $1,294,500 | $3,613,000 | $10,029,500 | $26,426,500 |
| 2 | $211,500 | $696,000 | $1,950,000 | $5,436,000 | $14,362,500 |
| 1 | $141,000 | $464,000 | $1,300,000 | $3,624,000 | $9,575,000 |

PSI = potential for safety improvement.

## Estimate of Planning Level Benefits

One of the challenges in this study was identifying CMFs for the potential countermeasures individually and in combination. CMFs for a combination of countermeasures are needed to match the tiered countermeasure approach used in this effort, but CMFs are not available for many of the countermeasures. Moreover, the implemented plan may include fewer or additional countermeasures based on the final plan to be developed by VDOT district traffic engineers (DTEs) based on the intersection study. The study *Safety Evaluation of Multiple Strategies at Stop-Controlled Intersections,*[13, 14] described in the literature review, provides CMFs for combined treatments for intersections maintained by SCDOT. It does not include intersections of two local roads that are maintained by county agencies. The combination of devices is similar to those in Tier 3 without the pavement marking message and transverse rumble strips. Excluding the nighttime CMF (0.853), the CMFs ranged from 0.899 to 0.941. The total crash CMF was 0.917. The study determined that the B/C ratio, estimated with conservative cost and service life assumptions and considerations of the benefits for total crashes, was 12.4:1. With the sensitivity analysis, these B/C ratios could range from 7.1:1 to 17.5:1 for a 3-year service life. For a 7-year service life, the range is 14.5 to 35.9, with an average of 25.5. The estimated costs for treatments by VDOT are lower than those used by SCDOT.

Table 12 displays a range of CMFs for each tier. This range is conservative, based on the literature and assumptions by the researchers with input from VDOT staff.

**Table 12. Planning Level Estimates of Total Crash CMF Ranges and B/C Ratios by Tier**

| Tier | CMF Range for Total Crashes | B/C Ratio |
|---|---|---|
| 1 | 0.90-0.98 | 5-7 |
| 2 | 0.85-0.95 | 8-10 |
| 3 | 0.80-0.91 | 11-13 |

CMF = crash modification factor; B/C ratio = benefit-cost ratio.

## Plan Process/Framework

The following is a brief step-by-step plan for action.

1. VDOT's Traffic Engineering Division (TED) provides an Excel spreadsheet with candidate intersections arranged by the four focus collision types to DTEs for the designated funding level.

2. DTEs review the list and then plan and conduct intersection safety/field studies.

3. DTEs determine candidate intersections to move forward for implementation and propose the treatments using the tier structure, countermeasure options provided in this report, and other countermeasures that they may select.

4. DTEs move forward with requesting and then allocating funding for treatment and initiating the implementation.

5. After the plan has been in place 5 years, the TED evaluates it, makes changes as needed, and repeats CHAID to generate an updated spreadsheet.

# CONCLUSIONS

- *There were 25,420 unsignalized intersections with one or more crashes during the 5-year study period, 2011-2015, in Virginia.*

- *The four intersection focus collision types with the highest percentage of crashes were 3-leg angle, 3-leg FOOR, 4-leg angle, and 4-leg rear-end.*

- *CHAID revealed that the sites with the following characteristics typically had a higher than average proportion of the targeted crash types:*

- *Angle crashes at 3-leg stop-controlled intersections where angle crashes were greater than 22.5 percent; functional classifications of Primary Arterial–Collector, Minor Arterial–Minor Arterial, Minor Arterial–Collector, and Local–Local.*

- *FOOR crashes at 3-leg stop-controlled intersections with FOOR crashes greater than 33.1 percent; AADT less than 5,000; administrative classifications of Primary–Primary and Secondary–Secondary.*

- *Angle crashes at 4-leg stop-controlled intersections where angle crashes were greater than 43.7 percent; AADT greater than 5,001; AADT ratios of 50–50, 60–40, 70–30, and 80–20.*

- *Rear-end crashes at 4-leg stop-controlled intersections where rear-end crashes were greater than 13.7 percent; AADT greater than 10,001 at intersections of two undivided roads.*

- *Potential countermeasures were grouped into three tiers. The countermeasures were intended to warn of the stop ahead, make the stop sign and stop location more visible on the minor street; and warn of the intersection ahead on the major street.*

- *A plan was developed combining the four groups and the countermeasure options. The PSI was used to prioritize the candidate intersections for study. A study of each intersection is included in the plan to determine the tier/countermeasures that are appropriate for the intersections.*

- *A conservative B/C ratio for the three tiers of treatment countermeasures ranges from 5 to 13.*

## RECOMMENDATIONS

1. *VDOT's TED should lead and promote the safety improvement plan for unsignalized intersections developed in this study as an element of its safety program.* Systemic treatment of unsignalized intersections is the foundation of the plan. Additional details may be added as needed. A partial list of the potential locations to consider that were identified in this study for each collision type is provided in Appendices C through F. An Excel spreadsheet with the complete lists will be made available to the TED. The list of intersections should be provided to each district. The DTE staff should conduct a field review and study of each intersection and then determine the appropriate treatment for implementation and develop a plan for implementation.

## IMPLEMENTATION AND BENEFITS

### Implementation

The TED's Assistant Division Administrator for Safety has agreed to implement Recommendation 1, the plan for systemic low-cost countermeasures for unsignalized intersections, as part of the TED's safety program. Available funding sources are not limited to safety funds. The TED will send this draft plan to the DTEs and others (as appropriate) within 6 months after the publication of this report. A 60-day (or less) period will be allotted for the districts to review and provide comments on the plan.

Comments will be assessed by the Virginia Transportation Research Council (VTRC) and the TED, and a final plan will be issued within 4 months after the review period ends. After the plan is implemented, TED's Highway Safety Section will update the list of candidate sites every 2 to 3 years. A before-after study to assess the effectiveness of the treatments will be conducted. VTRC, in cooperation with the TED, will evaluate the unsignalized intersection program including the development of CMFs for combination treatments as a technical assistance effort approximately 5 years after implementation.

### Benefits

In addition to the benefits noted for the systemic safety approach, implementing the study recommendation will help shape the future deployment of targeted systemic safety countermeasure projects at unsignalized intersections across Virginia with an ultimate goal of reducing the number of crashes occurring at such intersections. The plan developed in this study targets unsignalized intersections that have the highest potential for safety improvement. The plan includes options to phase in the investigation of intersections and subsequent treatment based on the needs at that intersection but using the tiered countermeasures as a starting point. The low-cost approach enables more intersections to be treated in a comprehensive manner.


