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Extent and Impacts of the Virginia Department of Transportation's Exception Process for Access Management Design Standards

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

LANCE E. DOUGALD
Senior Research Scientist

RYLEY S. STEVENS
Research Assistant

MATTHEW D. DEAN
Research Assistant

CATHERINE H. GAYNER
Research Assistant

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VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginiadot.org

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16. Abstract:

The Virginia Department of Transportation (VDOT) *Road Design Manual* requires that new commercial entrances meet certain minimum spacing standards depending on a facility's speed limit and functional classification. Landowners, however, may request an exception from these standards, leading to two questions relevant for Virginia's access management program: how often are such requests occurring, and are such requests associated with an increase in crash risk?

Based on data available for the period 2011-2016, such exception requests occurred for approximately 15% of all commercial entrances in Virginia, a lower figure than most, but not all, other states for which this information is available. Virginia's exception requests are diverse, covering functional classes ranging from local roads to principal arterials and speed limits from 25 to 55 mph; examination of a smaller subset of these requests showed that about one fifth included a mitigation measure, such as entrance consolidation, designed to reduce crash risk.

Examination of crash rates (e.g., crashes per year where only full years of data are used to minimize seasonal disparities) for 64 exception sites in four of the nine VDOT districts—Fredericksburg, Hampton Roads, Northern Virginia, and Staunton—showed no significant difference between the period before the entrance was constructed and the period after the entrance was constructed ($p = 0.63$). Using a subset of these exception sites—just 23 in the Northern Virginia District where a similar comparison site could be identified—a matched-pairs analysis was performed, in which one subtracts the change in crash rates at each exception site (from the before to the after period) from the corresponding change at each comparison site (for the same time interval). No significant difference in these changes was detected ($p = 0.94$).

Although these data suggest that the exception program is not associated with an increase in crash risk, the study suggests that the exception requests continue to be monitored to ensure that exception rates remain stable. To make this monitoring feasible, the study recommends that VDOT use a customized module, recently developed by staff in VDOT's Office of Land Use, which will facilitate the tracking of exception requests.

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FINAL REPORT

EXTENT AND IMPACTS OF THE VIRGINIA DEPARTMENT OF TRANSPORTATION'S EXCEPTION PROCESS FOR ACCESS MANAGEMENT DESIGN STANDARDS

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

Lance E. Dougald
Senior Research Scientist

Ryley S. Stevens
Research Assistant

Matthew D. Dean
Research Assistant

Catherine H. Gayner
Research Assistant

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Virginia Transportation Research Council
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DISCLAIMER

EXECUTIVE SUMMARY

Introduction

The Virginia Department of Transportation's (VDOT) *Road Design Manual* (VDOT, 2017c) requires that new commercial entrances meet certain design standards based on a roadway facility's functional classification and speed limit and the nature of the entrance. An example is that if a proposed signalized commercial entrance will be built on a 40 mph principal arterial, the proposed entrance must be at least 1,320 feet away from any signalized intersections; at least 1,050 feet away from any full access unsignalized intersections; and at least 305 feet away from any partial access unsignalized intersections. Because there may be situations when it is not feasible to meet these standards, Virginia—as do other states—has a process in which landowners who are seeking a commercial entrance permit can request an exception to these standards. The literature (Frawley and Eisele, 2000; Ginder et al., 2013; Gluck and Lorenz, 2010) clearly indicates the need for an exception process, but such literature (e.g., Frawley and Eisele, 2000) and others (Sarasua et al., 2015; Schultz, 2016) warned that exceptions have the potential to affect safety adversely.

This study sought to address three concerns facing Virginia: (1) how do Virginia standards and exception processes compare with those of other states; (2) to what extent are commercial access exceptions used in Virginia; and (3) at those sites where exceptions are granted, what has been the impact on crashes in Virginia? In this context, a commercial access request often refers to industrial or business land uses (e.g., a warehouse or a shopping center), but it can also include public facilities (such as a park-and-ride lot) or a collection of residences (e.g., a set of 35 dwelling units). Although the Virginia Administrative Code indicates there are in fact six access management standards, the access management requests that were reviewed by the research team for this study all pertained to either a spacing standard, such as that noted previously, or a corner clearance standard.

Use of Exceptions in Other States

Although the literature (e.g., Gluck and Lorenz, 2010; Williams, 2002) discusses exceptions, the research team did not find a source that provided information regarding other states' practices with respect to setting spacing standards and processes for consideration of exceptions to those standards. Accordingly, a survey was designed to gather information from access management representatives in each state regarding (1) what criteria are used for those standards, and (2) if a process exists for applicants to request a deviation from those standards.

Each of the 27 states that completed the survey has some form of guidance, policy, or standard related to access management, and every state's standard (or policies or guidance) applies to commercial entrances. The criteria for these standards, however, were not consistent. For example, as shown in Table ES1, whereas Virginia uses speed limit and functional classification, other states use either fewer criteria such as speed only (e.g., Alabama) or more criteria such as area type (e.g., North Carolina). About one-third of the responding states (i.e., 9 of 27) use roadway classification, speed limit (10 of 27), or area type (10 of 27), and fewer responding states (4 of 27) use cycle length. The state with criteria most similar to those of

Virginia appeared to be New Mexico: like Virginia, New Mexico uses speed limit and roadway classification, but unlike Virginia, New Mexico has different standards for urban and rural areas.

Thus, state-by-state comparisons require some judgment to interpret. For example, to compare Virginia to Florida, one must consider whether a Virginia principal arterial matches a Florida Class 2, 3, or 4 roadway. With consideration of the assumptions noted in the body of this report, Virginia's minimum spacing standards for signalized intersections appear to be either equal to or less restrictive than those of other states where a comparison is feasible. For example, for a principal arterial with a speed limit of 45 mph, Virginia's standard (1,320 feet) is equal to those of Alabama, Georgia, and Vermont (if in an urban location) and less restrictive than those of Florida, New Mexico, Georgia, and Vermont (if in a rural location). Further, Virginia's standard is also less restrictive than those of Missouri, South Carolina, South Dakota, Oregon, Washington State, Utah, Illinois, New Jersey, Kansas, and Nevada. Virginia's standard is more restrictive than that of two states: Nebraska and North Carolina.

Of the 27 responding states, almost one half (13 of 27) did not indicate how often a permit request entails an exception request. (Reasons given for not providing this information include permitting processes are decentralized, records are not kept, and there is no tracking measure for the information.) Of the remaining 14 responding states, the percentage of entrance permits requiring an exception ranges from less than 1% (California) to as high as 75% (Nebraska and Nevada). Virginia's percentage of 15% is the third lowest in this list, behind that of California and Connecticut (given as a range of 5% to 10%). Less information is available regarding the approval rate for these exception requests: no states had definitive data, and most respondents (16 of 27 states) indicated that a majority of requests are approved (which is the case in Virginia). About one-half of these states require that some type of traffic impact analysis accompany the exception request.

Table ES1. Examples of State Spacing Standards for Signalized Intersections

State	Area Type	Roadway Classification	Speed Limit (mph)	Spacing (ft)
Alabama			≤45 >45	1,320 2,640
Virginia		Principal Arterial	≤30 35-45 ≥50	1,050 1,320 2,640
		Minor Arterial	≤30 35-45 ≥50	880 1,050 1,320
		Collector	≤30 35-45 ≥50	660 660 1,050
North Carolina	Urban/Suburban	Main Street Avenue Boulevard Parkway	20-25 25-35 25-40 >35	<400 400-1,000 <400-1,000 >1,000
	Rural	Main Street Avenue Boulevard Parkway Rural Road	20-25 25-35 30-40 >35 25-55	400-1,000 <400-1,000 <400-1,000 >1,000 >1,000

Extent to Which Access Exceptions Are Used in Virginia

In June-July 2016, VDOT district staff were asked to provide information indicating the number of exception requests approved and denied and the number of commercial land use permits approved based on the multiyear period from January 2011 to the time the survey was conducted; responses were received from July-September 2016. To increase the survey response rate, researchers provided information that could be obtained from various VDOT databases, such as the Access Management Team Site and the Land Use Permit System (LUPS), and provided this information to district staff, asking them to verify it. Generally, LUPS was complete: only about 9% of the 1,846 commercial entrance permits were not found in the database. However, 57% of the entrance requests (230 of 403) were not found on the Access Management Team Site; the district responses were essential for obtaining this information.

These unlisted exception requests were incorporated into Table ES2, which provides the number of approved exception requests and the total number of commercial entrance permits sought based on survey responses received from July-September 2016. Table ES2 suggests that about 14.5% of commercial entrance permit requests (393 of 2,714) entailed an approved request for an exception. Although most commercial entrance permits thus do not require an exception, once an exception was sought, most were approved: 393 were approved, and only 10 were denied during this same period. In at least one district, alternatives and mitigations were discussed rather than an outright denial being issued (Joseph, 2016). However, having an approved request does not necessarily mean the site will be constructed: outside the Northern Virginia District, slightly more than one-half of the exception requests (184 of 318) had been built. (As pointed out by a reviewer of this report, it would have been more proper to state that the *requested entrance that was the subject of the exception requests* had been built.) There can also be several years lag time between the entrance permit being issued and when construction occurs; for example, a permit for a site near Ox Road and Braddock Road was approved on December 22, 2011, and that site was under construction in February 2017 when this study was under way.

Table ES2. Approved Exception Requests and Commercial Entrance Permits in Each VDOT District

District	Approved Exception Requests			Approved Commercial Entrance Permits
	Built	Not Built	Total	
Bristol	17	11	28	155
Culpeper	16	15	31	172
Fredericksburg	9	18	27	230
Hampton Roads	15	7	22	146
Northern Virginia	At least 28[a]	At least 10[a]	113	At least 868[a]
Lynchburg	19	14	33	165
Richmond	13	14	27	425
Staunton	17	20	37	259
Salem	50	25	75	294
Total (excluding Northern Virginia District)	184	134	318	1,846
Total (including Northern Virginia District)			393	2,714

[a] Rough estimate from respondent. There were an additional 75 approved exception requests beyond the 28 built and the 10 not built, but it was not known which of those 75 requests had been built. The respondent also indicated that for one of the three counties in the Northern Virginia District, the number of approved commercial entrance permits was higher than the estimate provided by the researchers but did not indicate by how much.

