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Pilot Implementation of a Resource Guide to Enhance the Incorporation of Safety Into the Regional Planning Process

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JOHN S. MILLER, Ph.D., P.E.
Associate Principal Research Scientist

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<p>To incorporate safety into the regional planning process, a Virginia-specific resource guide was recently developed for use by districts of the Virginia Department of Transportation (VDOT) and planning district commissions (PDCs). In order to determine how to enhance the implementation of the guide throughout Virginia, a pilot implementation of the guide was conducted in one Virginia PDC—the Roanoke Valley-Alleghany Regional Commission—where representatives helped identify tasks the guide should help them accomplish. Deliverables included (1) acquiring crash locations for incorporated cities (for which VDOT has not historically maintained roads); (2) identifying high-crash locations; (3) determining potential crash countermeasures; and (4) using safety-related performance measures that do not rely exclusively on crash data. These four deliverables corresponded to three modules in the resource guide: data needs (Deliverable 1), data analysis (Deliverables 2 and 3), and performance measures (Deliverable 4).</p> <p>The pilot implementation showed that most (87% of county crashes and 93% of city crashes) crashes could be successfully located in a geographic information system environment; that potential crash countermeasures could be identified based on a study of the characteristics of these crashes; and that for instances where crash data are likely to be sparse, non-crash-based performance measures are feasible. However, the pilot implementation showed that four additional types of guidance, not fully specified in the resource guide, may make accomplishing these tasks easier:</p> <ul style="list-style-type: none"> • the steps for querying crashes from VDOT's Crash Records Database and then importing those crashes into a geographic information system for an entire jurisdiction • approaches for determining what constitutes a crash cluster and whether a given cluster represents a relatively high concentration of crashes • ways to identify crash countermeasures based on examining crash characteristics; geometric characteristics; and, if necessary, the crash diagram and narrative • ways to use performance measures to support a program of interest to the region. <p>These four types of guidance are provided in Appendix B and in the examples provided in the body of this report. The pilot implementation also showed that it may be productive to focus on using the guide for short-term safety and planning initiatives first rather than focusing only on long-range planning issues.</p>					
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FINAL REPORT

**PILOT IMPLEMENTATION OF A RESOURCE GUIDE TO ENHANCE
THE INCORPORATION OF SAFETY INTO THE REGIONAL PLANNING PROCESS**

**John S. Miller, Ph.D., P.E.
Associate Principal Research Scientist**

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ABSTRACT

To incorporate safety into the regional planning process, a Virginia-specific resource guide was recently developed for use by districts of the Virginia Department of Transportation (VDOT) and planning district commissions (PDCs). In order to determine how to enhance the implementation of the guide throughout Virginia, a pilot implementation of the guide was conducted in one Virginia PDC—the Roanoke Valley-Alleghany Regional Commission—where representatives helped identify tasks the guide should help them accomplish. Deliverables included (1) acquiring crash locations for incorporated cities (for which VDOT has not historically maintained roads); (2) identifying high-crash locations; (3) determining potential crash countermeasures; and (4) using safety-related performance measures that do not rely exclusively on crash data. These four deliverables corresponded to three modules in the resource guide: data needs (Deliverable 1), data analysis (Deliverables 2 and 3), and performance measures (Deliverable 4).

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1. the steps for querying crashes from VDOT's Crash Records Database and then importing those crashes into a geographic information system for an entire jurisdiction
2. approaches for determining what constitutes a crash cluster and whether a given cluster represents a relatively high concentration of crashes
3. ways to identify crash countermeasures based on examining crash characteristics; geometric characteristics; and, if necessary, the crash diagram and narrative
4. ways to use performance measures to support a program of interest to the region.

These four types of guidance are provided in Appendix B and in the examples provided in the body of this report. The pilot implementation also showed that it may be productive to focus on using the guide for short-term safety and planning initiatives first rather than focusing only on long-range planning issues.

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INTRODUCTION

With the passage of the Intermodal Surface Transportation Efficiency Act of 1991, states and metropolitan areas were strongly encouraged to incorporate safety directly into the transportation planning process (Federal Highway Administration [FHWA], 1995) or highway planning (Depue, 2003) through the use of safety management systems (SMSs), which are described by Depue (2003) and FHWA (1995). Although the use of SMSs, along with six other management systems, was made optional in 1995 by the U.S. Congress, the concept of reducing crash risk by considering safety explicitly within the planning process has received additional emphasis under the terms *safety conscious planning* (Ritter, 2005) and *transportation safety planning* (FHWA, 2009).

One theme of SMSs, i.e., the integration of safety conscious planning and transportation planning, is that by the early consideration of safety in the planning process, crash reductions that otherwise would be infeasible can be achieved. Such integration may be performed at the regional level; for example, Naderan and Shahi (2010) developed methods for predicting crash frequency by transportation analysis zone—a computation that is integrated with the estimation of trips during the conventional travel demand forecasting process. Such integration may also be performed at the project level; for example, Roberts (2001) noted that a series of T-intersections rather than four-legged intersections may be used to reduce intersection conflict points and, by extension, crash risk but that such a decision is most effectively made prior to land development. Once development has occurred and a road is built, such retrofits remain feasible but are substantially more expensive.

Although the integration of transportation planning and safety may sound appealing, how precisely to accomplish this integration within Virginia's current planning processes has not been made clear. Thus, at the request of the Virginia Transportation Research Council's (now the Virginia Center for Transportation Research and Innovation [VCTIR]) Transportation Planning Research Advisory Committee, Miller et al. (2010c) developed a resource guide for incorporating safety into the regional transportation planning process. The guide is specific to Virginia and was designed for staff from planning district commissions (PDCs) (which support metropolitan planning organizations [MPOs]) and the districts of the Virginia Department of Transportation (VDOT). The resource guide has eight modules, as listed in Table 1.

Table 1. The Eight Modules of the Resource Guide^a and the Associated Steps for Completing Each Module

Name of Module	Associated Step
1. Vision Statement, Goals, and Objectives	Develop a vision statement, goals, and objectives that directly incorporate safety.
2. Stakeholders	Use diverse stakeholders to identify alternatives and evaluate their utility.
3. Performance Measures	Use safety-related performance measures to assess deficiencies.
4. Data Needs	Acquire data within the time constraints faced by the planner.
5. Data Analysis	Analyze data with available resources and thus select higher impact projects.
6. Prioritization	Prioritize projects to determine the largest expected crash avoidance given limited funds.
7. Funding	Identify alternative funding sources for safety-related projects.
8. Monitoring	Monitor the safety impacts of implemented projects.

^a Miller, J.S., Kamatu, J.N., and Garber, N.J. *Incorporating Safety Into the Regional Planning Process in Virginia: Volume II: A Resource Guide*. VTRC 10-R15. Virginia Transportation Research Council, Charlottesville, 2010.

At the time the guide was completed, a related recommendation in the accompanying report (Miller et al., 2010b) was that VDOT planning or engineering staff undertake a pilot effort to implement the resource guide in conjunction with an MPO's development of its Constrained Long-Range Transportation Plan. There were three main reasons for this recommendation:

1. *Additional guidance or information may be needed to implement the modules of the guide.* For example, data may have been available in locations where examples for the guide were developed that are not available in other locations in Virginia.
2. *Additional examples, available only from testing the guide on a wider audience, may be needed.* For example, although the guide includes urban and rural examples, suburban case studies may also be needed.
3. *For PDCs/MPOs, the additional work associated with using the guide may not justify its use to achieve the possible benefits or might be too time-consuming to undertake.*

PURPOSE AND SCOPE

The purpose of this study was to conduct a pilot implementation of the resource guide (Miller et al., 2010c) in one PDC/MPO area and, based on that pilot implementation, to identify information not already included in the guide that would enhance its use throughout Virginia.

The scope of the study was limited to piloting the guide within the Roanoke Valley–Alleghany Regional Commission (RVARC), one of the 21 Virginia PDCs, and to piloting only the modules of the guide that were of interest to RVARC staff. RVARC was selected as the location for the pilot implementation because although the guide provides Virginia examples, none of the examples involved RVARC, making it a desirable pilot test location.

METHODOLOGY

Four tasks were performed to achieve the study objectives:

1. Conduct a literature review to identify practices used for evaluating a user's guide.
2. Conduct a case study where modules of the resource guide (Miller et al., 2010c) were applied to questions of interest to RVARC staff.
3. Record the steps used in the case study analysis that were not explicitly provided in the resource guide.
4. Identify information learned through the case study that needs to be considered when applying the resource guide in order to enhance its implementation elsewhere in Virginia.

Task 1: Conduct Literature Review

To identify practices used for evaluating a user's guide, a literature search was conducted in TRID (Transport Research International Documentation) (Transportation Research Board [TRB], 2011a, b). Literature that focused explicitly on how to evaluate a user's guide was not identified. Further, a search through Google on the phrase "evaluation of a user's manual" (with and without the apostrophe and replacing the word "manual" with "guide") did not identify such literature as of July 18, 2011. Accordingly, literature in related areas, such as safety training, computer-based training, and implementation of research, was examined and those sources comprised the literature review.

It was later pointed out (Evans, 2011) that additional sources are available if the phrase "resource guide" is used in lieu of the phrase "user's manual," and indeed a search in TRID yielded many sources of available resource guides, such as FHWA and American Road and Transportation Builders Association (1998) and Tracy (1992). Although the author did not find examples of how to evaluate the utility of these guides, a detailed review of the various resource guides used in the transportation industry is another area of exploration that could be performed to identify characteristics of various available resource guides.

Task 2: Conduct Case Study

In this task, a case study was conducted where elements of the resource guide (Miller et al., 2010c) were applied to questions of interest to RVARC staff.

The task had two subtasks:

1. Identify modules in the resource guide for implementation.
2. Implement the modules identified.

Identification of Modules in Resource Guide for Implementation

An initial in-person meeting was held September 20, 2010, with representatives from five entities that comprised the project steering committee: RVARC, VDOT's Salem District, VDOT's Transportation and Mobility Planning Division (TMPD), VDOT's Traffic Engineering Division (TED), and the FHWA Richmond Division. At that meeting, the contents of the resource guide were presented and possible areas of exploration based on the needs of RVARC were discussed.

Specifically, two areas of exploration were noted in the meeting and a third was identified after the meeting.

1. *Acquiring crash locations for the cities of Roanoke and Salem.* All reportable crash data elements as recorded on the Virginia Police Crash Report (Form FR300) (hereinafter "crash report") by law enforcement officials at the scene of a crash are included in VDOT's Crash Records Database. However, because most streets in Virginia's cities are not maintained by VDOT, historically it has not been feasible to use VDOT data to create a map of city crash locations. This area focused on Module 4 of the guide (data needs).
2. *Incorporating safety into the future subarea plan for the Peters Creek-Hollins Community.* A subarea plan focuses on a specific portion of a county such as a corridor or a collection of census tracts. Because Roanoke County intended to develop a subarea plan for the Peters Creek-Hollins Community (Roanoke County, Virginia, n.d.), RVARC staff sought crash analysis and countermeasure identification as a starting point for the plan. This area of exploration focused on Module 5 of the guide (data analysis).
3. *Calculating performance measures in support of future Safe Routes to School (SRTS) initiatives.* SRTS is the safety planning topic of greatest emphasis in the Roanoke Valley Area Metropolitan Planning Organization's (RVAMPO) draft 2035 long-range transportation plan (RVAMPO, 2009) and is further supported by Virginia's Strategic Highway Safety Plan (Virginia's Surface Transportation Safety Executive Committee, 2006). Because the work in Tasks 1 and 2 had concerned crash data, the author addressed performance measures that did not rely on such data. This work focused on Module 3 (performance measures), noting that such measures can support other modules in the guide such as prioritization (Module 6); monitoring (Module 8); and vision statement, goals, and objectives (Module 1) (Miller et al., 2010c).

Implementation of Identified Modules

To implement the selected modules of the guide, three tasks were conducted:

1. Acquire crash locations for the cities of Roanoke and Salem.
2. Identify potential crash countermeasures for the Peters Creek-Hollins subarea.

3. Calculate non-crash-based performance measures in support of future SRTS initiatives.

Throughout the implementation of the modules, steering committee members requested information and provided comments that influenced the pilot application. Table A1 in Appendix A details this interaction.

Acquiring Crash Locations for Cities of Roanoke and Salem

For these two cities, crash locations from VDOT's Crash Records Database were imported into a geographic information system (GIS) after consultation with VDOT staff regarding alternative methods for executing this step. Metrics such as the proportion of crashes for which a location could be found, the proportion of crashes for which an incorrect location was given, and the estimated precision of the correct locations (e.g., the real location is within $\pm x$ feet of the estimated location) were recorded. One question was answered relating to implementing Module 4 (data needs) on a widespread basis: What step-by-step procedure can be used to import crashes into a GIS for an entire jurisdiction?