## ACKNOWLEDGMENTS

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## APPENDIX A

## CASE STUDIES FOR UNSIGNALIZED INTERSECTIONS

The crash histories for at least two intersections in each of the four targeted groups identified in the crash analysis were reviewed to gain insight into typical crash patterns and other factors such as driver characteristics, time of day, weather, etc., at these types of intersections. A summary of the analysis is provided here.

### 3-Leg Angle Intersections

The intersections most likely to have a higher than average proportion of angle crashes at 3-leg stop-controlled intersections had the following characteristics: angle crashes at 3-leg stop-controlled intersections where angle crashes were greater than 22.5 percent; and functional classifications of Primary Arterial–Collector, Minor Arterial–Minor Arterial, Minor Arterial–Collector, and Local–Local.

#### Routes 13 and 692 Accomack County

This section of Route 13 is a four-lane divided highway with left- and right-turn lanes into Route 692 (see Figure A1). The speed limit on Route 13 is 55 mph. There were 10 crashes: 8 angle, 1 rear-end, and 1 deer (5 were property-damage only [PDO]). Of the 8 angle crashes, 2 were at a nearby driveway to a flea market; 1 involved a mainline vehicle turning left and colliding with opposing traffic; and 5 involved a vehicle from the side road (of these 5, 3 involved drivers age 82 to 85). One driver involved in one of the nearby driveway crashes was 81. Crashes involving drivers over age 80 occurred during the daytime and under dry conditions.


**Figure A1. Routes 13 and 692 Accomack County. Source: Google StreetView.**

**Routes 220 and 919 Franklin County**

Route 220 is a four-lane divided highway with a speed limit of 55 mph (see Figure A2). There were 33 crashes: 25 angle, 7 rear-end, and 1 sideswipe same direction (15 PDOs). There were 18 angle crashes near the stop sign (6 with drivers age 17 to 19 and 4 at night and in dry conditions). Three angle crashes involved something blocking/impacting the view: 2 involved a right-turning vehicle and 1 had sunlight. Ten crashes involved vehicles in the median, with angle and rear-end crashes each accounting for 5. The cause of some crashes appeared to be related to errors in drivers judging gaps in the approaching traffic. With one-third of the angle crashes involving younger drivers, inexperience may also have been an issue.


**Figure A2. Routes 220 and 919 Franklin County. Source: Google StreetView.**

## 3-Leg FOOR

The intersections most likely to have a higher than average proportion of FOOR crashes at 3-leg stop-controlled intersections had the following characteristics: FOOR crashes at 3-leg stop-controlled intersections with FOOR crashes greater than 33.1 percent; AADT under 5,000; and administrative classifications of Primary–Primary and Secondary–Secondary.

**Routes 658 and 661 Accomack County**

For these two secondary roads, the speed limit is 55 mph (see Figure A3). There were 6 crashes: all FOOR, with 4 PDOs. The main road, Route 658, turns at the intersection. In 2 crashes, drivers failed to navigate the turn and went straight across Route 658 from the T-approach into a yard. One crash was under dark wet conditions (allegedly fog), and the other under day dry conditions. There was 1 run off road right (cell phone as distraction), 1 run off road left, and 1 run off road eluding the police.

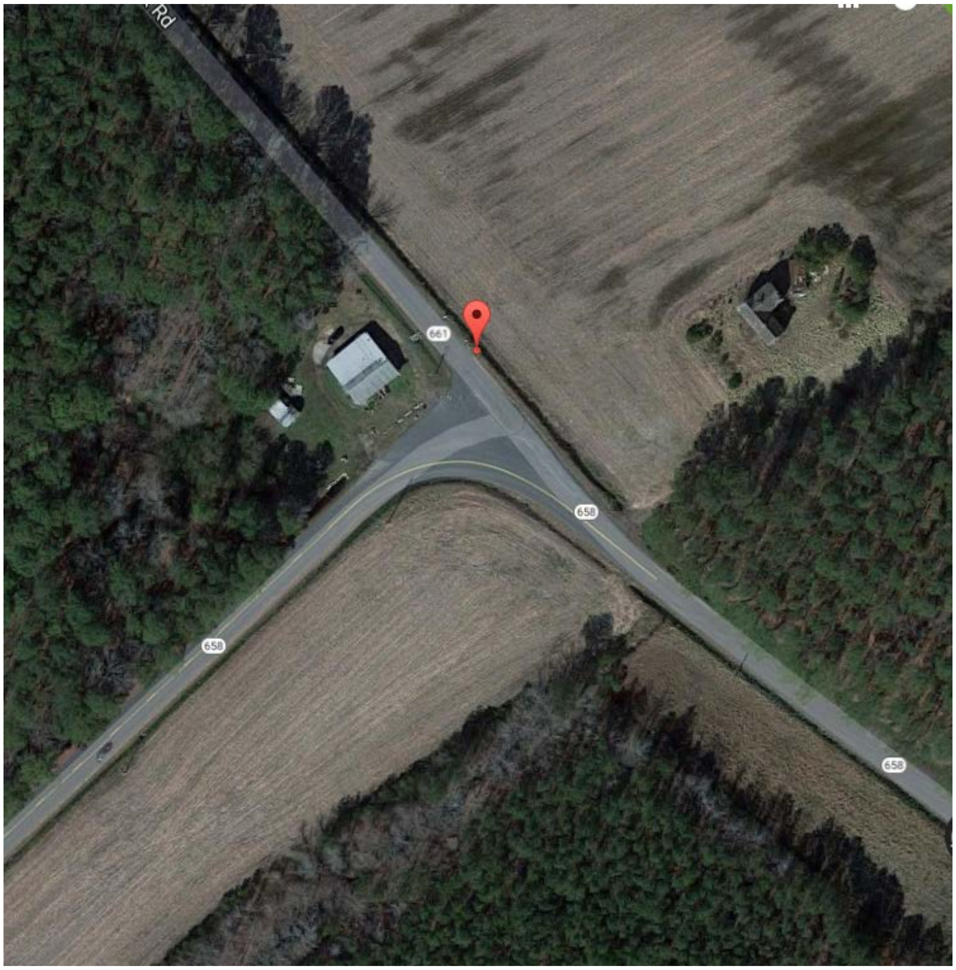

**Figure A3. Routes 658 and 661 Accomack County. Source: Google StreetView.**

### Routes 608 and 778 Augusta County

For these two secondary roads, the speed limit is 55 mph (see Figure A4). There were 6 crashes: 5 FOOR and 1 head-on, with 4 PDOs. In 3 crashes, the driver went straight at the T; in one of these crashes the driver was driving under the influence during mist conditions at dusk. Three crashes were at night, and 1 was at dusk under wet conditions. Two drivers fled the scene including the one driving under the influence.