A detailed review of 23 exception requests in the Northern Virginia District (chosen because they had sufficient detail so that they could be used in a later crash analyses for the period June-August 2016) showed substantial variation in the requests in terms of (1) the speed limit and functional class of the facility for which the request was sought; (2) the type of commercial land use supported by the request; (3) deviation from the standard; and (4) whether mitigation measures were in place.

- Of the 23 requests, sites had speed limits of 25 mph (4 sites), 30 to 35 mph (9 sites), 40 to 45 mph (8 sites), and 55 mph (2 sites), with functional classes including local roads, major collectors, minor arterials, and principal arterials. (Neither minor collectors nor major arterials were in the sample. Note in the crash analysis, however, that major and minor collectors were grouped in order to be consistent with the spacing standards, which do not differentiate between major and minor collectors.)

- These exception requests supported both large trip generators (e.g., a 279-space park-and-ride lot or a 240,500-square-foot office building) and relatively small trip generators (e.g., an electrical substation and a set of six residential dwelling units).

- The deviation from the standard also varied: 10 of the requests entailed a deviation of 100 feet or less and 10 entailed a deviation between 125 and 293 feet from the standard.

- Exception requests may also include a "mitigation measure"—that is, one or more actions that will reduce the negative impacts of the proposed entrance where such impacts are "degradation in safety or a significant increase in delay or a significant reduction in capacity beyond an acceptable level of service" (VDOT, 2013a). Of these 23 exception requests, 5 listed some type of "mitigation measure," such as the consolidation of two entrances.

One common characteristic of these exception requests was that they usually involved the spacing standard: of the 23 requests, 21 involved a spacing standard and 2 involved a corner clearance standard.

Virginia Crash Analysis

To reduce the data collection time associated with examining all 393 exception sites listed in Table ES1, a total of 64 exception sites were identified from four VDOT districts: Northern Virginia (23 sites), Fredericksburg (14 sites), Hampton Roads (12 sites), and Staunton (15 sites). One-half of these sites (32 sites) had 3 full years of "after" data, and the remaining sites had shorter after periods because the exception request was completed relatively recently. Most of the exception sites (54 sites) concerned the spacing standard; the remaining 10 involved a corner clearance standard. (A single site could include a location under construction; a location where proof of construction derived from either a completion date in LUPS or a news report; or a single entrance for a land use that had more than one entrance; for these reasons, the number of sites for the crash analysis was not the same as the number of built sites reported by survey respondents.

At each of these sites, the research team collected, where possible, up to 3 years of crash data before the month in which the site was completed and up to 3 years of crash data after the month in which the site was completed. Then, these data were converted into two crash rates: crashes per year, such that the "before" and "after" periods reflected the same seasons, and crashes per month, such that the dataset was as complete as possible. For example, for a site that was built in March 2015, the before period could be March 1, 2012–February 28, 2015, reflecting 3 years of crash data or 36 months of crash data. For the after period, however, one could insist that it have roughly the same seasons (e.g., define the after period as only April 1, 2015–March 31, 2016) or, at the expense of having exactly the same seasons, as April 1, 2015–December 31, 2016, which would yield a few extra months of data. The former approach was referred to as normalization by year, and the latter approach was referred to as normalization by month. Although normalization by month would seem less desirable, it was a way to capture a bit of data at sites that were constructed very recently, as the most recent construction dates for each district were May 2015 (Fredericksburg), August 2015 (Northern Virginia), September 2015 (Staunton), and December 2015 (Hampton Roads).

Using 300-foot buffers around these 64 exception sites, the research team compared the crash rates (normalized by month and by year) at the exception sites before and after completion of the exception. The difference in crash rates was not significant based on the Wilcoxon signed rank test ($p = 0.63$ or $p = 0.25$ depending on whether crashes were normalized by year or by month). A different test that requires fewer assumptions than the Wilcoxon signed rank test but has less statistical power—the one-sample sign test—also revealed no significant differences ($p = 1.00$ for normalization by year, and $p = 0.78$ for normalization by month). Adjustment of the crash data collection method to include crashes captured via the aforementioned method plus any crashes along the roadway up to the centerline of the adjacent intersection (what became Method 2) did not materially alter these results: there was no significant change in crash rates at the 64 exception sites.

Each exception site can be matched to a "comparison site" where ideally the comparison site has traffic and geometric exceptions similar to those of the exception site—minus the exception itself. Using the same 64 exception sites and a corresponding set of 64 comparison sites, the researchers performed a matched-pairs comparison, using the original data collection method of 300-foot buffers around the exception site. Equation ES1, adapted from Mokhtarian et al. (2002), shows the computation of a difference in ratios, where one examines whether the change in crash rates at the exception site (following completion of the entrance that is the subject of the exception request) differs from the change in crash rates at the comparison site (where no entrance was built). For instance, if Equation ES1 showed a positive value for each site, an implication would be that the entrance might be contributing to an increase in crash rates. For 33 pairs of sites that did not have a value of 0 in the before crash rate for the comparison sites or the exception sites, the Wilcoxon signed rank test shows no significant difference in ratios, whether normalizing by year ($p = 0.24$) or by month ($p = 0.17$).

$$\text{Difference} = \frac{\text{After crash rate (exception site)}}{\text{Before crash rate (exception site)}} - \frac{\text{After crash rate (comparison site)}}{\text{Before crash rate(comparison site)}} \qquad \text{[Eq. ES1]}$$

(The 31 pairs of sites that were excluded because of 0 crashes during the before period at either a comparison site or an exception site did not yield a consistent rate of change in crash rates from the before to the after period. For 9 pairs, the change from the before to the after period at exception sites and comparison sites was identical; for 11 pairs, the change in the exception site crash rate was greater than the change in the comparison site crash rate; and for 11 pairs, the change in the comparison site crash rate was greater than the change in the exception site crash rate.) An additional experiment with negative binomial models, reported in Appendix F, suggests that exception requests are not associated with a change in crash risk because the significance level for the presence of an exception request does not change from the before period (prior to the entrance being built) to the after period (after the entrance has been constructed) and the coefficient remains relatively constant for both periods.

Two additional modest experiments with the exception sites in the Northern Virginia District—a before-after analysis with 150-foot buffers and exclusion of not just the month in which the entrance was completed but also the month before construction and the month following completion of construction—did not materially alter these results. The Wilcoxon signed rank test (chosen because it did not rely on assumptions about the underlying distribution) showed no significant change when normalized by month ($p = 0.76$) or by year ($p = 0.59$) using the 150-foot buffer and excluding only the month in which the entrance was completed from the analysis. Repeating this test but excluding the month before and the month after construction was completed also yielded no significant difference ($p = 0.84$).

Conclusions

1. *The criteria used by states to establish spacing standards are not consistent.* Although Virginia uses roadway classification and speed limit (see Table ES1), other states use fewer criteria (e.g., Alabama uses speed only), additional criteria (e.g., North Carolina uses area type in addition to Virginia's criteria), or different criteria (e.g., Kansas uses speed and cycle length but not roadway classification).

2. *Virginia does not appear to have more restrictive spacing standards than other states based on the few cases for which a direct comparison can be made*. For example, for one particular standard, Virginia is less restrictive than either 13 or 14 states, as restrictive as 2 or 3 states, and more restrictive than 2 states. (The "or" is used because 1 state, Vermont, is either more restrictive than Virginia or as restrictive as Virginia depending on whether the standard applies to an urban or a rural location.)

3. *A minority (15%) of Virginia access permit requests entail a request for a deviation from access management standards*.

4. *Compared to other states where this information is available, a relatively small percentage of entrance permits in Virginia entail an exception request. Of the 14 states where this*

percentage is available, only 3 have lower percentages than Virginia: California (less than 1%), Connecticut (5% to 10%), and Iowa (10%).

5. *In Virginia, access permit requests are rarely (3%) denied. Rather, as explained by one VDOT district, alternatives and mitigations are discussed.*

6. *The VDOT databases vary in terms of completeness. Where it was possible to make a direct comparison, the Access Management Team Site contained less than one-half (43%) of the access management requests and LUPS contained most (91%) of the land use permit requests.*

7. *At sites where an exception request was granted, there was not a significant change in crash rates after the entrance was completed. This conclusion held whether crashes were normalized by year ($p = 0.63$) or by month ($p = 0.78$), based on the Wilcoxon signed rank test and the one-sample sign test, respectively. (The former test is more powerful, but because its assumptions did not necessarily hold for the monthly data, the results of the latter test, which is weaker but requires fewer assumptions, are also provided for the monthly data.)*

8. *There was not a significant difference in the ratio of after crash rates to before crash rates at exception sites and comparison sites. The results were $p = 0.24$ or $p = 0.17$ based on the Wilcoxon signed rank test and normalizing by year and by month, respectively.*

9. *The exception requests reflected relatively diverse situations. The exception requests spanned a range of values in terms of functional class, speed limit, land use, and presence of a mitigation measure. Most exception requests involved the spacing standard shown in Table ES1.*

Recommendations

1. *VDOT's Office of Land Use should ask VDOT's Information Technology Division to implement the customized module in LUPS that was developed by the Office of Land Use.* This customized module, in addition to instructions for its use, is shown in Appendix D.

2. *VDOT's Office of Land Use should notify the district transportation and land use directors to direct their permit specialists to indicate whether a permit required an exception request when they are entering commercial entrance permits into LUPS.* This can be accomplished by the use of the customized module developed by LUPS management in accordance with the instructions provided in the section of Appendix D titled "Entering Exception Request Information into LUPS."