Identifying Potential Crash Countermeasures for Peters Creek-Hollins Subarea

As requested by RVARC staff in support of an upcoming public meeting (Gilmer, 2011a), 2006–2008 crash data for the Peters Creek-Hollins subarea in Roanoke County were imported from VDOT's Crash Records Database into GIS and examined to accomplish five objectives: (1) provide a map of crash locations, including specific crash types; (2) develop graphs showing crash percentages for the subarea; (3) perform an analysis of the crash causal factors at the high-frequency crash locations; (4) identify crash countermeasures at these locations; and (5) examine additional publications (e.g., Cambridge Systematics, Inc., 2010) that might contain solutions not shown in the resource guide (Miller et al., 2010c). Four questions were answered relating to implementing Module 5 (data analysis) on a widespread basis:

1. For crashes not occurring at an intersection, what distance may be used to determine whether two or more crashes are likely related to the same geometric causal factor?
2. For crashes at an intersection, should crashes within 250 feet or only those crashes within 150 feet of the intersection be defined as intersection related?
3. When clusters of crashes within a given jurisdiction are tabulated, what crash frequency should be used as the cutoff to determine whether a given site merits further study?
4. What statistical test is suitable for determining whether certain types of drivers (e.g., persons aged 18 or under) are significantly overrepresented in crashes?

Calculate Non–Crash-Based Performance Measures in Support of Future SRTS Initiatives

In addition to identifying bicycle and pedestrian routes, an SRTS program seeks to determine barriers to the use of such facilities and related recommendations (RVAMPO, 2009). Accordingly, two questions were answered relating to implementing Module 3 (performance measures) on a widespread basis:

1. What performance measures supporting SRTS are feasible to collect?
2. How do performance measures enable identification and prioritization of countermeasures that support an SRTS program?

The measures were collected for four schools in the Peters Creek-Hollins subarea: Glen Cove Elementary, Northside High, Burlington Elementary, and Mountain View Elementary. The performance measures were obtained from three sources: (1) the resource guide (Miller et al., 2010c); (2) a survey of factors affecting safety reported in the *2035 Constrained Long-Range Transportation Plan* (RVAMPO, 2009); and (3) the *Safe Routes to School Online Guide* (Pedestrian and Bicycle Information Center, 2007). The *2035 Constrained Long-Range Transportation Plan* was chosen because it suggested the metrics that stakeholders valued, and the *Safe Routes to School Online Guide* was chosen as it provided metrics specific to the design of routes to school.

Task 3: Record Steps Used in Case Study Analyses Not Given in Resource Guide

The case study analysis described in Task 2 required analytical steps that were not explicitly described in the resource guide, and these steps were recorded.

Task 4: Identify Information Learned Through Case Study That Needs to Be Used in Conjunction with Guide to Enhance Implementation Elsewhere in Virginia

The steps recorded in Task 3 were used to identify information not included in the resource guide (Miller et al., 2010c) that would enhance the use of the guide in other Virginia locations.

RESULTS

Literature Review

Lessons to Assist in Evaluation of a User’s Guide

Although literature specific to evaluating a user’s guide was not identified, literature in the areas of safety training, implementation of research, and computer-based training offered three considerations that are relevant to the implementation of the resource guide (Miller et al., 2010c).

1. *The audience for the resource guide is persons with diverse backgrounds rather than solely safety experts.* The Committee for a Study of Supply and Demand for Highway Safety Professionals in the Public Sector (2007), convened by TRB, noted that although there are relatively few persons who spend “all or most of their workday on matters pertaining directly to road safety,” there are many persons who “contribute to road safety on a regular basis but do not view themselves as part of the road safety workforce.” In the short term, an example of such contributors is maintenance crews who remove shading from trees that causes thawing on sections of the roadway to be delayed; for the longer term, examples are developers and regional planning staff who may influence whether new developments provide pedestrian facilities and sufficient connectivity for transit.
2. *Discrete tasks should be able to be completed within a relatively short time frame, generally about 30 minutes, and the rationales for the tasks should be given.* Lindsey-King (2009) noted two lessons from the application of computer-based training that appeared applicable to the implementation of the resource guide given it is intended to be used as a resource rather than to be read in its entirety: (1) ensure discrete blocks can be completed within a short time frame—generally about 30 minutes, and (2) ensure that the reason the training is being provided is made explicit to the audience. Although these points were addressed when the resource guide was developed, they merit special attention when the guide is applied to locations that were not involved in its original development.
3. *Users of the resource guide should know how it can be applied if data are imperfect.* McReynolds (2004) noted that an “all or none approach to data collection” has hindered the deployment of a computerized sign inventory, leading the author to note that flexibility is an important attribute in the implementation of research results. A related finding (McReynolds, 2004) was that inconsistent data needs may hinder product acceptance, as a separate program to replace older signs not affected by construction projects required a different dataset than that used for the computerized inventory. An all or none approach to data collection would also be detrimental from a perspective noted by Khisty and Kikuchi (2003) that it is possible to overemphasize the collection of data at the expense of being able to interpret the data.

Limitations of Evaluation That Focuses on User’s Manual

A product-oriented assessment does not explicitly quantify what is learned by the user, which is why Kyte et al. (2010) emphasized the need for user-oriented assessments. An example of a user-oriented assessment is the controlled experiment by Miltz (1972) to evaluate a teaching manual; the objective of the manual was to improve the quality of explanations given by teachers in the classroom. In the assessment, an experimental group of 30 teacher trainees were given the manual, a control group of 30 trainees were not given the manual, and differences between the two groups in terms of their ability to complete certain tasks were recorded.

By contrast, the current evaluation of the resource guide (Miller et al., 2010c) was product oriented in that it concerned whether the guide contained sufficient information to use

the modules with relative ease in another setting. (It did have a user focus, however, in that the pilot application for which the guide was implemented came from users.)

Case Study: Implementation of Modules Identified by RVARC

The results of the implementation of the modules for the case study were shared with the technical review panel and are available from the author; key deliverables were (1) methods for locating crashes in incorporated cities (sent October 20, 2010, and December 6, 2010); (2) crash maps and associated analysis of the Peters Creek-Hollins subarea (sent March 17 and 31, 2011); and (3) applications of performance measures (sent July 22, 2011). The pilot implementation of the resource guide, where elements of Modules 3, 4, and 5 of the guide (see Table 1) were applied to questions of interest to RVARC staff, yielded four sets of results that would affect the implementation of the guide in other Virginia locations. Three sets of results concern crash data—notably, how to locate crashes in a GIS environment, how to visualize crash clusters, and how to identify potential crash countermeasures based on these data. The fourth set concerns selection of appropriate performance measures when crash data do not adequately describe crash risk.

Accordingly, the results of the case study are presented in four sections:

1. ability to locate crashes in a GIS environment
2. identification of crash clusters
3. identification of potential crash countermeasures based on crash clusters
4. selection of performance measures when crash data do not adequately describe crash risk.

Ability to Locate Crashes in GIS Environment

The necessary accuracy for locating crashes is governed by the type of analysis undertaken. To identify the intersections with the greatest crash frequency, simply assigning a given crash to the proper intersection is sufficient; to pinpoint engineering countermeasures, a more precise location is needed.

Determining an Approximate Crash Location

Most crashes may be located in the sense that a specific location in GIS can be determined from the crash node and offset or a recorded latitude and longitude. For the 1990–2010 period and the sample of crashes for which Roanoke County was the physical jurisdiction, most (87%) crashes could be assigned to a specific (and seemingly correct) location in the county (Table 2). Approximately 13% of the crashes could not be located; a possible reason includes the following: a node and offset were not given; a node was given but not matched to the roadway network; or a node and offset when matched to the roadway network gave what

Table 2. Ability to Locate Crashes with Physical Jurisdiction of Roanoke County, 1990–2010^a

Summary (% of Total Crashes)	Crash Location	Crash Frequency
Correct location based on node (87%)	Roanoke County	21,617
Correct location based on latitude/longitude (>0%)	Roanoke County	285
Located with link-node but incorrect location (2%)	Buchanan County	176
	Franklin County	19
	Henry County	138
	Prince William County	1
	Washington County	229
Not locatable with link node or latitude/longitude (10%)	--	2,523
Total		24,988

^aThe subsequent analysis of the Peters Creek-Hollins subarea used only 2006–2008 crashes.

appeared to be an incorrect location. Appendix B summarizes the procedure used to locate crashes in Roanoke County.

Historically, locating crashes in incorporated cities in Virginia has been more difficult than locating crashes in Virginia counties because many of the facilities in such cities are not maintained by VDOT. However, an examination of crash records for the City of Roanoke alone (on October 15, 2010) showed that for year 2008, most crashes were locatable with either a latitude/longitude or a node or milepost whereas for the period 1990–2007, slightly less than 1/4 of crashes were locatable. Thus, locating such crashes has recently become possible. For the 2008–2009 period, it was possible to locate approximately 93% of crashes occurring in the cities of Salem and Roanoke, as reported in Table 3.

Table 3. Results of Using Various Crash Location Methods in Cities of Roanoke and Salem, 2008–2009

Location Method	No. of Crashes Located	% Total Crashes
Successfully used latitude/ longitude given in VDOT's Crash Records Database	2,749	53
Successfully used route and milepost	1,745	34
Successfully used intersection node ^a	321	6
Could not determine crash location	354	7
Total ^b	5,169 ^b	100

^a For 321 cases, a crash could not be located by latitude/longitude or route and milepost but could be located by the nearest intersection node. This method gives some errors when the crash occurs near but not precisely at the location of the node, but it allows the crash to be placed in the approximate location. For the 148 (of 321) crashes where this method was used and a known error could be estimated, the average error was 0.147 mile (about 775 feet) and the median error was 0.068 mile (about 360 feet).

^b The total reflects crashes where the City of Roanoke or the City of Salem was indicated for either the accident city field or the physical jurisdiction field in VDOT's Crash Records Database (i.e., there are two fields in this database; if the City of Roanoke or City of Salem appeared in either field or in both fields, the crash was included).

Determining a Precise Crash Location

Visual inspection in GIS of a few crashes in the city of Roanoke showed up to a 50-foot difference between the location of the crash and the line segment representing the roadway (Figure 1) or some differences between the location given on the crash report and the location indicated in GIS (Figure 2). For some non-interstate divided facilities, such as U.S. 11, the crash