**Figure A4. Routes 608 and 778 Augusta County. Source: Google StreetView.**

## 4-Leg Angle

The intersections most likely to have a higher than average proportion of angle crashes at 4-leg stop-controlled intersections had the following characteristics: angle crashes at 4-leg stop-controlled intersections where angle crashes were greater than 43.7 percent; AADT greater than 5,001; and AADT ratios of 50–50, 60–40, 70–30, and 80–20.

### Routes 738 and 683 Fairfax County

For these two secondary roads, the speed limits are 40 mph on Route 738 and 25 mph on Route 683 (see Figure A5). There were 47 crashes (23 PDOs) at this site: 41 angle, 2 rear-end, 2 head-on, and 2 other. For angle crashes, 28 northbound and 13 southbound crashes involved a driver entering the intersection from the side street. There were 32 crashes during the daytime with dry conditions, 4 during rain, 2 at night/darkness, and 1 in snow. There were 7 three-vehicle crashes. In 3 crashes, a driver noted trees blocking his or her view. Two northbound drivers were waved through by a mainline driver and then hit from the opposite direction.

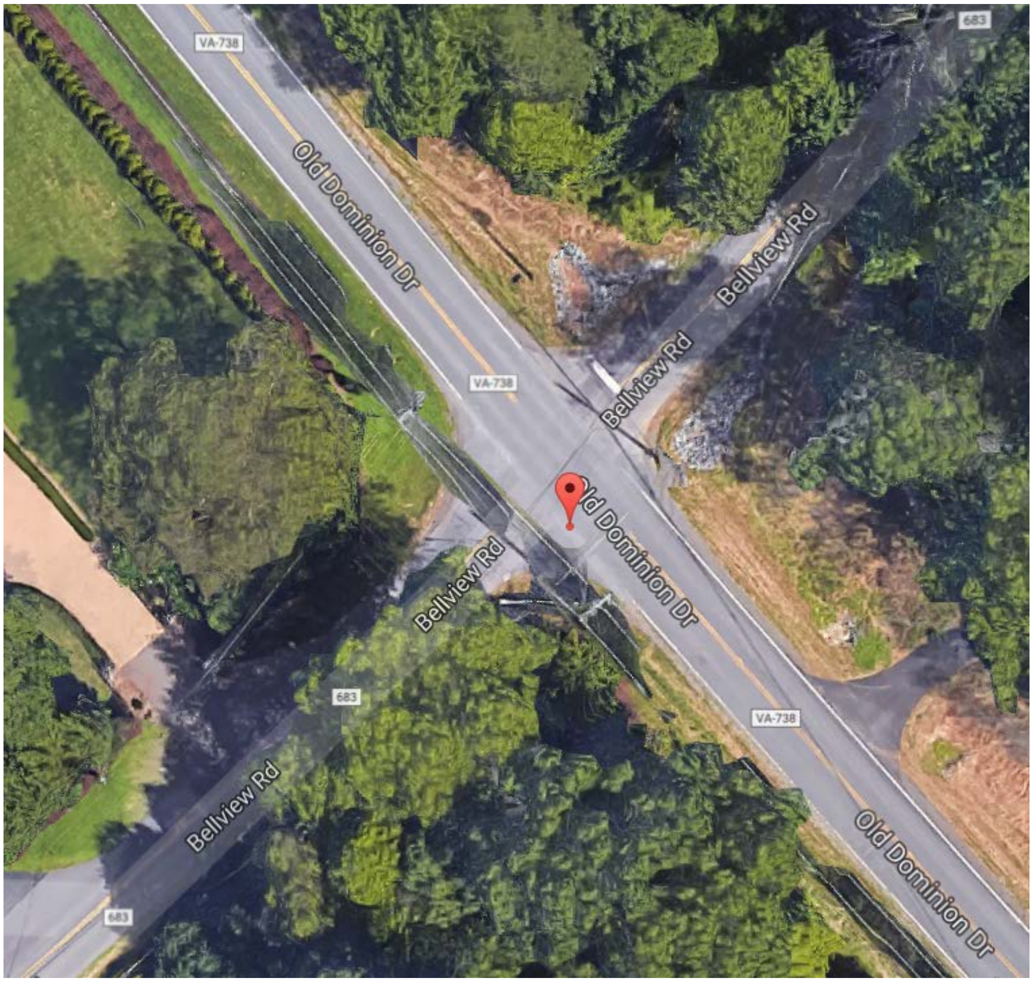

**Figure A5. Route 738 and 683 Fairfax County. Source: Google StreetView.**

### Lakeview Avenue and Route 625 Chesterfield County

The speed limit is 35 mph on both roads (see Figure A6). There were 40 crashes (22 PDOs): 31 angle, 3 sideswipe opposite direction, 3 FOOR, 2 rear-end, and 1 head-on. From the mainline, there were 10 crashes: 9 eastbound drivers turning left, and 1 westbound driver. From the side street, 13 northbound drivers and 16 southbound drivers were involved in crashes. Four drivers were cited with running the stop sign; 14 stopped prior to entering the intersection. There were 30 crashes during the day with dry conditions and 3 in darkness and dry conditions. One driver stated that he did not see the stop sign and thought there was a four-way stop. There were 6 three-vehicle crashes.

**Figure A6. Lakeview and Route 625 Chesterfield County. Source: Google StreetView.**

## 4-Leg Rear-End

The intersections most likely to have a higher than average proportion of rear-end crashes at 4-leg stop-controlled intersections had the following characteristics: rear-end crashes at 4-leg stop-controlled intersections where rear-end crashes were greater than 13.7 percent; and AADT greater than 10,001 at intersections of two undivided roads.

### Route 171/Victory Boulevard and Bowman Terrace York County

Route 171 is a two-lane road with a 55 mph speed limit, and Bowman Terrace is two lanes with a 25 mph speed limit (see Figure A7). There were 18 crashes: 14 rear-end, 3 FOOR, and 1 head-on (15 PDOs). Of the rear-end crashes, 8 were westbound and 6 were eastbound. The primary cause of the crashes appeared to be drivers not reacting to stopped or slowing traffic ahead. Six of the 18 crashes involved drivers age 17 to 18, including one ill driver; one-third of the crashes involved inexperienced/teen drivers.