3. *VDOT's Office of Land Use, in consultation with the district transportation and land use directors and other district staff, should periodically monitor the proportion of commercial entrance permits requiring an exception.* This can be accomplished by the use of the customized module developed by LUPS management in accordance with the instructions

provided in the section of Appendix D titled “Using LUPS to Query Commercial Entrance Permits.”

4. *VDOT’s Office of Land Use should update the Access Management Exception Request Form to include latitude and longitude for each proposed entrance*. If the latitude and longitude are recorded to five decimal places, the location in the database will be within 4 feet of its real-world location. The use of this latitude and longitude would provide another way to link information from two databases: the exception requests from VDOT’s Access Management Team Site and LUPS.

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Research Assistant

INTRODUCTION

The Virginia Department of Transportation's (VDOT) *Road Design Manual* (VDOT, 2017c) refers readers to Appendix F, titled *Access Management Design Standards for Entrances and Intersections* (VDOT, 2014), which includes design standards pertinent to the construction of commercial entrances. For example, if a new commercial entrance will require a traffic signal, one relevant standard is the spacing standard, shown in Figure 1. For a road that is functionally classified as a principal arterial with a speed limit of 35 to 45 mph inclusive, signalized intersections must be at least 1,320 feet apart. If the new commercial entrance will not be signalized, unsignalized intersections must be at least 1,050 feet apart, as indicated in Figure 1. The spacing standard shows how the distance changes as a function of highway functional class, speed limit, whether the intersection has a signal or not, and type of intersection or entrance. Thus, the spacing standard concerns not just intersections but also median crossovers and unsignalized commercial driveways. For example, on the same facility, if a median is present such that two commercial driveways provide only right-in right-out access, the spacing between them must be at least 305 feet. In addition to the spacing standard shown in Figure 1, three other standards exist: spacing standards near an interchange ramp on multilane crossroads; spacing standards near an interchange ramp on two-lane crossroads; and corner clearance standards. For example, the corner clearance standard indicates that a commercial entrance must be at least 225 feet away from an upstream intersection.

Quantitative impacts of access management standards on both congestion (e.g., preservation of capacity and smoother traffic operations) and safety (e.g., reduction of traffic conflicts) have been documented in the literature for almost two decades. For example, Gluck et al. (1999) suggested that a quarter-mile spacing standard (between signals) could increase travel times by 16% compared to a half-mile standard; cutting this spacing to one-eighth of a mile could increase travel times by 39%. It has also long been understood that access standards can improve safety by reducing rear-end crashes that result from interruptions to the traffic flow and sideswipe crashes that may result from sudden lane changes. Gluck et al. (1999) indicated that as the number of signalized access points per mile increases from fewer than two to more than six, the expected crash rate in millions of vehicle miles traveled increases from 4.13 to 9.13 (for a segment with two-way left-turn lanes) or from 2.94 to 5.40 (if the segment has a raised median). Perhaps the most compelling relationship is provided in the Transportation Research Board's *Access Management Manual* (Williams et al., 2104) that, citing research from Gluck et al. (1999), shows that as the total number of access points (e.g., the number of signalized intersections and unsignalized commercial driveways) increases from fewer than 20 per mile to more than 60 per mile, the crash rate almost triples.

Minimum Spacing Standards for Commercial Entrances, Intersections, and Median Crossovers

Highway Functional Classification	Legal Speed Limit (mph)①	Minimum Centerline to Centerline Spacing (Distance) in Feet			
		Spacing from Signalized Intersections to Other Signalized Intersections ② *a*	Spacing from Unsignalized Intersections & Full Median Crossovers to Signalized or Unsignalized Intersections& Full Median Crossovers ③ *b*	Spacing from Full Access Entrances & Directional Median to Other Full Access Entrances and Any Intersection or Median Crossover ④ *c*	Spacing from Partial Access One or Two Way Entrances to Any Type of Entrance, Intersection or Median Crossover ⑤ *d*
Principal Arterial	≤ 30 mph	1,050	880	440	250
	35 to 45 mph	1,320	1,050	565	305
	≥ 50 mph	2,640	1,320	750	495
Minor Arterial	≤ 30 mph	880	660	355	200
	35 to 45 mph	1,050	660	470	250
	≥ 50 mph	1,320	1,050	555	425
Collector	≤ 30 mph	660	440	225	200
	35 to 45 mph	660	440	335	250
	≥ 50 mph	1,050	660	445	360

Figure 1. Example of a VDOT Access Standard. Taken from Table 2-2 of VDOT (2014). Note that this source has been updated (VDOT, 2017); however, the spacing standards shown in Figure 1 have not changed since 2011 (VDOT, 2011).

Virginia's Process for Considering Exceptions to the Standards

As is the case with other transportation agencies (Ginder et al., 2013; Gluck and Lorenz, 2010), Virginia has a program by which landowners who are seeking a commercial entrance permit can request an "exception" to one or more of the access management standards. VDOT's public website titled Access Management Regulations and Standards (VDOT, 2017a) has a link to *Access Management Regulations* (24VAC30-73) (VDOT, 2013a). Section 120C of those regulations (VDOT, 2013a) outlines six access management standards for commercial parcels for which exceptions may be granted. These standards are abbreviated here as (1) locations cannot be within functional areas of interchanges, roundabouts, or intersections; (2) commercial entrances must serve at least two parcels; (3) proper spacing of commercial entrances must be maintained (this is part of the standard shown in Figure 1); (4) connections must be made to adjoining undeveloped properties to reduce circulation on mainline arterials; (5) traffic signal spacing must be maintained (this is also part of the standard shown in Figure 1); and (6) certain traffic movements (e.g., left turns) may be prohibited at the discretion of the district administrator. The mechanism through which these landowners may seek an exception for connections to the VDOT roadway network is the completion of the Access Management Exception Request Form (Form AM-E) (VDOT, 2015). Although the Virginia Administrative Code (VAC) specifies six design standards, for the purposes of applying the VAC, VDOT uses four standards. Figure 1 incorporates two of these standards: traffic signal spacing (see Column 3) and spacing of commercial entrances (see Columns 3 through 6 where a commercial entrance will be one of the entrance types shown in those columns).

As indicated at the top of Figure 2, an exception request is needed if a commercial entrance violates any of the four access management standards shown, respectively, in Table 2-2, Table 2-3, Table 2-4, or Figure 4-5 of VDOT's *Access Management Design Standards for Entrances and Intersections* (VDOT, 2014).

☑ **EXCEPTION TO THE SPACING STANDARDS FOR:**

- **Commercial entrances; intersections/median crossovers (Table 2-2);**
- **Commercial entrances/intersections near interchange ramps (Tables 2-3, 2-4);** or
- **Corner clearance (Figure 4-4).** Appendix F, Road Design Manual

Information on the Exception Request

☑ **ON A STATE HIGHWAY**

Functional classification: Principal Arterial: ☑ Minor Arterial: ☐ Collector: ☐ Local: ☐

Posted speed limit: 45 mph

☐ **NEAR AN INTERCHANGE RAMP** (Submittal of a traffic engineering study required)

☐ **CORNER CLEARANCE** (Submittal of a traffic engineering study required)

Type of intersection/entrance: Signalized ☐ Unsignalized ☑ Full Access ☐ Partial Access ☑

Required spacing distance 305 **ft**

Proposed spacing distance 95 **ft** to the west / 90 ft to the east

Requested exception: Reduction in required spacing 210 **ft** to the west / 215 ft to the east

Figure 2. Example of an Access Management Exception Request, Taken From VDOT's Access Management Team Site. In May 2016, Appendix F (VDOT, 2014) was updated such that "Corner Clearance" now refers to Figure 4-5 (VDOT, 2017).

For example, for New Hope Church on Route 606 in Albemarle County, an exception was sought in 2013 to allow this entrance to be just 100 feet from the upstream intersection rather than 225 feet as required by the corner clearance standard. This exception was granted, with three justifications being cited: limited sight distance that would result from moving the entrance the required distance, nearby residents' unwillingness to share an entrance, and avoidance of negative impacts to a nearby stream. A second example of an exception is shown in Figure 2: rather than maintaining a 305-foot spacing standard as required for a 45 mph principal arterial (see Figure 1), a reduction of 210 feet was requested.

Exception requests may also include a "mitigation measure"—that is, one or more actions that will reduce the negative impacts of the proposed entrance, where such impacts are "degradation in safety or a significant increase in delay or a significant reduction in capacity beyond an acceptable level of service" (VDOT, 2013a). The VAC (24VAC30-73-70) (VDOT, 2013a) provides examples of mitigation measures such as turning lanes, modifications to crossovers, installation or removal of traffic signals, entrance consolidation, the provision of additional right of way, and implementation of recommendations from related corridor studies. However, the VAC clearly states that mitigation measures are not limited to these examples. Thus, there is a great deal of flexibility in the types of mitigation measures that can be proposed; for instance, an applicant might propose to relocate an existing entrance or provide right of way (or an easement) for a proposed entrance. VDOT (2013a) noted that the mitigation measures, when considered by the "district administrator's designee" (e.g., district traffic engineer or resident engineer), will be considered on the basis of the ability of the mitigation measures to maintain the roadway's performance and to "protect the transportation corridor." Thus, the guidance for mitigation measures is not prescriptive; rather, the measures are judged on their ability to "preserve the operational characteristics of the highway."

As shown in Figure 3, although an exception is being requested (see the green overlay drawing), several entrances may be combined and one entrance is proposed to be moved farther away from the intersection (Proctor, 2016). In such cases, when a mitigation is proposed, it is possible that the "exception" could result in a reduction in crash risk. In fact, at this particular site, the VDOT district planner familiar with the request characterized it as beneficial in that safety improvements are needed, and rather than VDOT having to purchase right of way and pay for the improvements entirely, VDOT and the developer could share costs (Chuck Proctor, personal communication, June 7, 2017). Proctor (2016) noted that one can pay attention in particular to the exception requests that do not have a checked box indicating that the existing spacing does not meet current spacing standards. For example, Figure 4 shows that the box is checked for a parcel known as the "Backlick Road Property." Examination of the request does not reveal any evidence of any mitigations. However, the use of the checked box is only an early warning; to confirm that mitigations have not been performed, one must examine the entire application.