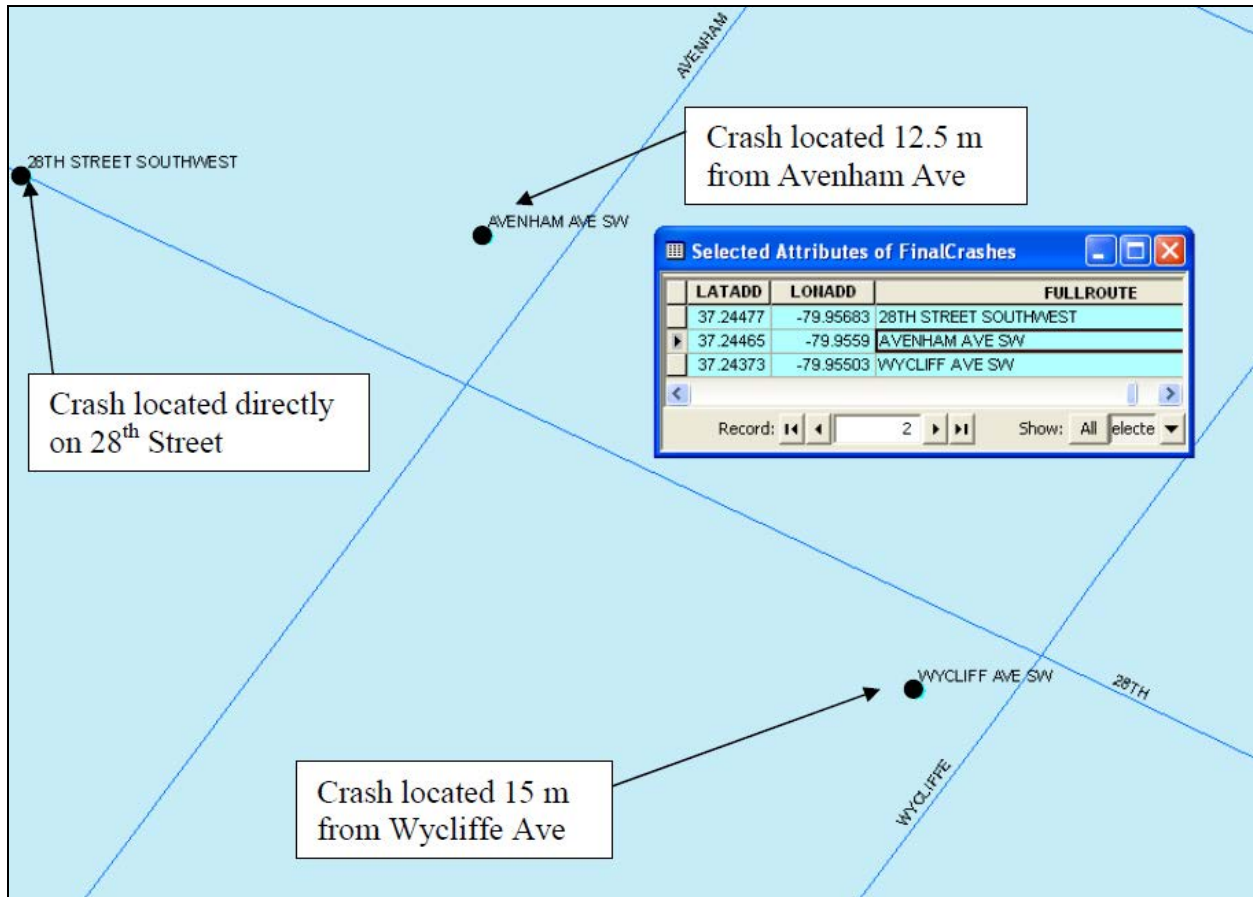


Figure 1. Example of Three Crashes in City of Roanoke

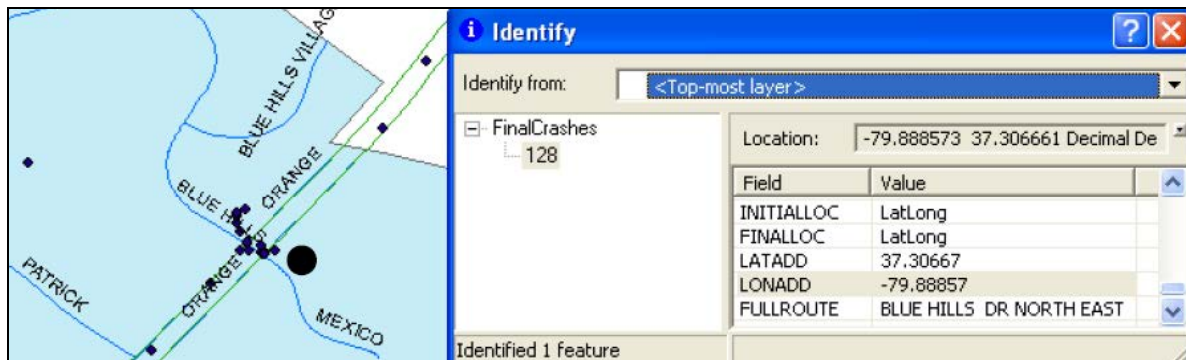


Figure 2. Crash 81205045 Occurred on Blue Hills Drive According to Crash Report (Form FR300) But on Mexico Way According to Latitude and Longitude

location as given in VDOT's Crash Records Database does not have a direction, meaning that all such crashes are arbitrarily assigned the northbound or eastbound direction (see Figure 3). Such differences suggest that the GIS representation of crashes may be useful for determining areas of interest but may need to be supplemented with a review of crash reports if detailed engineering studies are undertaken.



Figure 3. Crashes at Intersection 6 in Roanoke County. RE = rear-end crash; AN = angle crash; SS = sideswipe crash.

Associating Crash Data Elements with Crash Locations

Queries were executed to associate crashes with specific attributes (e.g., rear-end, fixed object, younger driver). This was found to be an iterative process. Proposed queries were shown to the project steering committee, and VDOT staff offered ways to make the queries more accurate. For example, although the *IntersectionType* field initially appeared useful for identifying crashes at signalized intersections, VDOT staff noted that it should not be used because it is no longer updated. The queries were thus revised, executed, and used to catalog crashes by type in the Peters Creek-Hollins subarea of Roanoke County for 2006–2008.

Identification of Crash Clusters

What constitutes a crash cluster? For example, if several crashes are located within 100 feet of one another, is this a cluster? If several crashes are located within 1,000 feet of one another, is this also a cluster? The question regarding what distance may be used to define a crash cluster may be considered separately for intersection and non-intersection crashes because the countermeasures for these types of crashes may differ. For example, for a cluster of sideswipe crashes located at an intersection, the appropriate countermeasure might be better channelization or some form of positive guidance to assist the driver with making the turning movement. However, for a cluster located on a two-lane roadway far from an intersection, an appropriate countermeasure might be centerline rumble strips or a warning system to alert drivers should they drift into the oncoming lane of traffic.

Selection of Radius to Define Intersection Crashes

With regard to whether a crash should be defined as intersection related, a variety of radii have been used as accepted practice, including 150 feet, 250 feet, and 75 feet and radii that varied depending on the intersection characteristics (Wang et al., 2008). In Virginia, a 150-foot radius has commonly been used in previous intersection-related studies (e.g., Miller et al., [2010a]); the *Highway Safety Manual* (AASHTO, 2010) uses a 250-foot radius. Because

intersections are defined in GIS as a crossing point between any two roadway nodes, the potential for overlap of such intersections always exists (Figure 4, *left*). However, in urban areas with a higher density street network, the 150-foot radius offers an advantage of simplifying the computations for cases where, as shown in Figure 4, *right*, adjacent intersections would not overlap with a sufficiently small radius. Thus, a question faced in the Peters Creek-Hollins analysis was: Would a 150-foot radius provide results consistent with those provided by a 250-foot radius?

To determine whether a 150-foot radius could be used, the total numbers of crashes within 150 feet and within 250 feet of each intersection were tabulated and the intersections were ranked from the highest number of crashes to the lowest number of crashes for each radius. Visually, the 150-foot and 250-foot radii yielded similar lists. For example, when the top 10 intersections from each list were identified, the same 9 intersections appeared in both lists. When the top 20 intersections from each list were identified, the same 17 intersections appeared in both lists.

The Friedman statistic (Eq. 1) showed that these lists were not significantly different for the top 10 and top 20 intersections, with p values of 0.75 and 0.45, respectively.

$$F_r = \frac{12}{bk(k+1)} \left[(\sum R_{150,i})^2 + (\sum R_{250,i})^2 \right] - 3b(k+1) \quad [\text{Eq. 1}]$$

F_r = test statistic

b = number of intersections being compared (10 or 20)

k = 2 categories (150-foot radius and 250-foot radius)

$R_{150,i}$ = 1, 1.5, or 2 depending on whether intersection i has a higher, equal, or lower rank than the same intersection when a 250-foot radius is used

$R_{250,i}$ = 1, 1.5, or 2 depending on whether intersection i has a higher, equal, or lower rank than the same intersection when a 150-foot radius is used.

For example, there were 19 crashes within 250 feet of Intersection A. Because only three other intersections had more than 19 crashes within 250 feet of the intersection, Intersection A had a ranking of 4 based on a 250-foot radius. Further, there were only 15 crashes within 150

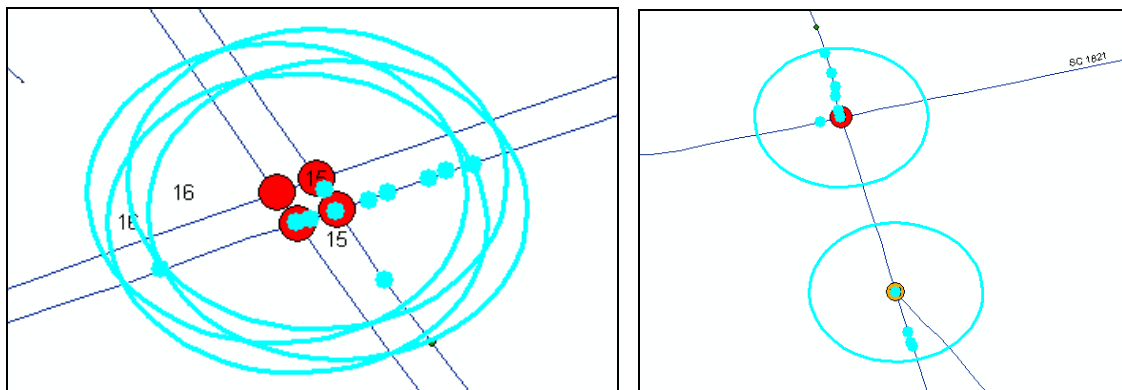


Figure 4. Two Instances Where Nodes Are in Close Proximity. Left: Aggregation of 4 adjacent nodes into a single node is desirable as the four circles overlap. Right: Aggregation into a single node is not desirable.

feet of Intersection A. Five other intersections had more than 15 crashes within 150 feet of the intersection, so the ranking of Intersection A was 6 based on a 150-foot radius. Accordingly, for this intersection, $R_{150,A} = 1$ and $R_{250,A} = 2$. The F_r value computed from Equation 1 was compared to the Chi-square statistic with $k - 1$ degrees of freedom.

Crashes located within 150 feet of an intersection were thus established as intersection related, and thus a cluster was defined as crashes at that intersection.

Selection of Clustering Distance for Non-Intersection Crashes

For non-intersection crashes, the question was: What threshold distance should be used to define a crash cluster? Equation 2 (Schneider et al., 2004) provided an approach to answer this question and thus establish a distance threshold. Crashes below the calculated distance threshold were presumed to be clustered; crashes above the threshold were not presumed to be clustered. Conceptually, Equation 2 provides a statistical basis for determining whether two crashes are closer than would be expected from chance alone and thus may reflect some common geometric phenomenon, such as a sharp curve. In Equation 2, the clustering distance D was found to be 544 feet for the Peters Creek-Hollins subarea, although other regions may yield different values of D .

$$D = 0.5 \sqrt{\frac{\text{Area}}{\text{Crash}}} - t \left(\frac{0.26136}{\sqrt{\text{Crash}^2 / \text{Area}}} \right) \quad [\text{Eq. 2}]$$

where

D = distance threshold below which crashes are considered a cluster (544 feet)
 Area = size of Peters Creek-Hollins subarea (about 429 million square feet)
 Crash = total number of non-intersection crashes (292 crashes)
 t = critical t -statistic (3.32 at the 0.001 confidence level for a two-tailed test).

Use of Clustering Distance to Define Locations of Interest

Crash clusters may thus be identified for intersection and non-intersection crashes. For the Peters Creek-Hollins subarea, for example, of the 519 intersections, most (435) had no injury crashes; the 173 injury crashes were spread among the remaining 84 intersections. An expected value analysis (Eq. 3) (Garber and Hoel, 2009) suggested that intersections with 3 or more injury crashes might warrant further attention. Such a criterion indicates there were 24 intersections (with 3 or more injury crashes) and, at these 24 intersections, there was a total of 98 injury crashes, which is a majority of the 173 injury intersection crashes.

$$EV = \bar{x} \pm zs \quad [\text{Eq. 3}]$$

where

EV = expected range of crash frequency (found to be between 0 and 2.33)
 \bar{x} = average crash rate (0.333 injury crashes/intersection for case study area)