**Figure A7. Route 171/Victory Boulevard and Bowman Terrace York County. Source: Google StreetView.**

## Burke Lake Road and Grantham Street Fairfax County

Burke Lake Road is a four-lane divided road with a speed limit of 35 mph, and Grantham is a two-lane road with a speed limit of 25 mph (see Figure A8). There were 30 crashes: 22 angle, 6 rear-end, 1 sideswipe same direction, and 1 pedestrian (14 PDOs). Five rear-end crashes involved northbound vehicles with vehicles stopped in traffic in 4 cases and 3 crashes involved three vehicles. The one southbound rear-end crash also involved vehicles stopped and three vehicles. Thirteen angle crashes involved westbound vehicles, and 13 involved southbound vehicles. In 7 crashes, vehicles were stopped in the right through lane; the vehicle from the side street proceeded and collided with a vehicle in the left through lane. In 3 of these crashes, drivers of stopped vehicles in the right through lane waved to the side street drivers so as to yield the right of way. Note that this intersection was screened as a candidate for improvement for rear-end crashes, but the predominant crash type was angle. Therefore, another case study follows for this group.

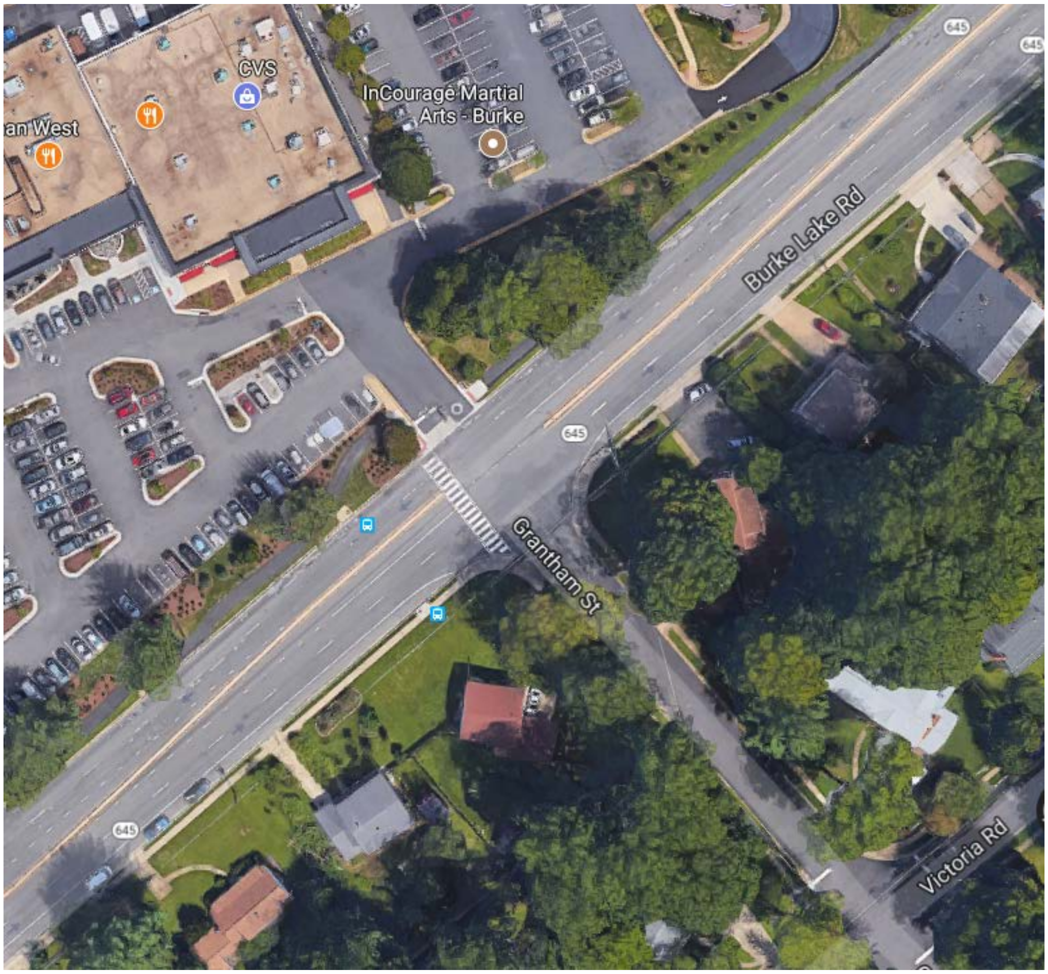

**Figure A8. Burke Lake Road and Grantham Street Fairfax County. Source: Google StreetView.**

## Arch Road and Redbridge Road Chesterfield County

The speed limit is 35 mph on Arch Road and 25 mph on Redbridge Road (see Figure A9). There were 13 crashes: 6 rear-end, 4 FOOR, 2 angle, and 1 other (12 PDOs; 1 injury). All 6 rear-end crashes involved a vehicle northbound on Arch Road stopped or stopping to turn left at Redbridge Road and a following vehicle colliding with it or a stopped following vehicle. Two angle crashes occurred during snow.

**Figure A9. Arch Road and Redbridge Road Chesterfield County. Source: Google StreetView.**

# APPENDIX B

## TABLE OF LOW-COST ENGINEERING COUNTERMEASURES FOR UNSIGNALIZED INTERSECTIONS FROM THE *UNSIGNALIZED INTERSECTION IMPROVEMENT GUIDE* (UIIG)[2]

This list was screened to identify countermeasures that would likely be implemented by VDOT in this effort. Information in Columns 1 and 3 is from the UIIG. Column 2 data (where available) are from the CMF Clearinghouse.[15] For CMFs, crash severity is all crash types: All/Angle/Rear End (RE); Area type: All (A)/urban (U)/rural (R); NS = not specified; * = quality < 3 stars. Blank cells indicate that CMFs are not available.

| Countermeasure Name | CMF Crash Type/Area Type | Target Crash Types |
|---|---|---|
| **Traffic Control Devices** | | |
| **Intersection Control** | | |
| Implement All-Way Stop Control | 0.25 Angle/U<br>0.52 All/RE | Right-angle<br>Pedestrian<br>Bicyclist |
| Install an Intersection Control Beacon | 0.87 Angle/A<br>0.92 RE/A | Right-angle<br>Opposing left turn<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Install a Stop Line | | Right-angle<br>Pedestrian |
| Install a Stop Beacon at Stop Sign | 0.87 Angle/A<br>0.92 RE/A | Right-angle<br>Rear-end (minor road) |
| **Operational Improvements** | | |
| Prohibit Turn Movements Using Signs | | Right-angle<br>Opposing left turn<br>Rear-end (major road) |
| Re-Time Adjacent Traffic Signals | | Right-angle<br>Rear-end (major road)<br>Pedestrian |
| **Intersection Warning** | | |
| Install Intersection Warning Signs | | Right-angle<br>Rear-end (major road) |
| Install Advance Traffic Control Warning Signs | | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road) |
| Install Post-Mounted Reflective Delineators at the Intersection | | Right-angle<br>Rear-end (major road) |
| **Conspicuity Enhancements to Traffic Control Devices** | | |
| Increase the Size of a Regulatory or Warning Sign | | Right-angle<br>Rear-end (major road) |