Figure 3. Example of an Exception Site With Proposed Mitigation Measures Near Route 29 (running left to right) and Route 33 (running top to bottom) in Ruckersville (Proctor, 2016). The photograph shows several existing entrances that presently violate spacing standards. The proposed mitigation (green) combines several entrances and moves one farther from the intersection. (In addition to the route names and entrances being labeled, the words within the figure indicate the proposed land uses; for example, the lower left green box indicates that a "retail" development of 14,560 square feet is proposed for that location.) Reprinted with permission of Timmons Group.

REASON FOR EXCEPTION:

☑ A. To be located on an older, established business corridor along a highway where existing spacing did not meet the standards prior to 7/1/08 or 10/14/09. (Regulation Section 120 C.3.c)

☑ Attached: Dated aerial photo of corridor identifying proposed entrance/intersection location.

REASON FOR EXCEPTION:

☒ **A. To be located on an older, established business section of a highway corridor where existing spacing did not meet the spacing standards prior to October 14, 2009.** (Regulation Section 120 C.3.c)

☒ **Attached:** Dated aerial photo of corridor identifying proposed entrance/intersection location.

Figure 4. Excerpt of an Access Management Exception Request. *Top:* a property for a service station. *Bottom:* a parcel located on Backlick Road. The checking of the box suggests that other entrances in this corridor do not meet the standard.

Other Agencies' Processes for Considering Exceptions to the Standards

The collective literature supports a process for allowing exceptions to standards. Note that Virginia generally uses the term "exception" to refer to a private property owner requesting a deviation from the standards. In another context, when facilities are designed and not related to access management in particular, Virginia uses the term "waiver" to refer to a facility that meets national standards but not Virginia standards (VDOT, 2016a). However, some literature (e.g., Williams, 2002) uses the terms "exception" and "waiver" interchangeably. For consistency, this report uses the term "exception" to refer to private property owners' request for a deviation from standards and uses the term "waiver," "variance," or "deviation" only if the term is in a direct quotation from the literature or was used in communication with staff of other transportation agencies who might be more accustomed to such terminology.

In reporting on the exception process used by the Port Authority of New York and New Jersey, Ginder et al. (2013) noted that a "fair, consistent, and systematic process" of review is critical for the agency's access management program. Based on a synthesis of the literature, Gluck and Lorenz (2010) suggested seven "situations" for which an exception may be granted: (1) the intersection that is the subject of the exception request is in an area where other nearby commercial entrances also do not meet the standard; (2) right-of-way constraints prohibit meeting the standard; (3) a site is very close to meeting the standard; (4) the agency's standard may conflict with requirements of another regulatory entity, such as an environmental agency; (5) the applicant would like to improve conditions voluntarily (e.g., an applicant may not need to move an entrance but may choose to do so in order to improve spacing); (6) an application of the standard would be "unreasonable" in the eyes of both the landowner and the transportation agency; and (7) the situation is unique. Frawley and Eisele (2000) recognized the necessity of a process for exceptions, noting that it is not possible to develop regulations that conceive of every possible situation—a reflection of the seventh situation noted. In fact, at least two of these situations have been considered in VDOT's exception process. Situation 1, i.e., that the proposed entrance is in a corridor where other entrances do not meet the standard, is an option that a landowner can indicate when requesting an exception, as shown in Figure 4. Situation 2, i.e., right-of-way constraints, was implicitly used in the aforementioned New Hope Church exception request.

The collective literature, however, warns that having an exception program, although essential, is not a panacea for handling all exception requests. Although reporting that more than one-half (52 of 93) of survey respondents representing all 50 state departments of transportation (DOTs) and 43 other transportation agencies indicated that they have an exception process, Gluck and Lorenz (2010) also highlighted the need for a careful administration of an exception program; further, they noted an observation from earlier literature that exceptions that are repeatedly granted should result in a modification of the standard. For example, in response to more than 60 requests for access exceptions, VDOT (2011) decided to reduce the spacing requirements in place at that time: "The number of exceptions indicates that a reasonable reduction in the spacing distances would be in order." As one example, the minimum spacing between traffic signals on principal arterials with a speed limit of 35 to 45 mph was reduced from 2,640 feet (VDOT, 2011) to 1,320 feet (as shown in Figure 1).

An implication, therefore, of standards that are too restrictive (e.g., one can imagine doubling the distances shown in Figure 1) is that exceptions could thus become common, resulting in a de facto elimination of the standards. Not surprisingly, agencies may be cautious in their allowance of exceptions. For example, Sarasua et al. (2015) reported that one state allows an exception only if certain conditions are met, such as the exception is essential to providing "reasonable" site access, no feasible alternatives exist, and the exception will not inhibit access for pedestrians. Schultz (2016), currently a member of the Transportation Research Board's Standing Committee on Access Management, stated: "**Every access point** is a fundamental safety problem" (emphasis in original). Frawley and Eisele (2000) repeated a comment from an interviewee associated with a state access management program who noted that an access management standard "is a tree and every waiver is a whack at the tree with an axe." (In this context, the term "waiver" is analogous to what Virginia calls an "exception" in that an entity is requesting a deviation from access management standards.) Finally, Williams (2002) emphasized the need for consistency in how exceptions are considered, noting that "inconsistent or infrequent application of standards makes them vulnerable to legal challenges."

Questions About Virginia's Exception Process

Although the aforementioned literature (Frawley and Eisele, 2000; Ginder et al., 2013; Gluck and Lorenz, 2010) clearly recognized the need for an exception process, the literature (Frawley and Eisele, 2000; Sarasua et al., 2015; Schultz, 2016) also recognized that exceptions have the potential to affect safety adversely. This literature supports a question posed by VDOT's Office of Land Use: In Virginia, does the exception process for access management standards as currently administered influence crash risk? Answering this question requires two categories of information: (1) the extent to which exceptions are granted in Virginia, and (2) the resultant impact on crashes at those sites for which exceptions are granted.

First, the extent to which exceptions have been granted and then acted upon is not known; that is, the number of exception requests and the percentage of such requests that are accepted have not been tabulated. Although the aforementioned New Hope Church received an exception on October 10, 2013, an entrance permit was believed to be "close" to being issued in May 2016 (Alkhadra, 2016a)—but 1 year later, in June 2017, the permit still had not been issued. The entrance had been built and had been used to reach and clear the property; however, the church itself had not been built (Alkhadra, 2017a). Further, VDOT's Office of Land Use was concerned that not all exceptions granted by the VDOT districts had been submitted to the Office of Land Use, such that it was possible that there were additional exceptions beyond those stored in VDOT systems.

Second, it is not known if these exceptions affected crash risk—that is, whether the allowance of exceptions resulted in higher crash frequencies than would have been the case had no exceptions been allowed. Although crash frequency is affected by a variety of factors (such as driver population and geometric design), a complication particular to access management is that to some extent, one would expect an increase in crash risk when any type of land development activity occurred, owing to an increase in vehicle volumes accessing the new land use, and hence an increase in the frequency of interruptions in the traffic stream. A related complication is that the standards (e.g., those shown in Figure 1) and the exception processes (elements of which are shown in Figures 2 and 3) used by other agencies were not known to the research team at the inception of this study.

PURPOSE AND SCOPE

The purpose of this study was to determine if Virginia's exception process is associated with an increase in crash risk. The study had three objectives:

1. Summarize practices used by other states regarding their access standards and the processes used to consider exceptions to such standards.

2. Document the extent to which access exceptions have been granted for the VDOT roadway network.

3. Identify, and then implement, a methodology to evaluate potential safety impacts of these exception requests at specific sites.

The scope of the study was limited in four ways: (1) the study was limited to entrances sought by a private entity (i.e., either a commercial entrance or an entrance sought by a developer for a collection of multiple residential dwelling units); (2) the study was limited to exception reports that were developed since January 1, 2011 (because examination of VDOT's Access Management Team Site confirmed that most exception requests were in 2011 or later); (3) the "after" period for the crash data was limited to 3 years or less (because many exception reports were not developed until 2013, with entrances being built some time thereafter); and (4) the crash analysis focused on data that could be obtained during the timeframe of the study, i.e., data from four of the nine VDOT districts: Fredericksburg, Hampton Roads, Northern Virginia, and Staunton.

METHODS

Four tasks were conducted to achieve the study objectives:

1. Conduct a literature review and a survey of access management practices in other states.

2. Determine the nature of VDOT access exception requests.

3. Develop approaches to address confounding factors.

4. Quantify the crash-related impacts of access exceptions.

Task 1. Conduct a Literature Review and a Survey of Access Management Practices in Other States

Literature Review

The researchers conducted a literature review to document state practices with regard to deviations from access management standards and what those standards were. Although information could be gleaned from a few states, much of this information was not available. For example, Gluck and Lorenz (2010) provided a table of minimum spacing standards required in interchange areas for 36 North American transportation agencies; for the agencies that had a standard, the value ranged from 100 to 750 feet; however, this table was based on literature published in 2004. Although several sources (e.g., Gluck and Lorenz, 2010; Williams, 2002) discussed exceptions, the research team did not find a source that provided information regarding the approval rates for such exceptions. Accordingly, a survey was designed to gather information from access management representatives in each state.

How the Survey Was Conducted

The objectives of the survey were to ascertain (1) if states have established access management standards, (2) the criteria that are used for those standards, and (3) if a process exists for applicants to request a deviation from those standards. The survey thus contained 12 questions designed to elicit this information. For instance, regarding the third objective, the survey asked if requests for a deviation required a traffic engineering study. The research team sought to be specific but also to allow respondents to provide information if a complete answer was not known. For example, when asking what percentage of commercial entrance permit requests includes a request for a deviation, the survey noted that if an exact percentage was not required, respondents should give an estimate but clarify that this response was indeed an estimate. A description of the development of the survey instrument, based on multiple reviews by the study's technical review panel (TRP) and the Virginia Transportation Research Council's editor, is provided in Appendix A along with the survey instrument itself.