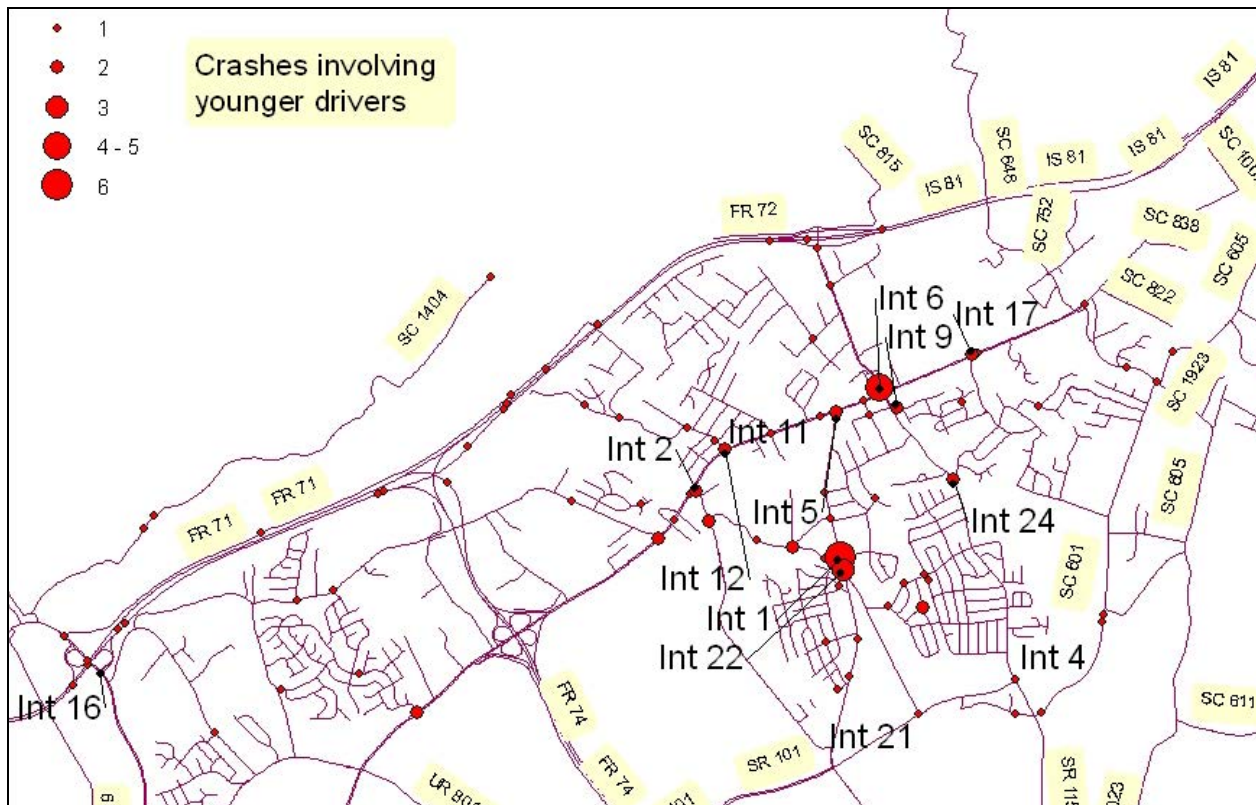


Figure 6. Crashes Involving Younger Drivers (aged 18 or younger). Intersections are numbered based on decreasing frequency of injury crashes; for example, “Int 1” had the largest number of intersection injury crashes.

Identification of Potential Crash Countermeasures Based on Crash Clusters

Techniques used to identify crash countermeasures were (1) determining locations overrepresented by a specific population, such as younger drivers; (2) identifying site-specific treatments based on specific crash data elements, such as collision type or traffic control; and (3) examining the crash report diagram and narrative.

Locations Involving Overrepresentation of Older or Younger Drivers

Table 4 shows that older drivers (i.e., aged 65 or older) were involved with 23% of all crashes at the 24 highest injury intersections shown in Figure 5 but with only 15% of crashes at the remaining intersections. The difference is statistically significant (see Eq. 4, $p = 0.02$). The difference was not significant with younger drivers (i.e., aged 18 or younger). Further, older drivers were not overrepresented in non-intersection crashes (including non-intersection crashes where there are high-injury locations).

Equation 4 (Garber and Hoel, 2009), where the computed Z test statistic is compared to 1.96 (to determine statistical significance at a 95% confidence level), may be used to determine whether the difference in (1) the proportion of crashes involving older drivers at the top 24 injury intersections, which is 23%, and (2) the proportion of crashes involving older drivers at the remaining intersections, which is 15%, is statistically significant.

Table 4. Proportion of Crashes Involving Younger and Older Drivers

Crash Type	Crash Subtype	Crashes Involving	
		Older drivers	Younger drivers
Intersection	Top 24 injury intersections in Figure 5	23%	14%
	Intersections not shown in Figure 5	15%	15%
	All intersection crashes	19%	14%
Non-intersection	Top 19 non-intersection injury clusters	4%	9%
	Top 25 non-intersection clusters	8%	9%
	All non-intersection crashes	11%	13%
All		16%	14%

Younger drivers = aged 18 or younger; older drivers = aged 65 or older.

$$Z = \frac{p_{24} - p_{\text{other}}}{\sqrt{p(1-p) \left(\frac{1}{n_{24}} - \frac{1}{n_{\text{other}}} \right)}} \quad [\text{Eq. 4}]$$

where

Z = Z test statistic, which is compared to 1.96 (2.30)

p_{24} = proportion of crashes with older drivers at the 24 intersections in Figure 5 (0.230)

p_{other} = proportion of crashes with older drivers at the intersections not in Figure 5 (0.149)

p = proportion of all intersection crashes with older drivers (0.187)

n_{24} = number of crashes at the intersections in Figure 5 (230)

n_{other} = number of crashes at the intersections not in Figure 5 (261).

Thus, because $Z = 2.30$, the difference is significant. Accordingly, potential crash countermeasures that might address the needs of older drivers may be examined. Such needs may be defined based on the language given by Staplin et al. (2001) where they stated that older drivers face “changes in their perceptual, cognitive, and psychomotor performances.” Tasks that Staplin et al. (2001) included as being more difficult for older drivers included reading street signs, following pavement markings, turning heads to see intersections at large skew (e.g., greater than 90 degrees), and merging. The National Highway Traffic Safety Administration (undated) noted that as drivers age, the ability to “fill in missing information” declines (i.e., as drivers age, they may not necessarily see the entire roadway environment because of high-speed traffic, reduced visibility, etc., and thus must use their knowledge to “fill in” what they cannot see). Stutts et al. (2009) noted that conditions that place older drivers at greater risk are those where using judgment is more important than following established rules, with examples being left turns and suburban arterials with 45 mph speed limits. Potential countermeasures given in the literature (Cambridge Systematics, Inc., 2010; Staplin et al., 2001) do not appear to apply exclusively to older drivers, but they may merit greater emphasis given the injury risk at these locations. Many engineering-related countermeasures given by Cambridge Systematics, Inc. (2010) as recommendations to reduce crash risk for older drivers concerned the provision of additional guidance for motorists. These included advance warning signs; better channelization such as raised pavement markings rather than painted markings only; improved lighting; larger

lettering on signs; and for signalized intersections, the use of an all-red clearance interval and a protected (rather than permissive) phasing for left turns.

Figure 7, which shows the intersection with the second largest number of injury crashes, indicates where some of these countermeasures could be applied. The two angle crashes and two (same direction) sideswipe crashes suggest that channelization may be helpful as vehicles turn left from Route 118 to Route 117 and as vehicles turn from Route 1828 to Route 118. Although sight distance on Route 117 does not appear to contribute to the eight rear-end crashes,



Figure 7. Intersection With 12 Crashes, 6 of Which Are Injury Crashes. AN = angle crash; RE = rear-end crash; SS = sideswipe crash. “SC” refers to the route number but specifically designates a secondary route (VDOT, 2008), which in Virginia is a route with a number of 600 or higher.

it is possible that the sharp curvature on Route 117 is a contributing factor to the crashes. Thus, improved signing on Route 117 (and possibly on Route 1828 to alert drivers to the intersection) is one potential low-cost crash countermeasure.

Identification of Site-Specific Treatments Based on Crash Data Elements

An ability to sort crashes by various data elements, coupled with a visual inspection of each site, enabled the tentative identification of countermeasures. For example, a large number of angle crashes at an unsignalized intersection suggests countermeasures such as removal of vegetation to improve sight distance, installation of a traffic signal (Garber and Hoel, 2009), or conversion from all-way stop control to two-way stop control (Cambridge Systematics, Inc., 2010). By contrast, a large number of rear-end crashes at a signalized intersection suggests countermeasures such as an adjustment of signal timing (to reduce stop and go movements) (Garber and Hoel, 2009), advance signing alerting drivers of the upcoming intersection, or better access management if there are commercial driveways quite close to the intersection (Cambridge Systematics, Inc., 2010).

As shown in Appendix B, Table B1, at least 18 specific types of crashes may be examined based on data elements available, with countermeasures mapped to intersections based on the crash types. Table 5 summarizes types of countermeasures that may be associated with intersections having crashes of a particular type.

Consideration of the various data elements coupled with the countermeasures in Table 5 can help in prioritizing where improvements may be most needed. For example, in the Peters Creek-Hollins subarea, of the 52 crashes that involved alcohol, the most common type was collision with a fixed object (34); the second most common was rear-end (8). However, at the site shown in Figure 8, three of the four crashes involved a fixed object and there was no alcohol involvement. Given the sharp curvature followed by two T-intersections approximately 90 feet apart, geometric considerations (such as guardrail to mitigate the fixed-object crashes or signing and/or possible speed reductions to prevent crashes) may be considered at this location.

Table 5. Examples of Countermeasures Based on Crash Types^a

Crash Type	Potential Countermeasure
Run off the road or fixed object	Install guardrail (if curvature is present). Install shoulder rumble strips.
Sideswipe (same direction)	Extend acceleration lanes leaving intersection.
Sideswipe (opposite direction)	Install centerline rumble strips.
Angle	At unsignalized intersections, increase sight distance by removing vegetation or consider reducing skew of intersection. At signalized intersections, improve channelization (e.g., provide puppy feet for left-turning vehicles or use raised splitter islands).
Rear-end	At signalized intersections, eliminate driveways within 250 feet of intersection and provide advance warning.
Pedestrian involvement	Install crosswalk and possibly provide grade separation.

^aList is not complete; for more details see Cambridge Systematics, Inc. (2010) and Garber and Hoel (2009).



Figure 8. Intersection 13 with 3 Fixed-Object Collisions. SR = State Route, SC = Secondary Route.

Identification of Site-Specific Treatments Based on Crash Diagram and Narrative

For some cases where no pattern was apparent from the crash data elements, the crash diagram and narrative provided additional insights. For example, the two intersections shown in Figure 9 had substantial angle and rear-end crashes. The crash diagram and narrative for the intersection on the right showed that four rear-end crashes had occurred when vehicles slowed or stopped specifically for the signal; thus, steps to improve signal visibility might be appropriate at that intersection.

Table 6 shows several other countermeasures that may be considered for the two intersections based on a review of the diagram and narrative. Advanced warning signals may be suitable at both intersections, given that rear-end crashes occurred when drivers may not have been aware of the intersection or the queue resulting from the intersection. In addition to the crashes shown in Table 6, two deer crashes were noted (such information may be compared with other locations to determine the extent to which deer crashes are prevalent in this region).



Figure 9. Intersections Necessitating Review of Crash Report (Form FR300). *Left: Intersection 16; right: Intersection 17.* DE = deer, AN = angle, RE = rear-end, Oth = other, US = U.S. Highway, SR = State Route, SC = Secondary Route.

Table 6. Causal Factors and Countermeasures Determined by Reviewing the Crash Narrative for Intersections 16 and 17 Shown in Figure 9

Causal Factor		Countermeasure
Intersection 16	Intersection 17	
<ul style="list-style-type: none"> Vehicle began making right turn, trailer struck curb, and trailer disconnected and overturned. 		Increase turning radius.
<ul style="list-style-type: none"> Vehicle 1, traveling south on exit ramp of I-81 North, rear-ended stopped Vehicle 2, which hit Vehicle 3. In a separate crash, Vehicle 1 traveling on Route 419: driver looking at signs to determine where to turn and ran a red light, hitting Vehicle 2, which was turning from exit ramp onto Route 419. 	<ul style="list-style-type: none"> Vehicle 1 rear-ended, slowing Vehicle 2 for signal Stopped vehicle rear-ended at signal (for 3 crashes) Stopped vehicle rear-ended at signal because of slick pavement (oil and water) Same direction sideswipe (improving signal visibility might or might not help) 	Improve signal visibility.
<ul style="list-style-type: none"> Vehicles stopped in traffic on Route 419; as traffic started to move, Vehicle 1 rear-ended Vehicle 2. 		Provide advance intersection warning signals.
<ul style="list-style-type: none"> Vehicle 1 was traveling on Route 419 as light was changing from yellow to red; Vehicle 2 was turning from exit ramp onto Route 419. 	<ul style="list-style-type: none"> Turning vehicle failed to yield right of way to through vehicle 	Adjust signal timing.

Selection of Performance Measures When Crash Data Do Not Adequately Describe Crash Risk

Performance measures from Table 7 that could be computed with relative ease were applied to four of the five schools in the Peters Creek-Hollins Area, and decisions these metrics could support were identified. (Because Northside Middle School is adjacent to Northside High School, the former was not considered.) With respect to implementing Module 3 (performance measures) elsewhere in Virginia, two questions were of interest: Which performance measures can be computed? What decisions do the performance measures support?

Which performance measures can be computed?