| | | |
|---|---|---|
| | | Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Add a Duplicate Regulatory or Warning Sign | 0.45 Angle/A* | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Install a Warning Beacon on a Standard Regulatory or Warning Sign | 0.63 RE/A*<br>0.38 Angle/A* | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Use LED Units within a Regulatory or Warning Sign | 0.59 Angle/A | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Install Reflective Panels on Sign Posts | | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Install Wider Longitudinal Pavement Markings | | Right-angle<br>Rear-end (major road)<br>Sideswipe, opposite direction<br>Sideswipe, same direction<br>Head-on |
| **Motorist Guidance** | | |
| Install Center Line Pavement Markings in a Median Crossing | | Right-angle<br>Opposing left turn<br>Sideswipe, same direction<br>Head-on |
| Install Center Line Pavement Markings on the Minor Road Approach | 0.99 All/R | Opposing left turn<br>Right-angle<br>Sideswipe, opposite direction<br>Head-on |
| Install Dotted Line Pavement Markings | | Right-angle<br>Opposing left turn<br>Rear-end (major road) |
| Install Lane Assignment Pavement Markings or Signing | | Rear-end (major road)<br>Rear-end (minor road)<br>Sideswipe, opposite direction<br>Sideswipe, same direction |
| Install Pavement Word and/or Symbol Markings | | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road) |
| Install Dotted Turn Path Markings | | Sideswipe, opposite direction<br>Sideswipe, same direction<br>Head-on |
| Install Raised Pavement Markers | | Right-angle |

| | | |
|---|---|---|
| | | Rear-end (major road)<br>Sideswipe, opposite direction<br>Sideswipe, same direction<br>Head-on |
| **Treatments Related to Non-Motorists** | | |
| Install or Modify Crosswalk Markings | | Pedestrian |
| Install a Rectangular Rapid-Flashing Beacon (RRFB) | NA | Pedestrian |
| Install Bicycle Lane Pavement Markings Across the Intersection | | Bicyclist |
| Install Signs Warning of Pedestrians and Bicyclists | | Pedestrian<br>Bicyclist |
| **Speed Control** | | |
| Add a Beacon to a Standard Speed Limit Sign | | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Install Speed Reduction Pavement Markings | | Right-angle<br>Rear-end (major road)<br>Sideswipe, opposite direction |
| Install a Dynamic Speed Feedback Sign | 0.95 All/R | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| **Geometric Features** | | |
| Eliminate Turn Movements Using Design Alterations and Channelization | | Right-angle<br>Opposing left turn<br>Rear-end (major road)<br>Pedestrian |
| Replace Left-Turn and Through Movements with a Right-Turn/U-Turn Combination | 0.8 All/N | Right-angle<br>Opposing left turn<br>Rear-end (major road)<br>Pedestrian |
| Close One or More Legs of the Intersection | | Right-angle<br>Opposing left turn<br>Rear-end (major road) |
| Close a Median Opening | | Right-angle<br>Opposing left turn<br>Rear-end (major road) |
| Reduce an Intersection Curb Radius | | Pedestrian<br>Bicyclist |
| Increase an Intersection Curb Radius | | Rear-end (major road)<br>Rear-end (minor road)<br>Sideswipe, opposite direction |
| Reduce the Width of the Travel Lanes on the Major Road Approach | | Right-angle<br>Rear-end (major road)<br>Pedestrian<br>Bicyclist |

| | | |
|---|---|---|
| Install a Splitter Island on the Minor Road Approach | | Right-angle<br>Rear-end (minor road) |
| Provide Offset to Left-Turn Lanes | 0.66 All/NS | Right-angle<br>Opposing left turn<br>Rear-end (major road)<br>Sideswipe, opposite direction<br>Head-on |
| Provide Offset to a Right-Turn Lane | | Inadequate intersection sight distance<br>Excessive intersection conflicts |
| Install a Bypass Lane at a T-Intersection | 0.95 All/R | Rear-end (major road) |
| Provide a Pedestrian Refuge Island | | Pedestrian |
| Install a Residential Traffic Circle | | Right-angle |
| Install Curb Extensions at the Crosswalk | | Pedestrian |
| Restrict Driveway Access | | Right-angle<br>Rear-end (major road) |
| **Roadside/Shoulder Treatments** | | |
| Clear the Intersection Sight Triangles | | Right-angle<br>Rear-end (major road) |
| Eliminate Parking at or near the Intersection | | Right-angle<br>Rear-end (major road)<br>Pedestrian |
| **Pavement Surface Treatments** | | |
| Install Transverse Rumble Strips on the Intersection Approach | | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road) |
| Install a High-Friction Surface Treatment on the Intersection Approach | | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road) |
| **Other Engineering Treatments** | | |
| Install Intersection Lighting | | Right-angle<br>Rear-end (major road)<br>Rear-end (minor road)<br>Pedestrian<br>Bicyclist |
| Relocate a Bus Stop | | Pedestrian<br>Right-angle |