With the assistance of staff of the VDOT Research Library, a list of state DOT contacts affiliated with access management in all 50 states was developed to include a name, telephone number, and email address. Since the researchers anticipated that a survey instrument distributed solely by email would have a low response rate given that many of the questions could potentially have open-ended answers, a telephone call was placed to each contact. If direct communication was established (i.e., a person answered the telephone), an introduction to the research project was given followed by a question asking the person about his or her willingness to complete a survey on the topic of state practices and deviations from access management policies. If the person indicated that he or she was not the most appropriate person to participate in the survey, the person was asked to provide another contact from the state. If the telephone call led directly to voicemail, a message was left describing the study. After a member of the research team spoke directly to a person or left a voicemail, the survey was administered via email. An attachment with Virginia's answers to the survey questions was included in the email and is shown in Appendix B. A follow-up email was sent if the survey was not returned within a 2-week timeframe. In some cases, the respondent provided materials in lieu of, or in addition to, answers to questions, and thus the researchers obtained the information for answering those questions from the materials provided. After the researchers had compiled the results, a 24-page summary of results was provided to the respondents on October 16, 2017 (and respondents were asked to indicate any concerns by November 1, 2017). In cases where respondents provided corrections, such corrections were incorporated into the analysis.

Task 2. Determine the Nature of VDOT Access Exception Requests

Three steps guided this effort: (1) develop a customized survey instrument for each VDOT district, (2) conduct the survey and analyze the results, and (3) examine a subset of access exception requests that were later used in the crash analysis.

Develop the VDOT District Survey Instrument

A customized survey was developed and sent to each VDOT district. The survey consisted of three components:

1. *A list of exception requests found by the research team [in 2016] on VDOT's Access Management Team Site (VDOT, 2018).* For each request, a table listed the county in which the entrance that was the subject of the exception request is located, the numbers for the routes between which the site that was the subject of the exception request is located, the permit number (if found in VDOT's Land Use Permit System [LUPS]), and whether the research team thought the relevant entrance had been built. (Throughout this report, the reporting that an exception request was or was not built means that the requested entrance that was the subject of the exception request was or was not built.) For each district, the list ranged from one to four pages, with the number of exceptions ranging from 1 (Bristol District) to 38 (Northern Virginia District). An excerpt of such a list for the Lynchburg District is shown in Figure 5. These lists were provided to survey respondents in Microsoft Word format.

Number	Function	Project Name	Route Number	Locality	Between Route	Between Route	Permit Number (if in LUPS)	Built
5	Commercial	Bojangles	29/679	Campbell	29 (Wards Rd)	1408 (George St)		No
8	Commercial	Buckingham Agricultural Research Network	60	Buckingham	648 (Hall Rd)	742 (Alcoma Rd)	319- 32460	Yes

Figure 5. Excerpt From the 21 Exception Requests for the Lynchburg District

2. *A list of commercial entrance permits found by the research team in LUPS.* A table listing all commercial entrances for each district from January 1, 2011, to the present found by the research team in LUPS was developed. By district, the number of permits ranged from as few as 146 (Hampton Roads District) to as many as 867 (Northern Virginia District). An excerpt of such a list for the Staunton District is shown in Figure 6; note that the figure shows just one permit. These lists were provided to survey respondents in Microsoft Excel format.

County Name	Function Name	Permit Prefix Number	Permit #	Customer Name	Route Number	Route Name	From Route Number	From Route Name	To Route Number	To Route Name
Bath County	CE	850	2197	Rhetson Companies, Inc.	220		660		646	

Received Date	Approval Date	Extension Date	Canceled Date	Reinstatement Date	Expired Date	Completed Date	Permit Status	Permitee Reference Number
05/09/2011	05/09/2011					03/12/2012	COMPLETED	

Figure 6. A Single Permit From the List of 259 Permits for the Staunton District

3. *Five questions.* The transportation and land use director for each district was asked to confirm the completeness of the list of exception requests (Figure 5), the completeness of the list of commercial entrance permits (Figure 6), and whether the "exception requests" had been built. (As pointed out by a reviewer of this report, it would have been more proper to ask whether the *requested entrances*, rather than the exception requests, had been built.) The five questions posed to each district were similar except that they were altered to reflect the data shown in Figures 5 and 6. For example, the five questions posed to the Lynchburg District, which had 21 exception requests and 165 entrance permit requests, were as follows.

    1. Are there any exception requests besides these 21 (prior to June 26, 2016)?

    2. Can you confirm that item numbers 6, 7, 8, 9, 11, 15, 16, 17, and 18 were built? It appears that two exception requests (numbers 6 and 7) were approved and built but are not in LUPS.

    3. Can you confirm that exception requests 1, 2, 3, 4, 5, 10, 12, 13, 14, 19, 20, and 21 have not been built?

    4. Are there any missing commercial entrance permit requests from the list of 165?

    5. Since January 2011, have there been any access management exception requests that were turned down by the Lynchburg District?

    In Question 5, January 2011 was chosen because a quick review of VDOT's Access Management Team Site showed that most exception requests were after that date. Because the research team thought it would be easier for respondents to be able to work with whole years (e.g., "Since January 2011" rather than "Since November 2010"), the survey focused on analyses for the period January 1, 2011, through either August or September 2016, depending on when the respondent completed the survey. (On April 21, 2017, several months after the survey was completed, an examination of VDOT's Access Management Team Site confirmed that most exception requests were in 2011 or later. For example, there were 38 requests in the Staunton District, with 37 after January 1, 2011, and 1 on November 10, 2010. The Lynchburg District showed 25 exceptions, with 23 after January 1, 2011, and the remaining 2 on November 10, 2010. The Northern Virginia District showed 31 exceptions, with 27 after January 1, 2011, and 4 on November 15, 2010.)

Conduct the Survey and Analyze the Results

The survey was sent to the transportation and land use director for each VDOT district since this individual is ultimately responsible for the land development review process (VDOT, 2013b). Each district has a district administrator to whom a planning and investment manager reports and a transportation and land use director, along with other individuals such as a district planner, who reports to the planning and investment manager. The district may have multiple area land use engineers, who are the first point of contact for private sector land developers and local governments (VDOT, 2013b); they report to the transportation and land use director. Thus, although a variety of personnel in each district are involved with the planning function generally, the transportation and land use director in each district should be the correct contact with regard to questions regarding private sector entrance permits. Because the Northern Virginia District had three survey recipients, one for each of the three counties in the district (Fairfax, Loudoun, and Prince William), the district had three sets of responses. To be clear, the transportation and land use director provides a recommendation for the granting or denial of an exception request. The entity responsible for approving connections to the VDOT network is ultimately the residency engineer/administrator (for local streets where one desires to have an entrance within the functional area of the intersection) or the district traffic engineer (for deviations from the spacing standards or corner clearance standards (VDOT, 2014, 2017h). (Although the regulations [VDOT, 2017h] use the term “engineer” for the residency, it was pointed out by a reviewer of this report that the term “administrator” for the residency is commonly used in practice.)

The surveys were distributed July 8-22, 2016, inclusive, and the survey responses arrived over the course of 8 weeks from August 1–September 23, 2016, inclusive. Where necessary, one or more researchers contacted the survey respondents by telephone or email to provide clarifying information. For example, one respondent wanted to know the purpose of the study and how the results would be used. In another district, an initial response was provided June 28, 2016, with additional information provided July 29, 2016. In another district, the respondent directed researchers to a SharePoint site where the researchers could then perform the tabulations.

The aggregate survey results were assessed with respect to two research questions. The first question concerned the quality of the data in VDOT’s databases: Had the transportation and land use directors not been available, how complete would the information have been based solely on the access management exception requests (VDOT, 2018) and LUPS? The second question concerned the frequency of exception requests: Given the number of access permits that are typically granted, how often are exception requests sought? These results were tabulated by district.

Examine a Subset of Access Exception Requests

The exception requests that were used for the crash analysis were tabulated with respect to the spacing distances requested. Then, a subset of those exception requests were examined with respect to five criteria: speed limit of the route where the exception was located, functional class of the route, land use that led to the entrance request, number of crashes that occurred during the year the request was sought, and whether a mitigation measure was proposed. The reason for this review was to determine if there were common properties in the exception requests, such as the types of routes where they tended to be situated, or the types of land use for which the exception request was made.

Task 3. Develop Approaches to Address Confounding Factors

For each exception and comparison site, data elements were obtained from databases unique to Virginia (VDOT 2017d-f), Google Maps, and Google Earth. Geometric data included number of through lanes, number of dedicated turn lanes, median type (none, traversable, or non-traversable), intersection type (three-way or four-way), access type (partial or full), and number of at-grade intersections (both within 300 feet of the intersection and within 0.5 mile of the entrance). Operational data included speed limit, type of traffic control (signalized or non-signalized), and average daily traffic (ADT). Locational data included functional classification of the facility, distance from affected entrance to adjacent intersection, and milepost of entrance. Other data elements included presence of a sidewalk and presence of a bicycle path or bicycle lane. Appendix C summarizes the data collection procedures used for these data elements. In cases where the research team noticed in the exception request a mitigation as clear as that shown in Figure 3, the site was excluded. However, the research team generally did not seek to exclude sites with mitigation measures because of the wide variety of such measures. (For example, if the Access Management Request Form noted that spacing was pushed to the property boundary in an attempt to meet spacing standards, the site could still be included in the crash analysis.)

A confounding factor is one where a variable in a given model (such as presence of an exception site) may be correlated (positively or negatively) with an unobserved variable (Washington et al., 2002). This could lead to the research team inferring an incorrect relationship between crashes and exception requests. (For example, if exception sites were built at the same time a change in driver population occurred, a change in crashes could be attributable to either the exception site or the change in the driver population; these two variables would be confounded.)