Measures that would have required substantial field data collection, such as the presence of crosswalks at all intersections within 1 mile of the school, were not recorded. Some metrics, such as sidewalk quality, were not recorded simply because many of the routes did not have sidewalks. Generally, however, the data sources given in the resource guide (Miller et al., 2010c) were used with three modifications: connectivity, population, and nonmotorized facilities.

1. *Measuring Connectivity.* A relative connectivity index (RCI) was measured for the area within 1 mile of each school. The RCI is measured by Equation 5 as

$$RCI = \text{Segments/Nodes} \tag{Eq. 5}$$

where

Segment = section of street between two nodes

Node = intersection with another street or cul-de-sac within the 1-mile radius.

The term “relative” connectivity index was used because nodes involving interstates were excluded and segments that extended from a node to an area outside the 1-mile radius of the circle were excluded. Because the GIS coverage was not complete (e.g., certain links appeared as dead-ends but were actually intersecting streets, whereas other links appeared as intersections but were actually grade-separated interchanges), the nodes and links were tabulated by hand. Because of the large numbers of estimated links and nodes (e.g., 197 links and 175 nodes for the area adjacent to Burlington Elementary), the tabulations are approximate.

2. *Measuring Population.* Population data for 2010 were obtained from a special census block-level tabulation that became available in 2011 (U.S. Census Bureau, 2011). At the time this research was conducted, VDOT’s more detailed population data by age reflected the 2000 Census rather than the 2010 Census; eventually, detailed 2010 census data by age will be available. These data were tabulated to the block level, and the area within a 1-mile radius of each school was estimated. Because some census blocks were not entirely within 1 mile of the school, Equation 6 was used to estimate the population that should be included in the tabulation.

$$\text{Population} = \text{Block population} \left(\frac{\text{Block area within 1 mile of school}}{\text{Total block area}} \right) \quad [\text{Eq. 6}]$$

3. *Measuring Nonmotorized Facilities.* The VDOT GIS layers do not show nonmotorized facilities, such as separate walking trails supporting the schools. There are walking trails on the grounds of Mountain View and Northside High and in the area not necessarily serving those schools (Belcher, 2011).

Table 7 shows the performance measures computed for four schools in the Peters Creek-Hollins subarea.

Table 7. Performance Measures Related to Safe Routes to School Computed for Four Schools in Peters Creek-Hollins Subarea

Performance Measure (Data Source or Literature Source for Computing Performance Measure)	Glen Cove Elementary	Northside High	Burlington Elementary	Mountain View Elementary
Main Access Road (GIS) ^a	Route 780	Route 117	Route 117	Route 115
Bicycle LOS ^b (SPS)	C	D	D	D
Bicycle Compatibility Index (GIS)	C	E	E	D
Pedestrian LOS ^b (Barsotti, 2004)	D	E	E	E
Sidewalks (SPS)	No	No	No	No
Speed Limit (SPS)	40 mph	45 mph	45 mph	40 mph
24-Hour Traffic Volume (SPS)	2,396	20,608	20,608	9,840
Population < 1 mile (GIS)	5,450	3,817	5,475	6,766
Relative Connectivity Index (GIS) ^c	1.09	1.18	1.13	1.25

GIS = geographic information system; SPS = Statewide Planning System.

^aInformation on other routes immediately serving each school is not available. These are Routes 850 and 1402 (Northside High), Route 1832 (Burlington Elementary), and Route 1899 (Mountain View Elementary).

^bLOS = level of service, where a value of A is best and a value of F is worst.

^cThis value should not be compared with the traditional connectivity index because links extending from a node to outside the 1-mile radius are excluded. Values are approximate because of the manual nature of the calculations.

What decisions do the performance measures support?

The pedestrian and bicyclist crash frequency in the Peters Creek-Hollins subarea is relatively low, with three pedestrian-related crashes and one bicycle-related crash for the period analyzed (i.e., 2006–2008). Of these, only one crash was within 1 mile of the four schools listed in Table 7. The low number of such crashes does not indicate a low risk for pedestrians or bicyclists, however. Rather, the performance measures shown in Table 7 may be used to mitigate this risk. There are three ways in which these performance measures may be applied.

1. *To identify specific types of needed improvements.* In this case, the provision of sidewalks is one possible countermeasure and a reduction in the speed limit on select routes may be another.
2. *To identify which schools most urgently need improvements for pedestrian facilities.* For example, Table 7 shows that all schools are likely candidates for improvement given the lack of sidewalks. If resources are limited, Table 7 shows that making Mountain View Elementary accessible to pedestrians (within 1 mile of the school) would serve a population that is 75% larger than would be the case for Northside High School.
3. *To identify specific areas within each school district where improvements may yield the greatest benefit.* For example, according to the 2010 Census (U.S. Census Bureau, 2011) approximately 2,250 persons live within the southwest quadrant of the school district (Figure 10). Thus, if pedestrian trails or sidewalks along some of the larger routes (e.g., Route 117) could accommodate pedestrians, a majority of the population within a 1-mile radius could be served.

With judgment, the performance measures may be modified. For example, the ratio of the population to total roadway mileage for a given census block may be computed. Conceptually, in an area where no sidewalks are present and all roads are equally beneficial to pedestrians, an investment of a given dollar amount in a block having a higher ratio would serve more residents than the same level of investment in a block having a lower ratio. Yet in practice, such a ratio has limitations: not all roadway facilities have the same need for sidewalks; not all populations will use sidewalks to the same degree; sidewalks benefit the pedestrians passing through an area in addition to those residing there; and there may be blocks where retrofitting some, but not all, roads with sidewalks is effective. Accordingly, population density can also be examined. With those limitations in mind, Figure 11, *left*, suggests that areas near the periphery of the 1-mile radius from the school—that is, the northwest and southeast areas—would benefit from pedestrian facilities, whereas Figure 11, *right*, suggests areas to the southeast and to the south. Both parts of Figure 11, however, suggest that the region to the southeast of Burlington Elementary School (circled) appears promising for determining where pedestrian facilities may serve a large number of people.

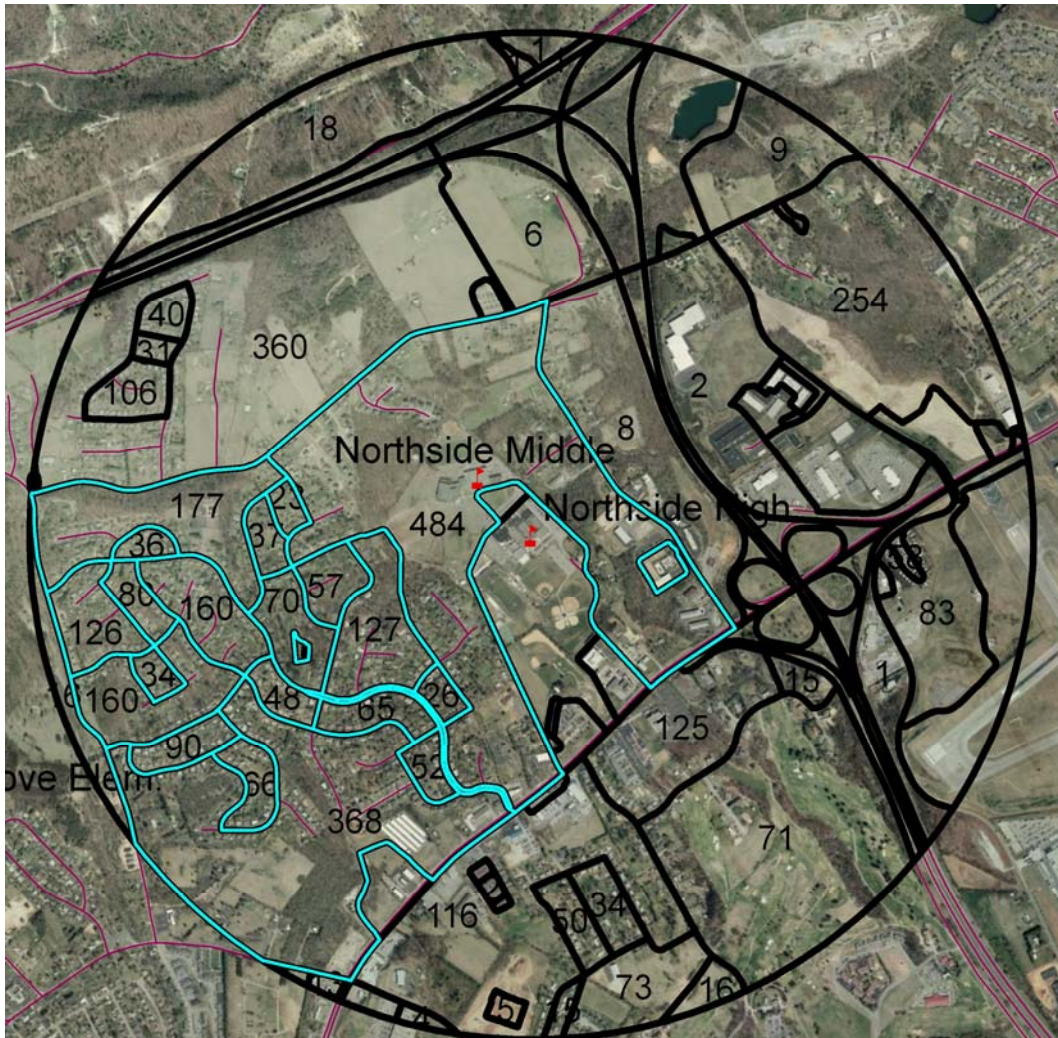


Figure 10. Census Block Populations Within 1 Mile of Northside High School. The lightly drawn blocks in the left of the figure represent approximately two-thirds of the population within 1 mile of the school.

Steps Used in Case Study Analyses Not Explicitly Detailed in Resource Guide

Five steps not explicitly detailed in the resource guide (Miller et al., 2010c) were necessary to address the questions that arose in the case study:

1. Import crashes into GIS and determine the crash attributes (Appendix B).
2. Establish distances that define a crash cluster (Eq. 2 and, if necessary, Eq. 1).
3. Determine which clusters merit further study (Eq. 3).
4. Use crash types and the crash narrative to determine potential crash countermeasures (Eq. 4, Figure 9, and Table 6).
5. Use GIS to obtain non-crash-based safety performance measures (Table 7 and Figure 11).

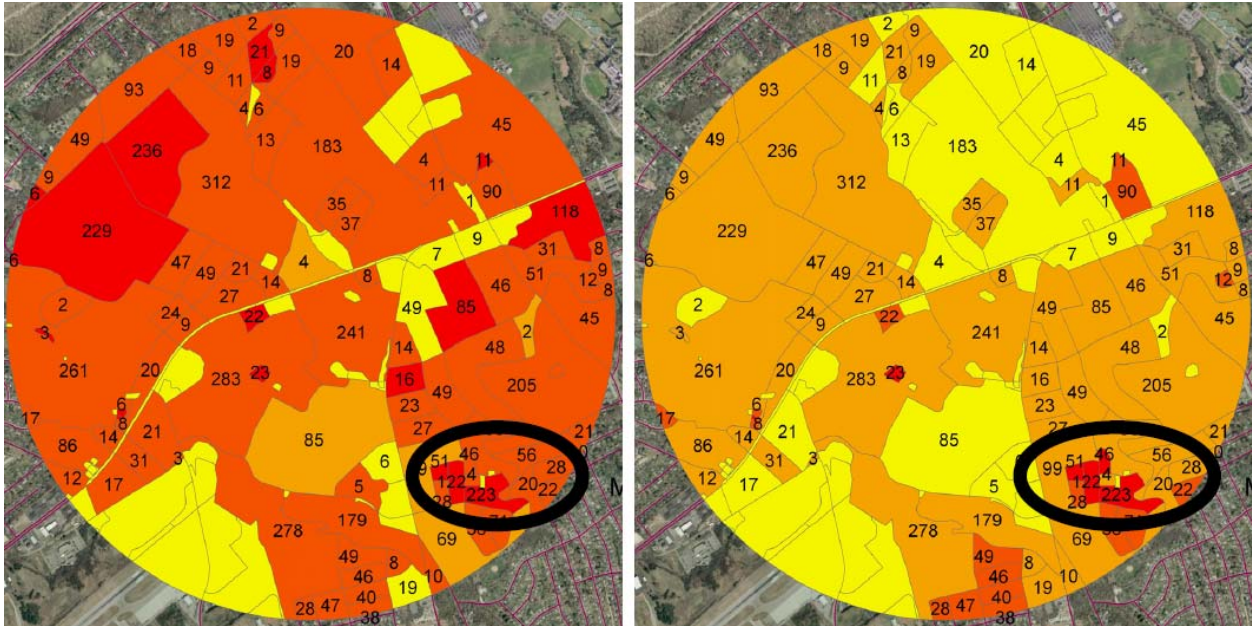


Figure 11. Census Block Populations Within 1 Mile of Burlington Elementary School. *Left:* Persons per roadway mile (dark [red] indicates a high ratio, suggesting retrofits would serve a larger number of people). *Right:* Population density (dark [red] indicates a higher density, suggesting retrofits would serve a larger number of people). Numbers indicate the block populations.