# APPENDIX C

## LIST OF 3-LEG UNSIGNALIZED INTERSECTIONS FOR ANGLE COLLISION PSI (4-5)

| Intersection Node | Approach 1 | Approach 2 | Approach 3 | District | 2011-2015 Total Crashes | PSI |
|---|---|---|---|---|---|---|
| 403039 | 4800610 | SR00003 | SR00003 | Fredericksburg | 15 | 5 |
| 541065 | 13408727 | US00058 | US00058 | Hampton Roads | 47 | 5 |
| 483069 | 12408545 | US00017 | US00017 | Hampton Roads | 25 | 5 |
| 484834 | 13108661 | 13108665 | 13108661 | Hampton Roads | 24 | 5 |
| 541354 | 13408833 | 13408627 | 13408627 | Hampton Roads | 23 | 5 |
| 483357 | 12208637 | SR00166 | SR00166 | Hampton Roads | 15 | 5 |
| 179527 | C1US00501 | 11806052 | C1US00501 | Lynchburg | 19 | 5 |
| 546251 | 7601781 | 7600640 | 7600640 | Northern Virginia | 30 | 5 |
| 279607 | 15306933 | 15306648 | 15306648 | Northern Virginia | 28 | 5 |
| 717148 | 2907442 | 2906363 | 2906363 | Northern Virginia | 27 | 5 |
| 428525 | 5300760 | SR00007 | SR00007 | Northern Virginia | 24 | 5 |
| 263044 | 2900602 | SR00193 | SR00193 | Northern Virginia | 20 | 5 |
| 203157 | 2000618 | US00001 | US00001 | Richmond | 54 | 5 |
| 209199 | 2000619 | US00001 | US00001 | Richmond | 43 | 5 |
| 205990 | 2002001 | SR00145 | SR00145 | Richmond | 25 | 5 |
| 379173 | 4307687 | 4307526 | 4307526 | Richmond | 25 | 5 |
| 328183 | 3300635 | US00220 | US00220 | Salem | 23 | 5 |
| 313061 | 3000628 | US00017 | US00017 | Culpeper | 14 | 4 |
| 621460 | 8901007 | SR00218 | SR00218 | Fredericksburg | 17 | 4 |
| 343108 | 3600623 | SR00003 | SR00003 | Fredericksburg | 11 | 4 |
| 413076 | 5000618 | US00360 | US00360 | Fredericksburg | 11 | 4 |
| 403026 | 4800607 | SR00003 | SR00003 | Fredericksburg | 10 | 4 |
| 541172 | 13408731 | SR00190 | SR00190 | Hampton Roads | 22 | 4 |
| 483054 | 13108531 | US00017 | US00017 | Hampton Roads | 18 | 4 |
| 483751 | 12208564 | US00460 | US00460 | Hampton Roads | 18 | 4 |
| 179319 | 11806083 | SR00163 | SR00163 | Lynchburg | 22 | 4 |
| 716081 | 10000008 | 2902532 | 10006622 | Northern Virginia | 25 | 4 |
| 715568 | 15100002 | SR00123 | SR00123 | Northern Virginia | 22 | 4 |
| 546030 | 7600605 | SR00028 | SR00028 | Northern Virginia | 19 | 4 |
| 263393 | 2907345 | 2900620 | 2900620 | Northern Virginia | 18 | 4 |
| 279502 | 11006795 | SR00007 | SR00007 | Northern Virginia | 17 | 4 |
| 276684 | 2900634 | 2900611 | 2900611 | Northern Virginia | 12 | 4 |
| 101041 | 0000025 | 0006710 | 0006710 | Northern Virginia | 10 | 4 |
| 263525 | 2900630 | 2900629 | 2900629 | Northern Virginia | 8 | 4 |
| 210160 | 12700001 | US00360 | US00360 | Richmond | 28 | 4 |
| 378740 | 4300029 | SR00271 | SR00271 | Richmond | 25 | 4 |
| 373127 | 4200623 | US00001 | US00001 | Richmond | 21 | 4 |
| 715450 | 2003867 | 2003600 | 2003600 | Richmond | 17 | 4 |
| 209687 | 12707548 | SR00010 | SR00010 | Richmond | 16 | 4 |
| 120327 | SR00153 | US00360 | US00360 | Richmond | 15 | 4 |
| 526347 | SR00013 | US00060 | US00060 | Richmond | 15 | 4 |
| 248178 | 2600632 | US00460 | US00460 | Richmond | 14 | 4 |
| 120013 | 0400604 | US00360 | US00360 | Richmond | 12 | 4 |
| 328737 | 3300919 | US00220 | US00220 | Salem | 33 | 4 |
| 328108 | 3300619 | US00220 | US00220 | Salem | 18 | 4 |