Although data collection protocols such as those shown in Appendix C are an expected approach for any study, the research team was aware of four confounding factors for which procedures specific to this study needed to be developed: (1) determining the date an entrance was considered "built," (2) establishing the crash analysis region at the site, (3) determining suitable comparison sites, and (4) excluding atypical exception sites. Accordingly, the research team addressed the confounding factors by developing standard approaches for handling them. For the first factor, staff familiar with LUPS were consulted. For the second and third factors, approaches were demonstrated with sample data and then modified based on comments from the TRP. For the fourth factor, a set of rules was developed in which the rules were based on whether the entrance was constructed, data availability, and whether a particular site required more than one exception request.

Task 4. Quantify the Crash-Related Impacts of Access Exceptions

To determine if there was a significant increase in crash risk at the exception sites, total crashes were examined before and after construction of the exception request in the four districts where suitable sites were identified. This required three decisions by the research team: establishing the time period for the analysis, resolving whether to include pedestrian crashes, and selecting the statistical approach for determining if nominal changes in crash rates were significant.

Establish the Time Period for Analysis

Throughout this study, with one exception, the date of January 1, 2011, was generally chosen as the earliest expected date for when access management exceptions would be required. (That is, prior to this time period, regulations requiring adherence to access management standards were generally not in force.) One reason this date was chosen as the beginning date was that it appeared to precede almost all exception requests based on a review of the data on VDOT's Access Management Team Site.

However, VDOT's access management standards were in place prior to January 2011. For example, a December 2011 document describing revisions to VDOT's spacing standards VDOT (2011) suggested that exception requests would have started, in theory, around January 1, 2009 (for principal arterial facilities), and around January 1, 2010 (for non–principal arterial facilities), given VDOT's explanation of these standards: "During the three years (principal arterials) and two years (other highways) the standards have been in effect the Central Office has received copies of 60+ approved spacing exceptions from the Districts—and at least one-half as many more have been approved." A review of VDOT's Access Management Team Site on April 21, 2017, showed a total of 25 exception requests prior to January 1, 2011, with none earlier than November 10, 2010.

Accordingly, for the crash analysis, the research team did not expect that an after period would start any earlier than January 1, 2011. (In theory, an after period could have begun on November 10, 2010, for a hypothetical site for which the access permit was approved and then the entrance (which was the subject of the access permit request) was immediately constructed, but barring such a possibility, January 1, 2011, was a reasonable estimate for the earliest beginning of an after period for an access management exception request.) The research team did find one site that was an exception to this rule in the Northern Virginia District, an auto repair shop for which the date of construction was August 2010. For that site, therefore, the 3 years for "before" crash data were August 1, 2007–July 31, 2010, and the 3 years for "after" crash data were September 1, 2010–August 31, 2013.

The before period and the after period excluded the month in which the site was constructed but otherwise were intended to include 3 years of data. Because the time periods for before installation and after installation of the exception site differed, crashes were further normalized by time. For example, one exception site was the addition of an entrance at Backlick Road (Route 617) in Fairfax County for the purpose of accommodating an additional nine residential units; the entrance was marked as "Completed" in LUPS on August 6, 2015. A different exception site was the addition of a Walgreens on Route 236, also in Fairfax County. The research team used the opening date of March 2014 based on an article titled “Annandale Walgreens is now open” posted on a site called “the Annandale Blog.” However, other online information appears to support the possibility of a March 2014 opening date; for example, comments associated with the blog seem to show visitors to the facility, and the Mid-Atlantic Construction Group (2018) lists a completion date of March 2014 in its profile.)

Table 1 shows the disparity in crashes at these two sites and how they are normalized by time. For example, because crash data were available for the period January 1, 2000–December 31, 2016, it was possible to acquire 3 years of before crash data for each site; however, after data were limited to 16 months at the former site and 21 months at the latter site.

There were two ways to perform the normalization. When the research team normalized by year, seasonal differences between the before and after periods were minimized because only whole years were used in the after period, whereas when the team normalized by month, data were maximized because every month of data in the after period were used.

Table 1. Example of Normalizing Crashes by Time for Two Exception Sites

Time Period	Category	Residential Site[a]			Commercial Site[b]		
		Crashes	Months	Crashes/ Month	Crashes	Months	Crashes/ Month
All[c]	Injury	22	204	0.11	105	204	0.51
	PDO	22	204	0.11	142	204	0.70
	Total	44	204	0.22	247	204	1.21
Before period (3 years)	Injury	2	36	0.06	19	36	0.53
	PDO	0	36	0.00	22	36	0.61
	Total	2	36	0.06	41	36	1.14
After period (available data)	Injury	0	16	0.00	8	33	0.24
	PDO	3	16	0.19	10	33	0.30
	Total	3	16	0.19	18	33	0.55

PDO = property damage only.
[a] The before period is August 1, 2012–July 31, 2015, and the after period is September 1, 2015–December 31, 2016.
[b] The before period is March 1, 2011–February 28, 2014, and the after period is April 1, 2014–December 31, 2016.
[c] Reflects crashes from January 1, 2000–December 31, 2016.

Include Pedestrian Crashes

The research team initially considered excluding pedestrian crashes with the rationale being that such crashes might not be related to the exception request. To make this determination, the team reviewed the crash narrative for each of the 7 pedestrian crashes in the Northern Virginia District. (There was a total of 474 crashes at the 23 Northern Virginia District crash sites, and 7 involved a pedestrian.) The narratives suggested that one could not definitively state whether pedestrian crashes should or should not be excluded. For example, for one crash, the narrative explicitly stated that the driver was not charged and that the pedestrian had been drinking and was lying in the road; by contrast, for another crash, the pedestrian was struck at the location of the entrance request and the driver left the scene (a hit-and-run crash). At a glance, the former crash would appear to be unrelated to the exception request and the latter crash would appear to be related to the exception request.

However, such a case-by-case basis could introduce an element of judgment into the analysis. For example, in one case, the driver failed to yield to a pedestrian crossing the street with the walk signal. An argument in favor of excluding the crash could be that this was a case of a motorist disregarding the law to yield to pedestrians; an argument against excluding the crash could be that additional entrances and exits could have distracted the driver.

Further, some literature suggests that commercial entrances and exits that are close to an intersection can influence crash risk for pedestrians. Fernandes et al. (2012) suggested that there can be a relationship between pedestrian crashes and access management, as the authors found a correlation between pedestrian crashes and the number of commercial entrances and exits within roughly 80 feet of a signalized intersection. Schneider et al. (2010) reported that the number of commercial entrances or exits within 50 feet of an intersection is “positively associated” with the number of pedestrian crashes (e.g., as the number of commercial driveways increases, so does the number of crashes). Accordingly, pedestrian crashes were included in the analysis.

Select Statistical Tests

To determine if there was a statistically significant difference in the crash rates, two types of analysis were performed with the data:

1. *A before-after comparison using all exception sites*. The comparison initially used a paired *t*-test (Montgomery, 2001), and the researchers initially sought to confirm that the difference in crashes at each site was normally distributed, which is a key assumption of the test (McDonald, 2014). Then, a non-parametric test that did not presume normality (the Wilcoxon signed rank test) and the one-sample sign test (which, in addition to not requiring normal differences, does not presume a symmetric distribution, which is a requirement for the Wilcoxon signed rank test) were used.

2. *A matched-pairs comparison using the exception sites and comparison sites.* The results of Task 3 (i.e., addressing confounding factors) led to the identification of one “comparison site” for each exception site that was intended to be similar to the exception site. One way to account for the additional information available for crashes at comparison sites is to perform a matched-pairs comparison (Mokhtarian et al., 2002). The Wilcoxon signed rank test was used to compare the rate of change in before-after crashes at exception sites and at corresponding comparison sites. For example, for total crashes at the residential site in Table 1, the change in crash rates is from 0.06 crashes per month to 0.19 crashes per month, for a difference in rates of 0.13 crashes per month. This difference at the exception sites may then be compared to the difference in rates at the corresponding comparison site, which is Leewood Forest Drive on Route 617. As with Category 1, three statistical tests were available: the paired *t*-test, the Wilcoxon signed rank test, and the one-sample sign test.

In addition, negative binomial models were developed in which presence of an exception request was included as an independent variable during both the before and after periods. Then, the models were examined to determine if this variable changed in terms of its coefficient value and its significance level from the before period to the after period.

RESULTS

The results of the study are presented in four sections: access management practices in other states, the extent to which access exceptions have been granted by VDOT, resolution of confounding factors specific to this study, and the crash impacts of access exceptions.

Access Management Practices in Other States

Telephone calls were placed and emails sent to access management contacts in all 50 states. (For those who were not reached by telephone, a message was left, followed by an email that included the survey.) Direct communication, by either telephone or email, was established with 29 states. Of those 29 states, 27 submitted a completed survey (see Table 2), for a response rate of 54%.

Table 2. State Departments of Transportation That Responded to the Survey

Alabama
Arizona
Arkansas
California
Colorado
Connecticut
Florida
Georgia
Illinois
Iowa
Kansas
Louisiana
Missouri
Nebraska
Nevada
New Jersey
New Mexico
North Carolina
Oregon
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Washington State
Wyoming

Existence of Access Management Standards

When asked about having standards relating to access management, 24 of the 27 respondents (89%) indicated having standards. Three states that indicated otherwise were Arkansas, Arizona, and Tennessee. Arkansas responded "not necessarily" to having access management standards but noted that they do have a documented titled "Rules for Access Driveways to State Highways" that was developed in 1990. At the time of the survey, an update to this document was under way, and since the completion of the survey, a document titled "Rules for Access Driveways to State Highways: 2017" has become available (Arkansas State Highway and Transportation Department, 2017). In addition to this document, Arkansas has a "Roadway Design Plan Development Guidelines" manual that provides information on urban and rural median opening spacing. Arizona responded that they do not have a stand-alone access management policy but that "we have Traffic Guidelines and Procedures that discuss turn lane warrants, median opening spacing, and traffic signal spacing. We have Roadway Design Guidelines that discuss access placement and access control. And there is a construction Standard Drawing that illustrates minimum spacing between adjacent driveways." Tennessee responded that they do not have an access management guide (although one is currently under development); however, they do have a recently updated "Manual for Constructing Driveway Entrances on State Highways: 2015 Edition" that discusses access design including corner clearance spacing.