For example, the guide shows how to locate crashes along a VDOT-maintained road in a county but does not give detailed instructions for locating crashes for an entire jurisdiction. Because locating crashes in the City of Salem and City of Roanoke and crashes in Roanoke County was undertaken to complete Task 2, the steps needed to acquire crash locations for an entire jurisdiction were documented.

As shown, these steps are detailed in Appendix B, Equations 1 through 4, the site-specific countermeasure identification supporting Figure 9 (and listed in Table 6), and the performance measures in Table 7.

Information Learned Through Case Study That Needs to Be Used in Conjunction with Guide to Enhance Implementation Elsewhere in Virginia

The pilot implementation showed that most (87% of county crashes and 93% of city crashes) crashes could be successfully located in a GIS environment; that potential crash countermeasures could be identified based on a study of the characteristics of these crashes; and that for instances for which crash data are likely to be sparse, non-crash-based performance measures are feasible. However, the pilot implementation also showed that four additional types of guidance, not fully specified in the guide, may make accomplishing these tasks easier:

1. the steps for querying crashes from VDOT’s Crash Records Database and then importing those crashes into GIS for an entire jurisdiction (Appendix B)

2. approaches for determining what constitutes a crash cluster and whether a given cluster represents a relatively high concentration of crashes (Eqs. 2 and 3)
3. ways to identify crash countermeasures based on examining crash characteristics; geometric characteristics; and, if necessary, the crash diagram and narrative (Eq. 4, Table 6, and Figures 7 through 9)
4. ways to use performance measures to support a program of interest to the region (Figure 11 and Table 7).

These four types of guidance are given in Appendix B and in the examples provided in the body of this report.

DISCUSSION

In addition to the four additional types of guidance needed, the pilot implementation showed three broad ways in which implementation of the resource guide (Miller et al., 2010c) may be made easier if used elsewhere: (1) providing additional details on the application of the guide, (2) highlighting new data sources that were not available when the guide was published, and (3) clarifying the role of the planner.

Providing Additional Details for How to Apply the Resource Guide

Additional details are needed as follows:

- *Module 3 (performance measures)*. Clarify that when many performance measures are possible, a logical approach is to pick enough performance measures that allow one to distinguish among alternatives. For example, whereas *sidewalks* turned out not to be a distinguishing performance measure for use with the four schools in the Peters Creek-Hollins subarea, *population < 1 mile* was. (An alternative approach would be to rank the safety of crossings within a smaller distance, such as 1/4 mile, of each school.) The *relative connectivity index* in Equation 5 is a new performance measure that may be appropriate when localities are evaluating rezoning requests or considering whether to support the inclusion of subdivision streets into the state's secondary system of roads.
- *Module 4 (data needs)*. Describe the step-by-step procedure needed to import crashes into GIS on a jurisdiction-wide basis, especially because experimentation with this procedure may be necessary for individual jurisdictions. This procedure is given in Appendix B, and Step 7 shows where some variation by jurisdiction may be necessary. Of special note for users of VDOT's Crash Records Database is that the manner for identifying certain crash types is not necessarily straightforward. For example, although there is a field called *CollisionType* for which a code of 13 indicates a bicycle, the use of this field to query bicycle crashes will not give a

complete answer. Instead, crashes where a different field (i.e., VehicleType) in a different table (titled CrashVehicle) of VDOT’s Crash Records Database denotes a bicycle would also need to be identified. The queries needed to perform such analyses are given in Table B1 in Appendix B; Table B2 shows why a data dictionary is needed to perform these queries.

- *Module 5 (data analysis).* Clarify that crashes may be clustered at intersections based on a 250-foot radius or, in some cases, a 150-foot radius (see Eq. 1). Clarify that when grouping crashes at non-intersection locations, a threshold may be computed via Equation 2. Although a complete guide on countermeasure identification was beyond the scope of this study, the examples provided for the Peters Creek-Hollins subarea (see Eqs. 3 and 4 for identifying high-crash locations and determining if older drivers are overrepresented in certain types of crashes) are possible resources. A few examples based on Table 5 may be a productive introduction to the relationship between crash types and potential crash countermeasures, with references made to more detailed texts.
- *Modules 4 and 5.* When the maps of high-crash locations (e.g., Figures 5 and 6) were presented at a public meeting, one comment was that attendees would prefer to see the route names as well as the route numbers. Further, it was productive to provide RVARC staff with a variety of maps and charts from which they could choose a smaller set to present to the public; Figure 12, for instance, provided an understanding of which crash types were most common. For these reasons, it seems likely that there will be some iterations in applying these modules in other locations.

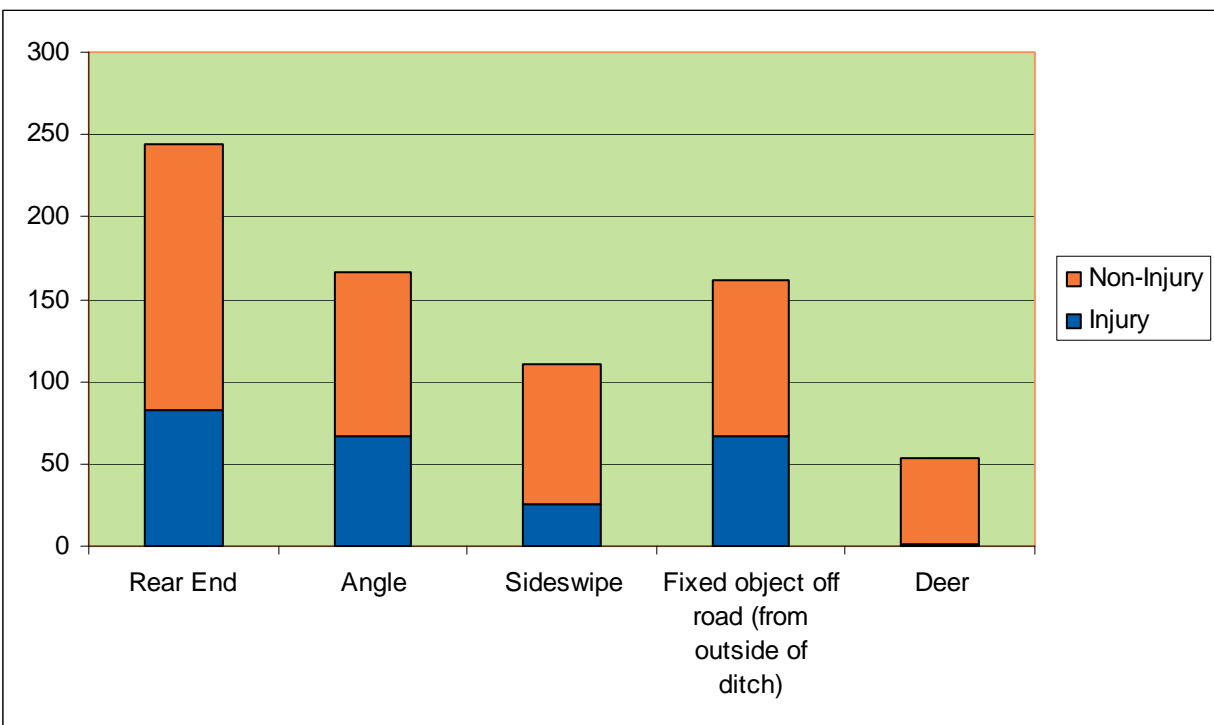


Figure 12. Most Crashes in Peters Creek-Hollins Subarea, 2006-2008 (48 of the 783 crashes not shown)

Highlighting New Data Sources

Since the publication of the resource guide (Miller et al., 2010c), additional data sources have become available. The GIS roadway layers described in Appendix B and available from VDOT (Hopkins, 2011) were quite helpful for locating crashes, notably the layers specified in Step 5 of Appendix B. For all crashes, the latitude and longitude are also helpful. Even though there may be error in the roadway file upon which the crash is placed, the latitude and longitude can help determine the approximate location of the crash when other information is missing. Although more detailed than may be feasible for some planning applications, the crash diagram and report narrative on Form FR300 was essential for the analyses for some locations, as shown in Figure 9.

One weakness of the analysis shown in Table 7 is that nonmotorized trails are not included. Because VDOT's online GIS resources facilitated computing several of the measures, a logical place to house GIS files containing trail information, if such trails become available, may be either VDOT's GIS program or the Virginia Geographic Information Network. This possibility was not investigated in this study.

Clarifying the Role of the Planner in Applying the Resource Guide

Without a field visit, the planner's role may be to identify potential crash countermeasures that merit consideration and then to work with engineering staff regarding which specific measures should be implemented. For example, regarding Figure 5, it is not necessarily the case that a transportation planner should select the countermeasures; however, the planner can identify locations where problems exist based on crash data and determine where a full engineering analysis would be productive. For MPOs, this role will be more complex than it would appear because multiple traffic engineering units will be involved: VDOT's TED and the VDOT district maintain streets within the county (except for the counties of Arlington and Henrico); however, in Virginia, individual cities maintain their own non-interstate facilities. For example, a planner with RVARC would necessarily work with VDOT, the City of Salem, and the City of Roanoke.

For this pilot effort, the types of analysis sought were primarily to respond to existing problems (e.g., identify deficiencies based on recent crash data rather than forecast additional crashes that might result from new growth). It might be the case that in locations other than RVARC the integration of safety and planning would be accomplished best by using the guide first to address current problems and then, perhaps in concert with an updated long-range plan, to examine how new growth scenarios might influence crash risk. In that sense, coordination between engineering and planning staff for short-term problems may be productive. Then, future efforts can link crash risk to various forecasts of travel associated with a long-range plan, as has been suggested in the literature (e.g., Naderan and Shahi, 2010).

CONCLUSIONS

Conclusions Regarding the RVARC Case Study

- *It is possible to determine approximate locations for most (roughly 90%) recent crashes in incorporated cities (where most streets are not maintained by VDOT) and counties (where streets are maintained by VDOT). In the case study, 87% of all crashes in Roanoke County (for 1990-2010) and 93% of all crashes in the cities of Roanoke and Salem (for 2008-2009) were successfully located. The word “approximate” is used because visual inspection of the crash locations in the City of Roanoke suggested that a typical location error was ± 50 feet; in addition, for 6% of these crashes, the procedure for locating crashes (discussed in Appendix B) had an estimated average location error of 775 feet. Accordingly, crash locations are useful for identifying problem areas and potential crash countermeasures, but a more accurate crash diagram will be needed to evaluate engineering alternatives at the design stage.*
- *It is feasible to import city and county crashes into GIS and subsequently identify crash clusters with the understanding that the importation procedure used in Appendix B is not fully automated and requires judgment. Examples of this judgment include (1) checking for obvious errors (such as crash being located in the wrong jurisdiction); (2) experimenting with alternative ways of defining the crash location (such as using the nearest node when the milepost and offset are not available); (3) defining intersections in the GIS network by aggregating adjacent nodes; and (4) defining the distances used to determine crash clusters, which for the case study area were 150 feet (for an intersection) and 544 feet (for clusters of crashes not located at an intersection). It is likely that over time, the best ways to query VDOT’s Crash Records Database will change in concert with changes in how certain data elements are recorded.*

Information Learned Through Case Study That Needs to Be Used in Conjunction with Guide to Enhance Implementation Elsewhere in Virginia

- *Four types of guidance, not fully specified in the resource guide, would enhance the implementation of the guide throughout Virginia:*
 1. the steps for querying crashes from VDOT’s Crash Records Database and then importing those crashes into a GIS for an entire jurisdiction (Appendix B)
 2. approaches for determining what constitutes a crash cluster and whether a given cluster represents a relatively high concentration of crashes (Eqs. 2 and 3)
 3. ways to identify crash countermeasures based on examining crash characteristics; geometric characteristics; and, if necessary, the crash diagram and narrative (Eq. 4, Figure 9, and Table 6)
 4. ways to use performance measures to support a program of interest to a region (Table 7 and Figure 11).

This guidance is detailed in Appendix B, Equations 2 through 4; the site-specific countermeasure identification supporting Figure 9 and Table 6; and the performance measures in Table 7.