## APPENDIX D

## LIST OF 3-LEG UNSIGNALIZED INTERSECTION FOR FIXED-OBJECT OFF ROAD COLLISION PSI (4-5)

| Intersection Node | Approach 1 | Approach 2 | Approach 3 | District | 2011-2015 Total Crashes | PSI |
|---|---|---|---|---|---|---|
| 233135 | 2300636 | 2300644 | 2300644 | Culpeper | 6 | 5 |
| 358066 | 3900623 | 3900633 | 3900633 | Culpeper | 6 | 5 |
| 503028 | 6800621 | 6800608 | 6800621 | Culpeper | 6 | 5 |
| 183157 | 1600738 | 1600738 | 1600639 | Fredericksburg | 9 | 5 |
| 621074 | 8900628 | 8900608 | 8900608 | Fredericksburg | 7 | 5 |
| 728248 | 3601342 | 3600618 | 3600618 | Fredericksburg | 6 | 5 |
| 519849 | SR00041 | SR00057 | SR00057 | Lynchburg | 15 | 5 |
| 428307 | 5300673 | 5300690 | 5300673 | Northern Virginia | 10 | 5 |
| 348361 | SR00045 | SR00006 | SR00006 | Richmond | 9 | 5 |
| 742618 | 2600609 | 2600619 | 2600619 | Richmond | 6 | 5 |
| 463166 | 6000718 | 6000652 | 6000652 | Salem | 7 | 5 |
| 463226 | 6000679 | 6000669 | 6000669 | Salem | 6 | 5 |
| 586016 | 8200947 | 8200602 | 8200602 | Staunton | 7 | 5 |
| 606161 | 8600638 | 8600637 | 8600637 | Bristol | 4 | 4 |
| 651973 | 9500694 | 9500609 | 9500609 | Bristol | 4 | 4 |
| 110115 | 0200627 | 0200795 | 0200795 | Culpeper | 10 | 4 |
| 313350 | 3000802 | 3000802 | 3000687 | Culpeper | 9 | 4 |
| 313355 | 3000742 | 3000688 | 3000688 | Culpeper | 9 | 4 |
| 110203 | 0200819 | 0200649 | 0200649 | Culpeper | 7 | 4 |
| 313913 | 3000610 | 3000610 | 3000612 | Culpeper | 7 | 4 |
| 313103 | 3000639 | 3000616 | 3000616 | Culpeper | 6 | 4 |
| 313110 | 3000801 | 3000616 | 3000616 | Culpeper | 6 | 4 |
| 561212 | SR00231 | US00522 | US00522 | Culpeper | 6 | 4 |
| 111187 | 0200641 | 0200606 | 0200641 | Culpeper | 5 | 4 |
| 313074 | 3000616 | 3000610 | 3000616 | Culpeper | 5 | 4 |
| 313545 | 3001133 | 3000802 | 3000802 | Culpeper | 5 | 4 |
| 313956 | 3000678 | 3000691 | 3000691 | Culpeper | 5 | 4 |
| 503023 | 6800606 | 6800608 | 6800608 | Culpeper | 5 | 4 |
| 111110 | 0200627 | 0200627 | 0200626 | Culpeper | 4 | 4 |
| 313086 | 3000611 | 3000806 | 3000806 | Culpeper | 4 | 4 |
| 503050 | 6800638 | 6800612 | 6800612 | Culpeper | 4 | 4 |
| 403030 | 4800677 | 4800609 | 4800609 | Fredericksburg | 7 | 4 |
| 616040 | 8800617 | 8800605 | 8800605 | Fredericksburg | 7 | 4 |
| 258067 | 2800618 | 2800619 | 2800619 | Fredericksburg | 5 | 4 |
| 183048 | 1600607 | 1600606 | 1600606 | Fredericksburg | 4 | 4 |
| 403041 | 4800610 | 4800631 | 4800610 | Fredericksburg | 4 | 4 |
| 363073 | 4000681 | 4000619 | 4000619 | Hampton Roads | 9 | 4 |
| 106094 | 0109501 | 0100691 | 0100691 | Hampton Roads | 6 | 4 |
| 626012 | 9000604 | 9000617 | 9000617 | Hampton Roads | 6 | 4 |
| 626062 | 9000616 | 9000622 | 9000622 | Hampton Roads | 6 | 4 |
| 393097 | 4600652 | 4600620 | 4600620 | Hampton Roads | 5 | 4 |
| 626059 | 9000630 | 9000616 | 9000616 | Hampton Roads | 5 | 4 |
| 178377 | 1500761 | 1500699 | 1500761 | Lynchburg | 9 | 4 |
| 701274 | 4100640 | 4100640 | 4100668 | Lynchburg | 7 | 4 |
| 473615 | 6200724 | 6200655 | 6200655 | Lynchburg | 5 | 4 |
| 130046 | 0600667 | 0600608 | 0600608 | Lynchburg | 4 | 4 |
| 130171 | 0600643 | 0600691 | 0600691 | Lynchburg | 4 | 4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 428655 | 5300617 | 5300860 | 5300860 | Northern Virginia | 11 | 4 |
| 428352 | 5300702 | 5300690 | 5300690 | Northern Virginia | 6 | 4 |
| 546352 | 7600652 | 7600652 | 7600656 | Northern Virginia | 5 | 4 |
| 428236 | 5300662 | 5300707 | 5300662 | Northern Virginia | 4 | 4 |
| 203212 | 2000626 | 2000654 | 2000654 | Richmond | 8 | 4 |
| 203076 | 2000784 | 2000604 | 2000604 | Richmond | 7 | 4 |
| 203077 | 2000605 | 2000604 | 2000604 | Richmond | 7 | 4 |
| 526017 | 7200610 | 7200604 | 7200604 | Richmond | 6 | 4 |
| 248131 | 2600658 | 2600619 | 2600619 | Richmond | 5 | 4 |
| 348057 | 3700612 | 3700621 | 3700621 | Richmond | 5 | 4 |
| 526042 | 7200614 | 7200613 | 7200614 | Richmond | 5 | 4 |
| 203036 | 2000603 | 2000603 | 2000655 | Richmond | 4 | 4 |
| 453146 | 5800641 | 5800903 | 5800903 | Richmond | 4 | 4 |
| 328110 | 3300902 | 3300619 | 3300619 | Salem | 7 | 4 |
| 571200 | 8000653 | 8000688 | 8000688 | Salem | 6 | 4 |
| 463058 | 6000674 | 6000615 | 6000615 | Salem | 5 | 4 |
| 463061 | 6000669 | 6000615 | 6000615 | Salem | 5 | 4 |
| 556008 | 7700623 | 7700600 | 7700600 | Salem | 5 | 4 |
| 556084 | 7700617 | 7700627 | 7700627 | Salem | 5 | 4 |
| 571110 | 8000697 | 8000624 | 8000624 | Salem | 5 | 4 |
| 188012 | 1700606 | 1700721 | 1700606 | Salem | 4 | 4 |
| 383070 | 4400620 | 4400610 | 4400610 | Salem | 4 | 4 |
| 383443 | 4400779 | 4400698 | 4400698 | Salem | 4 | 4 |
| 463524 | 6000693 | 6000600 | 6000693 | Salem | 4 | 4 |
| 556115 | 7700625 | 7700627 | 7700627 | Salem | 4 | 4 |
| 333012 | 3400600 | 3400600 | 3400614 | Staunton | 7 | 4 |
| 136156 | 0700608 | 0700608 | 0700778 | Staunton | 6 | 4 |
| 641061 | 9300619 | 9300673 | 9300619 | Staunton | 6 | 4 |
| 135113 | 0700619 | 0700611 | 0700611 | Staunton | 4 | 4 |