Upon a review of access management documents provided by each of the 27 responding states (via hyperlinks to materials on the internet) all states were found to have some form of guidance, policy, or standards related to access management and every state's standards (or policy or guidance) apply to commercial entrances. Arizona commented that there is no differentiation between private and commercial entrances, and California commented that entrance permit requirements have no relationship to land use as the law is that each parcel shall have an access.

Access Management Criteria

To understand better how Virginia's spacing standards for commercial entrances compare to those used in other states, a comprehensive review of documents provided by each state was performed (Alabama DOT, 2014; Arizona DOT, 2015; Arkansas DOT, 2017; Arkansas State Highway and Transportation Department, 2017; California DOT, 2016; Colorado DOT, 2002; Connecticut DOT, 2013; Florida DOT, 2017; Georgia DOT, 2016; Illinois DOT, 2015; Iowa DOT, 2012; Kansas DOT, 2013; Louisiana Department of Transportation and Development, 2014; Missouri DOT, 2016; Nebraska Department of Roads, 2006; Nevada DOT, 1999; New Jersey DOT, 2017; State of New Mexico, 2017; North Carolina DOT, 2012, 2013; South Carolina DOT, 2015; South Dakota Legislative Research Council, 2003; State of Oregon, 2017; Tennessee DOT, 2015; Texas DOT, 2011; Utah DOT, 2013; Vermont Agency of Transportation, 2005; Washington State DOT, 2016; Wyoming DOT, 2014). This review included determining the principal criteria used for three broad categories of access connections (signalized intersections, unsignalized intersections or median crossovers, and partial or restricted access entrances) and then developing comparative tables for each of the three categories.

Variability in State Criteria for Establishing Access Standards

Comparing other states' spacing standards with Virginia's proved challenging because of variability in the criteria used. For example, whereas Virginia uses roadway classification and speed to set spacing standards for signalized intersections, Florida, New Mexico, and North Carolina use roadway classification, speed, and area type. Alabama uses only speed, and Illinois, Kansas, Nevada, and New Jersey use speed and cycle length.

Table 3 shows that there are up to four principal categories of criteria states may use for signal spacing standards: roadway classification, area type, signal cycle length, and posted speed limit. Nine states use roadway classification; 10 use area type; 4 use cycle length; 10 use speed; and 3 have spacing standards but the standards were not related to specific criteria. Six states use only one criterion; 9 use a combination of two criteria (including Virginia); and 3 use a combination of three criteria. Signalized spacing standards for 6 states were not included in Table 3 because either no standards existed or standards could not be definitively determined.

Table 3. Criteria Used for Signalized Intersection Spacing Standards

	Criterion				
State[a]	**Roadway Classification**	**Area Type**	**Cycle Length (sec)**	**Speed**	**No Criteria[b]**
Colorado					X
Louisiana					X
Wyoming					X
Alabama				X	
South Carolina	X				
Washington State	X				
Georgia		X			
Vermont		X			
Nebraska		X			
Montana	X	X			
South Dakota	X	X			
Utah	X	X			
Oregon		X		X	
Virginia	X			X	
New Mexico	X	X		X	
Florida	X	X		X	
North Carolina	X	X		X	
Illinois			X	X	
Kansas			X	X	
New Jersey			X	X	
Nevada			X	X	

[a] For 6 states, standards are not shown because they either do not exist (Arizona and California) or could not be definitively determined (Arkansas, Tennessee, Connecticut, and Iowa).
[b] Spacing standards exist but are not based on specific criteria.

Not only do the criteria vary, but variability also exists in the comparison of what seems to be the same criterion for state *x* and state *y*. For example, for the purposes of spacing standards, Virginia's roadway classification is divided into three types (principal arterial, minor arterial, and collector) and is based on the Federal Highway Administration's functional classification system (although Virginia's spacing standards do not differentiate between urban and rural areas). Florida uses a roadway class system divided into seven classes, and each class has levels of order based on land use (developed or undeveloped) and presence of a median. Washington State uses five classes of roadway, and each class has levels of order based on traffic volume, speed, and presence of a median. Utah incorporates roadway classification, but it is based on area type descriptions of "system, regional, or community importance"; traffic volume (high, moderate, low); speed; and corridor mobility.

Finally, definitions used by states can vary. In Georgia, "urban" typically refers to roadways that have curb and gutter, sidewalks, posted speed limits of 45 mph or below, and higher land use density. In Utah, "urban" refers to a census designated area with a population of 5,000 or more or any portion of a designated urbanized metropolitan planning organization (MPO) planning boundary.

That said, with the exception of cycle length, the same criteria shown in Table 3 are often (but not always) applied to each state's standards for median crossovers and partial or restricted entrances. Thus, the diversity of criteria in Table 3 is germane to comparisons of spacing standards across states.

Criteria for Spacing of Signalized Intersections

To understand differences in signalized intersection spacing standards, states were grouped based on similarity of criteria. The three states shown in Table 3 as not using criteria (Colorado, Louisiana, and Wyoming) have a spacing standard of 2,640 feet, and states with only area type as a criterion typically use 2,640 feet for rural locations and 1,320 feet for urban locations. Missouri, Oregon, and Utah extend spacing requirements in rural locations to 5,280 feet. Washington State also extends minimum spacing requirements to 5,280 feet for Class 1 roadway classifications, defined as:

> highways that provide for high-speed and/or high-volume traffic movements for interstate, interregional, and intercity (and some intracity) travel needs. Service to abutting land is subordinate to providing service to major traffic movements. Highways in Class 1 are typically distinguished by a highly-controlled, limited number of (public and private) access points, restrictive medians with limited median openings on multilane facilities, and infrequent intersections. It is the intent that Class 1 highways be designed to have a posted speed limit of 50 to 65 mph (Washington State DOT, 2016).

Table E1 in Appendix E shows spacing criteria for nine states that use area type (urban/rural) and/or roadway classification as a criterion for spacing of signalized intersections. Table E2 in Appendix E shows the spacing criteria for four states (Illinois, New Jersey, Kansas, and Nevada) that use cycle length and speed limit criteria for spacing of signalized intersections. Illinois and New Jersey cap their minimum spacing standards at 2,640 feet with a cycle length of 150 seconds over all speed ranges, whereas Kansas and Nevada extend their minimum spacing criteria to 5,720 feet (at 65 mph and a 120-second cycle length) and 8,580 feet (at 65 mph and a 180-second cycle length), respectively.

Of the 21 states listed in Table 3, only 3, in addition to Virginia, use roadway classification and speed limit to set spacing standards. Table 4 shows the standards for these states, and in an effort to increase the number of states to which Virginia's standards may be compared, Table 4 also shows the 1 state that uses speed limit exclusively, i.e., Alabama. None of these comparisons is perfect, however, because Florida, New Mexico, and North Carolina (unlike Virginia) also use area type. Of these four states, New Mexico has criteria most similar to Virginia's because of its roadway classification system and use of three speed bins.

Table 4. Spacing From States Using Speed and Roadway Classification and/or Area Type As Criteria for Signalized Intersections

State	Area Type	Roadway Classification	Speed Limit (mph)	Spacing (ft)
Virginia	[a]	Principal Arterial	≤30	1,050
			35-45	1,320
			≥50	2,640
	[a]	Minor Arterial	≤30	880
			35-45	1,050
			≥50	1,320
	[a]	Collector	≤30	660
			35-45	660
			≥50	1,050
Alabama	[a]	[a]	≤45	1,320
			>45	2,640
Florida	Developing or Undeveloped	Class 2-4		2,640
	Developed	Class 5	>45	2,640
			≤45	1,320
		Class 6-7		1,320
North Carolina	Urban/Suburban	Main Street	20-25	<400
		Avenue	25-35	400-1,000
		Boulevard	25-40	<400-1,000
		Parkway	>35	>1,000
	Rural	Main Street	20-25	400-1,000
		Avenue	25-35	<400-1,000
		Boulevard	30-40	<400-1,000
		Parkway	>35	>1,000
		Rural Road	25-55	>1,000
New Mexico	Urban	Principal Arterial	≤50	2,640
			≥55	5,280
		Minor Arterial	≤40	1,760
			45-50	2,640
			≥55	5,280
		Collector	≤30	1,100
			35-40	1,320
			45-55	1,760
	Rural	Principal Arterial	≤40	2,640
			≥45	5,280
		Minor Arterial	≤30	1,760
			35-50	2,640
			≥55	5,280
		Collector	≤30	1,320
			35-40	1,760
			≥45	2,640

[a] Empty cells indicate that the state does not use the factor in the establishment of the spacing standard. For example, Virginia does not use area type to establish the spacing standard.

Generally, Virginia's minimum spacing standards are either equal to or less restrictive than those of the states shown in Table 4 and Tables E1 and E2 in Appendix E. For example, for a principal arterial with a speed limit of 45 mph, Virginia's standard (1,320 feet) is equal to that of Alabama, Georgia, and Vermont (if urban) and less restrictive than that of Florida (presuming a Virginia principal arterial matches a Florida Class 2-4 roadway), New Mexico, Georgia, and Vermont (if rural). Further, for a principal arterial with a speed limit of 45 mph, Virginia's standard is less restrictive than that of Missouri, South Carolina, South Dakota, Oregon, Washington State (presuming a Virginia principal arterial matches a Washington Class 1-4 roadway), Utah (presuming a Virginia principal arterial matches a Utah regional and system priority), Illinois, New Jersey, Kansas, and Nevada. Virginia's standard is more restrictive than that of two states: Nebraska (which has a 1,000-foot standard as shown in Table E1) and North Carolina. Virginia's standards are particularly less restrictive for collectors, minor arterials, and low-speed (e.g., 30 mph or less) principal arterials—in fact, none of the aforementioned states other than North Carolina has any spacing standard less than 1,000 feet, whereas Virginia has spacing standards for collectors (less than 50 mph) and minor arterials (less than 30 mph) less than 1,000 feet. North Carolina's standards were the least restrictive of all states examined; their spacing standards have minimum requirements ranging from 400 to 1,000 feet based on low, medium, and high descriptors of traffic volume and access density.