RECOMMENDATIONS

1. *VDOT's TMPD should disseminate the following to VDOT district planners, PDCs, and MPOs:*
 - *The methodology for locating crashes (Appendix B).* The results with Roanoke County, the City of Roanoke, and the City of Salem suggest that individual PDCs may need to experiment with various location methods to find the most effective method for their region.
 - *Examples for identifying crash countermeasures (e.g., Figure 9 along with Table 6 or the text introducing Table 5) and examples of using non-crash-based performance measures (Table 7).* The results with the Peters Creek-Hollins subarea analyses showed that questions of interest to planners can be answered provided there is sufficient staff time to perform the tasks described.
 - *Current GIS shapefiles in use by VDOT concerning roadways, intersections, and population.* These shapefiles were essential for completing many of the tasks shown herein—notably the locating of crashes—and presumably will be updated periodically. Hopkins (2011) noted that these data are available to PDCs/MPOs who request them by sending an email to GIS@vdot.virginia.gov.
2. *VCTIR, with assistance from VDOT's TMPD, TED, Learning Center, and/or other units as appropriate, should facilitate a workshop introducing PDC/MPO staff to the material listed in Recommendation 1.*

BENEFITS AND IMPLEMENTATION PROSPECTS

A method for accomplishing Recommendation 1 is to share this report with VDOT district planners and PDC staff. A method for accomplishing both recommendations is to introduce them at a high level to the Transportation Committee of the Virginia Association of Planning District Commissions and the Virginia Association of Metropolitan Planning Organizations.

The context of Recommendation 2 is that no entity in VDOT necessarily has responsibility for providing training to MPOs and PDCs for crash data acquisition and analysis methods such as those used in the body of this report. After remarking that these methods resulted from work performed by VCTIR, a VDOT TED staff representative (Li, 2011) suggested that VCTIR could facilitate such a workshop. Staff in certain VDOT divisions have

expertise that would be productive to share and that would complement the material presented in this report. Thus, portions of a workshop may be led by VCTIR staff with the involvement of one or more staff from VDOT's TED and TMPD regarding certain expertise, such as the use of Crash Analysis Tools and potential improvements, that existed prior to this research effort.

As pointed out by Gilmer (2011b), the presentation noted in Recommendation 2 may include, or be followed by, formal training for Crash Analysis Tools, the Statewide Planning System, and other data sources as well as discussions regarding how PDCs, MPOs, and VDOT can share such data. Such a discussion could support a separate research effort underway (VCTIR, n.d.) to address unmet planning data needs. Further, if two other pieces of information become available—the crash latitude/longitude and a crash diagram and narrative (with all personally identifying information removed)—their value could also be discussed (although the latter may not be feasible at this point). Further, conversations among the technical review panel during the review of this report in September 2011 suggested that a single workshop might be less effective than smaller regional workshops tailored to the interests of individual MPOs. To determine these interests, a survey of MPOs/PDCs could help gauge their interest in these topics, such as crash data acquisition, GIS data acquisition, GIS queries, updating of the resource guide (Miller et al., 2010c), use of statistical reasoning, etc., with the results being used to guide a workshop.

In short, it is not yet clear if VDOT has the staff resources to institutionalize long-term crash analysis assistance for MPOs/PDCs, and thus without an explicit dedication of staff, it appears unlikely that such assistance can be expected to be provided on a regular basis. However, Recommendations 1 and 2, as written, can feasibly be implemented at least once or on a resource availability basis—and if the results are judged by attendees to have merit, then VCTIR and VDOT's TMPD can make a case for VDOT to make a longer term commitment to performing Recommendations 1 and 2 on a long-term basis.

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APPENDIX A

INTERACTIONS WITH STEERING COMMITTEE

Throughout the implementation of the selected modules of the resource guide (Miller et al., 2010c) in the case study, members of the steering committee requested information and provided comments that influenced the pilot application.

For example, the committee asked why in some applications crashes tended to cluster at integer mileposts (e.g., milepost 3.0) given that crash locations were reported to the nearest 1/100th of a mile (e.g., milepost 3.14). The answer involved the order in which individual crash records were imported into GIS; thus, a procedure to maintain location precision to the nearest 1/100th of a mile was documented as part of Task 2. Because the committee indicated that only 3 years of crash data should be used for the Peters Creek-Hollins subarea analysis, Task 2 focused on ways to identify countermeasures based solely on such data rather than on a longer period of analysis.

Table A1 summarizes interactions with the project steering committee that influenced Task 2.

Table A1. Summary of Interactions with Project Steering Committee

Date	Deliverable	Summary
Sept. 20, 2010	In-person meeting with steering committee.	Project should focus on (1) obtaining crash data for incorporated cities (using Roanoke and Salem as a case study) and (2) conducting analyses that support a subarea plan (using Peters Creek-Hollins subarea as a case study).
Acquire crash locations for cities of Roanoke and Salem		
Oct. 15, 2010	Emailed spreadsheet containing 48,506 crashes for City of Roanoke.	It is possible to obtain archival crash data for cities back to 1990. The weakness of such data is that locations are not readily available to be directly imported into GIS in semi-automated fashion as discussed in Appendix B.
Nov. 15, 2010	Emailed table showing annual crash frequency for City of Roanoke.	Confirms that average number of crashes for Roanoke has varied from a high of 2,834 (in 1990) to a low of 2,124 (in 2008).
Dec. 6, 2010	<ul style="list-style-type: none"> • CD of crash data for cities of Roanoke and Salem. • Document explaining how to incorporate these data into GIS. 	<ul style="list-style-type: none"> • It is possible to locate 93% of crashes in incorporated cities for 2008-2009. • Caveats for location methods are needed (e.g., format number of decimal places in a .dbf file).
Dec. 9, 2010	Emailed .kmz file of Roanoke and Salem crashes and .ppt file of graphics and tabulations (e.g., crashes by collision type and injury severity, etc.).	It is possible to perform GIS-based analysis with Salem and Roanoke data, such as normalizing crashes by population of a given census tract.
Identify potential crash countermeasures for Peters Creek-Hollins subarea		
Jan. 11, 2011	Teleconference. On January 13, RVARC asked for generation of maps, histograms, and countermeasures for Peters Creek-Hollins subarea.	Next step is to identify types of analysis suitable for subarea plan. RVARC was able to use CAT to locate almost all 17,000 crashes for County of Roanoke.
Jan. 20-21, 2011	Email and telephone call concerning discrepancies between crash location (defined by route milepost) and crash location (defined by latitude/longitude).	<ul style="list-style-type: none"> • Do not use 2009 data yet as these are being checked. • Do not rely on latitude/longitude unless they are only data available.
March 17, 2011	In response to January 13 email from RVARC, sent analysis of crashes in Peters Creek-Hollins subarea to RVARC and VDOT.	<ul style="list-style-type: none"> • Analyzed and mapped 783 crashes for period 2006-2008 (the 3 most recent years for which accurate crash locations are available). • Identified potential crash countermeasures pertaining to signing and geometry; list is tentative.
April 1, 2011	Sent 8 high-quality PDFs to RVARC for use at public meeting.	<ul style="list-style-type: none"> • Added two maps showing locations of crashes from older drivers (65 or older) and younger drivers (18 or younger).
May 27, 2011	Maps should include route names rather than only numbers.	<ul style="list-style-type: none"> • Added this suggestion to list of best practices for sharing crash information.

CAT = Crash Analysis Tools; RVARC = Roanoke Valley-Alleghany Regional Commission; VDOT = Virginia Department of Transportation.

APPENDIX B

SUMMARY OF STEPS FOR ACQUIRING AND ANALYZING CRASH DATA

Overview

A clarification regarding nomenclature arose during discussions with the project steering committee. In Virginia, crash data elements are originally extracted from the Virginia Police Crash Report (Form FR300). These same data may be accessed through several user interfaces, such as a local crash system maintained by a city police department, a Microsoft access .mdb file from VDOT's Traffic Engineering Division, or a GIS shapefile from VDOT's Information Technology Division. Although the user may view these as distinct sources, and there are some variances among these formats because of differences in processing, a clarification is that these are different interfaces based on the same core set of data, i.e., the crash report.

Steps 1 and 2 may be executed with VDOT's Crash Records Database or the VDOT Crash Analysis Tool (CAT), both of which are based on crash data elements from Form FR300. The former interface is directly accessible by VDOT employees; the latter interface has been made available on an annual basis to PDCs.

Steps for Acquiring and Analyzing Crash Data

1. Using Microsoft Access or Structured Query Language (SQL), query all crashes located in the physical jurisdiction of interest.
2. Based on these records, query three of the linked data tables: CrashDocument, CrashVehicle, and CrashPedestrian. Queries for specific types of crashes are shown in Table B1.
3. In either Excel or Access, manipulate the results such that there is a single table with one line for each crash. Add a "Location" field by concatenating the route prefix, route number, and route suffix; use the "trim" function in Excel to eliminate extra spaces.

For example, the following will be a location field for a crash on I-81:

"Location" = IS00081N

[This appendix and report generally use the word "field" to describe each column associated with a given crash in a given row because the GIS commands also use "field." However, other words that may be used are "attribute" (commonly used when designing databases) or "variable" (commonly used when developing crash prediction models based on the underlying data). Although "field," "attribute," and "variable" are thus often used in these different contexts, for the purposes of this report their meaning is the same. For the sake of consistency, the term "field" is used throughout, where field designated a column (such as "Collision Type" or "Number of Injuries") associated with a specific row (e.g., "Crash Number 991234123") in a relational database.]

Table B1. Tabulations by Crash Type

No.	Type of Crash ^a	How to Detect
1	Head-on	(CrashDocument.CollisionType = 03)
2	Left turn head-on	(CrashDocument.CollisionType = 03) AND (CrashVehicle.VehicleManeuver = 03)
3	Angle crashes at signalized intersections	(CrashDocument.CollisionType = 02) AND (CrashDocument.TrafficControl = 03 ^b)
4	Angle crashes at unsignalized intersections	(CrashDocument.CollisionType=02) AND (CrashDocument.TrafficControl = 04 ^b)
5	Rear-end crashes at signalized intersections	(CrashDocument.CollisionType = 01) AND (CrashDocument.TrafficControl = 03 ^b)
6	Rear-end crashes at unsignalized intersections	(CrashDocument.CollisionType = 01) AND (CrashDocument.TrafficControl = 04 ^b)
7	Run off the road ^c	Used VDOT query and/or collision type = 9
8	Deer	(CrashDocument.CollisionType = 10 or 11)
9	Pedestrian	(CrashDocument.Number appears in the CrashPedestrian Table)
10	Bicyclist	(CrashDocument.CollisionType = 13) OR (CrashVehicle.VehicleType = 09)
11	Motorcyclist	(CrashDocument.CollisionType = 14) OR (CrashVehicle.VehicleType = 11)
12	Driver inattention	(CrashVehicle.DriverAction = 23)
13	Speeding	(CrashVehicle.DriverAction = 02 OR 03)
14	Driver fatigued	(CrashVehicle.DriverCondition = 6 or 7)
15	Younger drivers (16-18)	(CrashVehicle.DriverAge <=18) AND (CrashVehicle.DriverAge >=1)
16	Older drivers (65 or older)	(CrashVehicle.DriverAge >=65) FUTURE <=99
17	Alcohol involvement	(CrashVehicle.Drink = 2-5)
18	Work zone crash	CrashDocument.WorkZone = 1 [valid only after 2004]
Not used	Safety equipment used	Requires manual examination of crash reports (Form FR300) ^d

^a Key fields, also known as variables or attributes, and the respective codes that are commonly used are shown in Table B1 and are defined as follows: *collisiontype field*: rear-end (code 01), angle (code 02), head-on (code 03), fixed object in road (code 06), non-collision, overturned, jackknifed or ran off road [no object] (code 08), fixed object off road (code 09), deer (code 10), other animal (code 11), pedestrian (code 12), bicyclist (code 13), motorcyclist (code 14); *drink field*: codes (2-5); *driver action field*: driver inattention (code 23), speeding (codes 02 or 03); *driver condition field*: fatigued (code 6), apparently asleep (code 7); *traffic control field*: traffic signal (code 03), stop sign (code 04); *vehicle maneuver field*: left turn (code 03), run off the road—right (code 09), run off the road—left (code 10); *vehicle type field*: bicycle (code 09), motorcycle (code 11); *work zone field*: active (code 01), inactive (code 02), none (code 03).

^bTrafficControl as reported here is obtained from the law enforcement official's indication of traffic control on the FR300. Accordingly, this field is most useful when analyzed for several crashes in proximity. For example, if 10 crashes occur at an intersection and traffic control is indicated as a signal for 7, probably either of the following is true: all 10 crashes occurred at a signalized intersection or the intersection was signalized after the first 3 crashes occurred.