## APPENDIX E

## LIST OF 4-LEG UNSIGNALIZED INTERSECTION FOR ANGLE COLLISION PSI (4-5)

| Intersection Node | Approach 1 | Approach 2 | Approach 3 | Approach 4 | District | 2011-2015 Total Crashes | PSI |
|---|---|---|---|---|---|---|---|
| 468639 | 13301332 | 13301332 | 13301310 | 13301310 | Hampton Roads | 15 | 5 |
| 178196 | 1500646 | 1500646 | SR00024 | SR00024 | Lynchburg | 17 | 5 |
| 264457 | 2900683 | 2900683 | 2900738 | 2900738 | Northern Virginia | 47 | 5 |
| 263275 | 2901157 | 2901157 | 2900617 | 2900617 | Northern Virginia | 42 | 5 |
| 722783 | 7603682 | 7600643 | 7600642 | 7600642 | Northern Virginia | 39 | 5 |
| 265266 | 2908591 | 2908591 | 2900858 | 2900858 | Northern Virginia | 34 | 5 |
| 737335 | 5302237 | 5302237 | 5300742 | 5300742 | Northern Virginia | 33 | 5 |
| 546143 | 7600622 | 7600622 | US00029 | US00029 | Northern Virginia | 29 | 5 |
| 546079 | 7600760 | 7600760 | 7600616 | 7600616 | Northern Virginia | 28 | 5 |
| 428643 | 5300864 | 5300864 | 5300846 | 5300846 | Northern Virginia | 24 | 5 |
| 100928 | 0006626 | 0006626 | 0006682 | 0006682 | Northern Virginia | 21 | 5 |
| 703165 | 2907960 | 2907960 | 2907969 | 2907969 | Northern Virginia | 20 | 5 |
| 264199* | 2900667 | 2900667 | 2900665 | 2900665 | Northern Virginia | 18 | 5 |
| 706499 | 2907435 | 2907435 | 2900656 | 2900656 | Northern Virginia | 13 | 5 |
| 263135 | 2900611 | 2900611 | SR00242 | SR00242 | Northern Virginia | 12 | 5 |
| 546114 | 7600648 | 7600648 | 7600619 | 7600619 | Northern Virginia | 10 | 5 |
| 203207 | 2000625 | 2000625 | 2000626 | 2000626 | Richmond | 40 | 5 |
| 203104 | 2000611 | 2000611 | 2000637 | 2000637 | Richmond | 29 | 5 |
| 373033 | 4200606 | 4200643 | 4200606 | 4200643 | Richmond | 23 | 5 |
| 373386 | 4200671 | 4200671 | SR00054 | SR00054 | Richmond | 23 | 5 |
| 745233 | 2000638 | 2000638 | 2000651 | 2000651 | Richmond | 22 | 5 |
| 203155 | 2000618 | 2000617 | 2000617 | 2000618 | Richmond | 21 | 5 |
| 373139 | 4200626 | 4200626 | 4200657 | 4200657 | Richmond | 15 | 5 |
| 378945 | 4300031 | 4300031 | 4307559 | 4307559 | Richmond | 11 | 5 |
| 526053 | 7200615 | 7200615 | US00522 | US00522 | Richmond | 11 | 5 |
| 328344 | 3300834 | 3300670 | 3300670 | 3300834 | Salem | 19 | 5 |
| 313414 | SR00055 | 3000709 | 3000709 | SR00055 | Culpeper | 12 | 4 |
| 403113 | 4800632 | SR00218 | SR00206 | SR00206 | Fredericksburg | 19 | 4 |
| 728029* | 8801976 | 8801716 | 8800610 | 8800610 | Fredericksburg | 19 | 4 |
| 541601 | 13408679 | 13408749 | 13408749 | 13408679 | Hampton Roads | 15 | 4 |
| 253013 | 11407059 | 11407059 | US00060 | US00060 | Hampton Roads | 13 | 4 |
| 178299 | 1500681 | 1500681 | 1500682 | 1500682 | Lynchburg | 14 | 4 |
| 428636 | 5301402 | 5301402 | 5300846 | 5300846 | Northern Virginia | 20 | 4 |
| 265930 | 2901157 | 2901157 | 2901158 | 2901158 | Northern Virginia | 19 | 4 |
| 264376 | 2900676 | 2900676 | 2900738 | 2900738 | Northern Virginia | 18 | 4 |
| 546236 | 7600740 | 7600740 | 7600639 | 7600639 | Northern Virginia | 17 | 4 |
| 546373 | 7600661 | 7600661 | 7600692 | 7600692 | Northern Virginia | 17 | 4 |
| 546101 | 7601108 | 7601108 | 7600619 | 7600619 | Northern Virginia | 16 | 4 |
| 265437* | 2900937 | 2900937 | SR00193 | SR00193 | Northern Virginia | 15 | 4 |
| 735914 | 5301951 | 5301999 | 5301795 | 5301795 | Northern Virginia | 15 | 4 |
| 263710 | 2906100 | 2906100 | 2900641 | 2900641 | Northern Virginia | 13 | 4 |
| 428166* | 5301010 | 5301010 | 5300637 | 5300637 | Northern Virginia | 13 | 4 |
| 719677 | 7600751 | 7600751 | 7600643 | 7600643 | Northern Virginia | 10 | 4 |
| 717472 | FR00782 | FR00782 | 2900756 | 2900756 | Northern Virginia | 8 | 4 |
| 210490 | 12707643 | 12707643 | 12707542 | 12707542 | Richmond | 27 | 4 |
| 203697* | 2000718 | 2000718 | 2000678 | 2000678 | Richmond | 24 | 4 |
| 203100 | 2000611 | 2000611 | 2000642 | 2000642 | Richmond | 22 | 4 |
| 348103 | 3700708 | 3700623 | US00250 | US00250 | Richmond | 18 | 4 |
| 203002 | 2000628 | 2000600 | 2000628 | 2000600 | Richmond | 13 | 4 |
| 498281 | 6700723 | 6700723 | US00460 | US00460 | Richmond | 13 | 4 |
| 709459 | 2004713 | 2004713 | 2004700 | 2004700 | Richmond | 13 | 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 210630 | 12707562 | 12707562 | 12707603 | 12707603 | Richmond | 12 | 4 |
| 373278 | 4201155 | 4201155 | 4200643 | 4200643 | Richmond | 12 | 4 |
| 203339 | 2001607 | 2001607 | 2000641 | 2000641 | Richmond | 11 | 4 |
| 338155 | 3500640 | 3500640 | US00460 | US00460 | Salem | 20 | 4 |
| 463118 | 6000637 | 6000637 | US00011 | US00011 | Salem | 17 | 4 |
| 513288 | 7000680 | 7000680 | US00058 | US00058 | Salem | 15 | 4 |

* PSI >= 3 on both angle and rear-end collisions.

# APPENDIX F

## LIST OF 4-LEG UNSIGNALIZED INTERSECTIONS FOR REAR-END COLLISIONS PSI (4-5)

| Intersection Node | Approach 1 | Approach 2 | Approach 3 | Approach 4 | District | 2011-2015 Total Crashes | PSI |
|---|---|---|---|---|---|---|---|
| 264199* | 2900667 | 2900667 | 2900665 | 2900665 | Northern Virginia | 18 | 5 |
| 728029* | 8801976 | 8801716 | 8800610 | 8800610 | Fredericksburg | 19 | 4 |
| 616083 | 8800609 | 8800609 | US00017 | US00017 | Fredericksburg | 14 | 4 |
| 468138 | 13300629 | 13300629 | 13300627 | 13300627 | Hampton Roads | 23 | 4 |
| 671954 | 9901656 | 9901656 | SR00171 | SR00171 | Hampton Roads | 20 | 4 |
| 263847 | 2905910 | 2905910 | 2900645 | 2900645 | Northern Virginia | 32 | 4 |
| 263938 | 2902304 | 2902304 | 2900649 | 2900649 | Northern Virginia | 16 | 4 |
| 547408 | 7601532 | 7601532 | 7601530 | 7601530 | Northern Virginia | 16 | 4 |
| 265437* | 2900937 | 2900937 | SR00193 | SR00193 | Northern Virginia | 15 | 4 |
| 263170 | 2900819 | 2900819 | 2900611 | 2900611 | Northern Virginia | 13 | 4 |
| 428166* | 5301010 | 5301010 | 5300637 | 5300637 | Northern Virginia | 13 | 4 |
| 263385 | 2908456 | 2903569 | 2900620 | 2900620 | Northern Virginia | 11 | 4 |
| 546430 | 7600682 | 7600682 | US00015 | US00015 | Northern Virginia | 7 | 4 |
| 267286 | 2903683 | 2903683 | 2901845 | 2901845 | Northern Virginia | 5 | 4 |
| 203697* | 2000718 | 2000718 | 2000678 | 2000678 | Richmond | 24 | 4 |
| 203167 | 2000619 | 2000619 | 2000620 | 2000620 | Richmond | 11 | 4 |
| 209316 | 2000661 | 2000661 | 2000621 | 2000621 | Richmond | 7 | 4 |

* PSI >= 3 on both angle and rear-end collisions.