^cAlthough it is possible to define "Run off the road" crashes as those with a collisiontype field having a code of 08 or 09, a vehiclemaneuver field having a code of 09 or 10, or a *fixed object field* having a code between 01 and 12 inclusive, VDOT staff provided an internal query that could define "Run off the road" crashes (Lim, In-Kyu, Email to John S. Miller, February 8, 2011). (Note that the *fixed object field* is not shown in this table as this field was not needed for this analysis.)

^dNote that in September 2003 the Virginia Police Crash Report form (Form FR300) changed such that a new category of safety equipment used, i.e., category 8—booster seat, was added (see Table B2). Because of the change in codes, the individual Form FR300 must be examined to determine safety equipment used.

Table B2. Comparison of 1978, 2003, and 2007 Virginia Police Crash Report (Form FR300) Codes for Safety Equipment Used

1978 ^a	2003 ^b	2007 ^b
1. No restraint used	1. No restraint used	1. Lap Belt Only
2. Lap belt	2. Lap belt only	2. Shoulder Belt Only
3. Harness	3. Shoulder belt only	3. Lap and Shoulder Belt
4. Lap belt and harness	4. Lap and shoulder belts	4. Child Restraint
5. Child restraint	5. Child restraint	5. Helmet
6. Airbag	6. Helmet	6. Other
7. Other	7. Other	7. Booster Seat
	8. Booster seat	8. No Restraint Used
		9. Not Applicable

^a Accreditation Commission for Traffic Accident Reconstruction. FR-300P 1/78. North Platte, NE, undated. http://www.actar.org/pdf/va_ovl1.pdf. Accessed November 7, 2011.

^b National Highway Traffic Safety Administration. Contact Information. Washington, DC, undated. <http://nhtsa-tsis.net/stateCatalog/states/va/crash.html>. Accessed November 7, 2007.

4. Export the table as a .dbf file.

To ensure that a proper number of decimal places will be recorded for each field, do the following in Excel for non-integer attributes: right click on the column, choose format, and make the number of decimal places the maximum needed to ensure accuracy. For example, consider the milepost field, which shows the distance (in miles) along a route, and suppose two records have the following values for that field in Excel:

- Milepost = 3
- Milepost = 1.04562.

When importing into GIS, if the record containing a “3” is imported first, all records will be truncated to the nearest integer—unless, prior to this importation, the numbers are formatted such that they appear as follows:

- Milepost = 3.00000
- Milepost = 1.04562.

Example: Steps 1-4 yielded a table of 24,988 records for Roanoke County crashes.

5. Using Geographic Information Systems (GIS), acquire two VDOT layers that show roads and intersections, respectively:

- Roads: GIS_DATA.MOD_VDOT_RTE_MASTER_LRS_V_94
- Intersections: GIS_DATA.SDE.VA_ROADS_INTERSECTIONS

To increase the speed of calculations, take two steps: store the layer on a local machine, and clip only the portion of the layer for the county of interest.

6. If necessary, project certain layers.

Example: A shapefile for the Peters Creek-Hollins region of Roanoke County had already been projected. Accordingly, other layers were placed into the same projection system used by the project boundary file. In GIS, the sequence of commands for such projections is:

Toolbox: Data Management Tools\Projects and Transformations\Features\Project

To increase the speed of calculations, users can create a geodatabase (in Arc Catalog) and then store subsequent layers in this geodatabase.

7. Locate the crashes. There are two ways to do this:

- *For crashes with a route and milepost*, use Tools\Add Route Events where:
 - Route Identifier is the Location field defined in Step 3.
 - Measure is either the ROUTESYSID or the TRUE_HTRIS field.
- *For crashes with a latitude/longitude*, use Tools\Add XY data where
 - X field is longitude.
 - Y field is latitude.

It may be the case that Step 7 requires experimentation depending on the year and county in order to achieve the highest proportion of locatable crashes.

8. Combine the crashes from Step 7 into a single layer. One way to do this is:

Toolbox\Data Management Tools\General\Append.

9. To examine intersection crashes only, create a layer that consists of a circle around each intersection node and then count the number of crashes within each such polygon. For example, if you want to count all injury crashes within 150 feet of each intersection, the steps are:

- *Create a 150-foot buffer around each node* using Toolbox/Analysis Tools/Proximity/Buffer.
- *Aggregate overlapping buffers* using Toolbox/Data Management Tools/Generalization/Aggregate Polygons.
- *Count crashes within each buffer* by right clicking on the shapefile created from the bullet above, choosing joins and relates, clicking “join data from another layer based on spatial location,” and then joining the shapefile to the layer containing the individual crashes.

- *Indicate these are intersection crashes* by selecting all crashes that intersect each buffer, adding an intersection field, and using calculate field = 1 to indicate an intersection crash.

10. To examine non-intersection crashes only, one procedure is to identify crash clusters. Steps are:

- *Determine the point distance between each non-intersection crash.*

The commands Toolbox\Analysis Tools\Proximity\Point Distance may identify crashes within a certain distance of each other. (The threshold distance for this project was 544 feet, although other distances are possible.) Export this table of crashes and distances to a .dbf file.

- *In Excel, identify all non-duplicative crash clusters.*

Although crash clusters can be identified manually, a challenge is that clusters may overlap as shown in Figure B1. Accordingly, an Excel macro was written that identifies

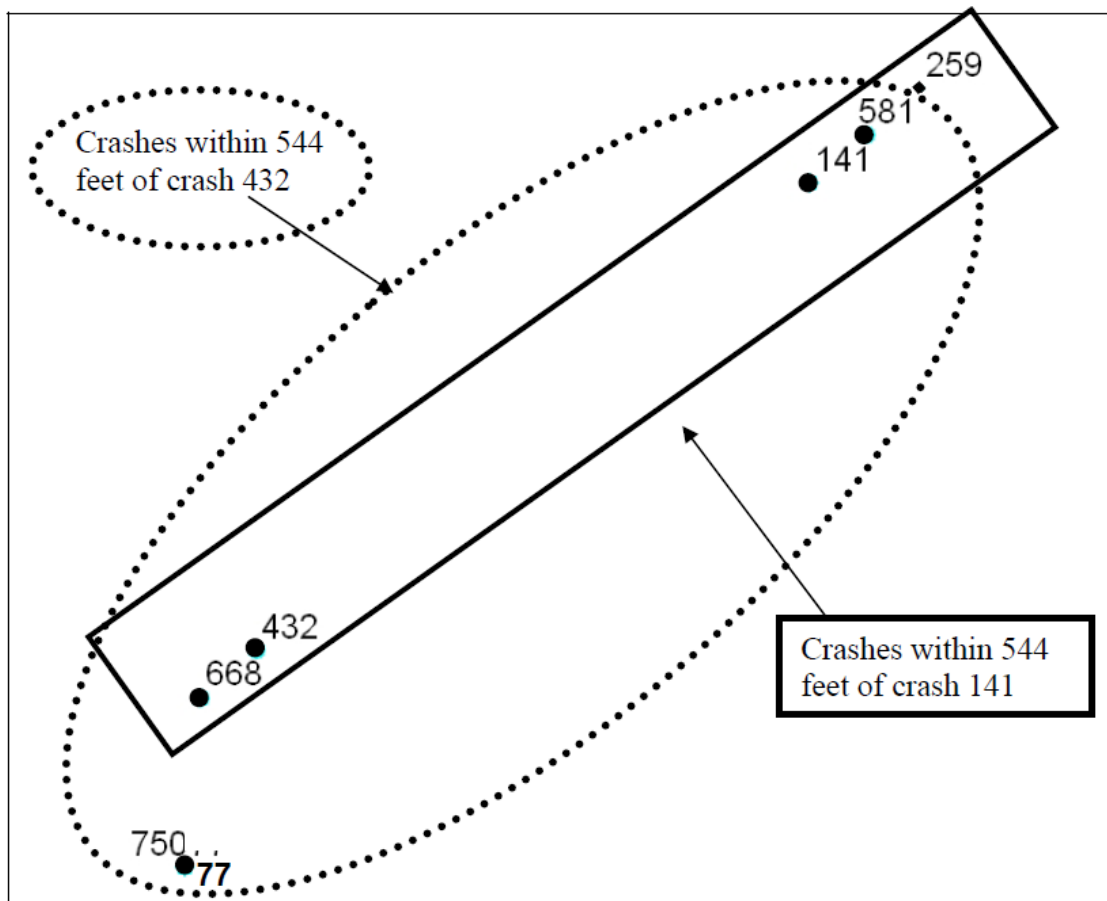


Figure B1. Example of Identifying Crash Clusters. Note that there is a 6-crash cluster centered on Crash 432 where Crashes 77, 750, 668, 141, and 581 are within 544 feet of Crash 432. Although there is initially a 5-crash cluster centered on Crash 141, some of these crashes overlap with the cluster centered on Crash 432.

the largest cluster of crashes (e.g., the largest pool of crashes within 544 feet of each other), removes these crashes from further consideration, and then identifies the next largest cluster of crashes within 544 feet of one another. This approach avoids double-counting crashes when defining clusters.

(Other approaches for clustering crashes are feasible; for example, one could manually identify two clusters of crashes within a relatively small distance of each other in Figure B1, although the feasibility of developing comparable size clusters for all non-intersection crashes would need to be assessed.)

- *Visually inspect the crash clusters in GIS.*

A cluster definition table consisting of each cluster center (e.g., from Figure B1, the cluster center would be Crash 432) and all crashes in that cluster may be imported into GIS and then linked to the original table of crashes. Thus in Figure B1, a six-crash cluster is defined that is centered on Crash 432.

APPENDIX C

DETERMINATION OF THRESHOLD FOR IDENTIFYING INTERSECTIONS OF INTEREST

Equation 3 showed how an expected value analysis was used to determine for a given set of intersections which intersections likely merit further study based on the number of injury crashes observed. For the Peters Creek-Hollins subarea, Equation 3 showed that sites with more than 2.3 injury crashes could be considered outliers that at least merited a second examination. A criticism of Equation 3, however, is that it is based on a normal distribution of crash frequency, whereas crashes are generally thought to follow the negative binomial distribution. Accordingly, an alternative method for determining which intersections should be examined is given here, although these results were found to be consistent with those from Equation 3 presented in the body of the report.

One formulation of the negative binomial distribution is that offered by Shilane et al. (2008) where the probability (P) of a given crash frequency (x) is given by Equation C1:

$$P(x) = \frac{\mu^x \Gamma(\theta + x)}{x! \Gamma(\theta) (\mu + \theta)^x \left(1 + \frac{\mu}{\theta}\right)^\theta} \quad [\text{Eq. C1}]$$

where

- x = a given crash frequency
- u = mean crash rate
- Γ = gamma function
- Θ = dispersion parameter.

Table C1 shows the crash frequency by intersection and also gives the fit based on three distributions: normal, Poisson, and negative binomial. These data suggest that the negative

Table C1. Number of Intersections With a Given Crash Frequency

Crash Frequency	Normal Distribution	Poisson Distribution	Negative Binomial Distribution ^a	Observed Sites
0	294	372	435	435
1	162	124	45	45
2	55	21	18	15
3	7	2	9	14
4	0	0	5	2
5	0	0	3	4
6	0	0	2	3
7	0	0	1	0
8	0	0	1	0
9	0	0	0	0
10	0	0	0	1
Sum	519	519	519	519

^aBased on a dispersion parameter of $\theta \approx 0.15$.

binomial distribution is the proper fit; note that the low value of θ in Equation C1 ($\theta \approx 0.15$) suggests the data have a high amount of dispersion (e.g., a relatively long tail to the right). That is, had these data followed the Poisson or normal distribution, there would have been very few sites with more than 3 crashes per year. Because there were, in fact, several sites with more than 3 crashes per year, the negative binomial distribution appears to be a more proper fit.

For example, the first row in Table C1 shows that there were actually 435 intersections that had 0 crashes. Based on the mean and variance in the dataset, the normal distribution would have forecast 294 sites with 0 crashes, the Poisson distribution would have forecast 372 sites with 0 crashes, and the negative binomial distribution would have forecast 435 sites with 0 crashes.

A visual inspection of Table C1 shows that the number of intersections in the “Observed Sites” column exceeds the number in the “Negative Binomial Distribution” column for intersections with a crash frequency of 3. Thus anecdotally, Table C1 suggests that sites with 3 or more crashes may merit attention. Although this does not constitute a test of statistical significance per se, the fact that the Observed Sites column tends to show a larger number of intersections than the Negative Binomial Distribution column when the crash frequency is 3 or higher suggests that sites with 3 or more crashes may merit additional study.