Unsignalized Intersections and Median Crossovers

Virginia's spacing standards for unsignalized intersections and median crossovers are divided into two categories: (1) spacing from unsignalized intersections and full median crossovers to signalized or unsignalized intersections and full median crossovers; and (2) spacing from full access entrances and directional medians to other full access entrances and any intersection or median. Many states do not explicitly distinguish between full median crossovers (including unsignalized intersections) and directional medians. Tables E3 and E4 in Appendix E show spacing standards from 13 states that did not differentiate between the two types of medians: most of these states (7 of 13) use area type as the principal criterion where area type is some variant of rural and urban (e.g., Illinois uses rural new, rural existing, and urban existing). Of the remaining 6 states, 2 use functional classification (Utah and Washington State); 2 use speed (North Carolina and Vermont); and 2 (Kansas and Oregon) use a combination of roadway classification, area type, and speed. Table E4 shows Oregon's spacing standards for full median crossovers, which are based on five roadway classifications, area type, and five speed limit bins.

For a more appropriate comparison to Virginia's spacing standards, states that provided both full and directional median spacing are listed in Table 5. Except for South Carolina (which uses class only) and Alabama (which uses speed only), those states use both roadway classification and area type. With respect to full median crossovers, as shown in Table 5, Virginia's standards are, for the most part, less restrictive than those of other states. For example, for a road classified as a principal arterial in Virginia with speed limits ranging from 35 to 45 mph, the spacing standard is 1,050 feet. For a similar facility, the spacing standard is higher in Alabama, Nevada, New Mexico, rural South Carolina (1,320 feet), and Florida (either 1,320 or 2,640 feet depending on the class of the facility). Only urban facilities in South Carolina (500 feet) have a less restrictive standard than Virginia's.

Table 5. Unsignalized Intersection / Full Median and Directional Median Spacing

State	Roadway Functional Class or Area Type	Speed (mph)	Unsignalized Intersection or Full Median (ft)	Directional Median (ft)
Virginia	Principal Arterial	≤30 35-45 ≥50	880 1,050 1,320	440 565 750
	Minor Arterial	≤30 35-45 ≥50	660 660 1,050	355 470 555
	Collector	≤30 35-45 ≥50	440 440 660	225 335 445
Alabama	[a]	≤45 >45	1,320 1,320	440 660
Florida	Class 2	[a]	2,640	1,320
	Class 5	>45 ≤45	2,640 1,320	660
	Class 7	[a]	660	330
New Mexico	Urban Principal Arterial	≤30 35-40 45-50 ≥55	1,320	200 325 450 625
	Urban Minor Arterial	≤30 35-40 45-50 ≥55	660 660 660 1,320	175 275 400 600
	Urban Collector	≤30 35-40 45-50	330 330 660	150 225 350
	Rural Principal Arterial	≤30 35-40 45-50 ≥55	1,320 1,320 2640 2640	225 350 500 775
	Rural Minor Arterial	≤30 35-40 45-50 ≥55	660 660 1,320 2640	200 325 450 725
	Rural Collector	≤30 35-40 45-50 ≥55	330 660 1,320 1,320	200 300 425 550
Nevada	Principal Arterial	35-45 50-55 60-70	1,320 2,640 5,280	250 450 800
	Minor Arterial	35-45 50-55	1,320 2,460	250 450
	Collector	25-35 40-45	660 1,320	150 300
South Carolina	Urban Rural	[a]	500 1,320	500 1,000

[a] Empty cells indicate that the state does not use the factor in the establishment of the spacing standard. For example, Alabama does not use functional class or area type to establish a spacing standard.

Generally, Table 5 shows that states that distinguish between rural and urban area types provided lower spacing standards for the latter. Rural collectors in New Mexico with a speed limit of 35 to 45 mph have a spacing standard of 660 feet, whereas urban collectors with the same speed limit range have a spacing standard of 330 feet. Virginia's spacing standard for collectors with the same speed limit range is 440 feet.

With respect to directional median spacing, Virginia's spacing standards can be either slightly more restrictive or slightly less restrictive, depending on speed limits. For example, for the two other states that have explicit standards for principal arterials in Table 5, Virginia's standards are more restrictive up to 50 mph; however, standards for New Mexico rural principal arterials with speed limits of 55 mph or higher (775 feet) and for Nevada principal arterials with speed limits in the 60 to 70 mph range (775 feet) are more restrictive than Virginia's 750-foot limit for any principal arterial with a speed limit of 50 mph or higher. The standards for Virginia collectors (which range from 225 to 445 feet) are more restrictive than those for Nevada (150 to 300 feet) and New Mexico (200 to 425 feet) except for the case of the New Mexico rural collector with a speed limit of 55 mph or greater, for which a standard of 550 feet applies.

Restrictive or Partial Access Entrances

A restrictive or partial access entrance is one that does not allow the full range of turning movements that would normally be associated with a full or unrestricted access entrance. For example, a commercial entrance opposite a continuous median such that vehicles enter the property and exit the property only via a right turn would be classified as a restrictive or partial access entrance. A definition used by Virginia for a partial access entrance is one "with movements limited to right-in or right-out or both, with or without left-in movements" (VDOT, 2017).

Table 6 shows Virginia spacing standards for partial access one- or two-way entrances to any type of entrance, intersection, or median crossover. Two states with similar criteria (roadway classification and speed limit) for restrictive or partial access entrances are New Mexico and Oregon (see Table 7).

Table 6. Virginia's Spacing Standards for Partial Access Entrances

Roadway Classification	Speed (mph)	Spacing (ft)
Principal Arterial	$\leq$30	250
	35-45	305
	$\geq$50	495
Minor Arterial	$\leq$30	200
	35-45	250
	$\geq$50	425
Collector	$\leq$30	200
	35-45	250
	$\geq$50	360

Table 7. New Mexico and Oregon Spacing Standards for Restrictive or Partial Access Entrances

State	Roadway Classification	Area Type	Speed (mph)	Spacing (ft)
New Mexico	Principal Arterial	Urban	≤30 35-40 45-50 ≥55	200 325 450 625
	Minor Arterial		≤30 35-40 45-50 ≥55	175 275 400 600
	Collector		≤30 35-40 45-50	150 225 350
	Principal Arterial	Rural	≤30 35-40 45-50 ≥55	225 350 500 775
	Minor Arterial		≤30 35-40 45-50 ≥55	200 325 450 725
	Collector		≤30 35-40 45-50 ≥55	200 300 425 550
Oregon	State Highways	Urban	≤25 30-35 40-45 50 ≥55	175 250 400 550 660
		Rural	≤25 30-35 40-45 50 ≥55	275 385 495 550 660
	Regional Highways	Urban	≤25 30-35 40-45 50 ≥55	125 175 250 415 495
		Rural	≤25 30-35 40-45 50 ≥55	225 300 375 415 495
	District and Unclassified Highways	Urban	≤25 30-35 40-45 50 ≥55	125 175 250 275 350
		Rural	≤25 30-35 40-45 50 ≥55	200 200 250 275 350

Virginia's standards are generally less restrictive at higher speeds. For example, for a 45 mph principal arterial, the spacing standard in Virginia is 305 feet, in New Mexico is 450 feet urban and 500 feet rural, and in Oregon is 400 feet urban and 495 feet rural (assuming a Virginia principal arterial is equivalent to an Oregon state highway). Table 7 shows that using area type criteria and more speed bins for spacing standards provides greater flexibility in New Mexico and Oregon compared to Virginia. For example, a 25 mph principal arterial would have a spacing standard of 250 feet, as it falls in the category of 30 mph or less and applies to all area types. By contrast, in Oregon, urban and rural state highways with a 25 mph speed limit have spacing standards of 175 and 275 feet, respectively.

Table E5 in Appendix E shows spacing standards from five other states (Alabama, Florida, Georgia, South Carolina, and Texas) for which direct comparisons to Virginia based on similar criteria were more difficult to perform. For example, for a right-in/right-out access point at 45 mph, Virginia's standard ranges from 250 to 305 feet depending on the functional class. Ranges for these other states depend on whether or not the facility is a two-lane facility (250 to 275 feet in Alabama), ADT, number of peak hour trips (225 to 325 feet in South Carolina), and the state classification system (125 to 660 feet in Florida). Because Texas uses speed limit as the sole criterion (the standard is 425 feet for any facility with a speed limit of 50 mph or more), one could say that for a 50 mph facility, Virginia has a more restrictive standard than Texas (if a principal arterial), the same standard as Texas (if a minor arterial), and a less restrictive standard than Texas (if a collector). Georgia also uses speed limit as the sole criterion; however, Georgia's standards are less restrictive than those of Texas and Virginia except at speeds of 60 mph (for which Georgia's 450-foot standard surpasses those of Texas and Virginia minor arterials and collectors) and 65 mph (for which Georgia's 550-foot standard surpasses those for all Texas and Virginia facilities).

Deviations From Access Management Standards

State practices for handling deviations from access management standards were considered with respect to five elements: terminology, frequency of deviation requests, requirements for traffic impact studies (TISs), extent to which requests are approved, and the process for requesting a deviation.

Terminology

Figure 7 shows the terminology that responding states use when a commercial developer requests a deviation from access management standards. The most common term is "variance" (37% of respondents), followed by "waiver" (19%), "exception" (18%), and "deviation" (11%). Four of the 27 respondents (15%) indicated that there is no specific terminology used. A few states indicated that terminology depends on the order of magnitude of a request. For example, Connecticut uses the term "deviation" for driveway and commercial entrances but uses "exception" for bigger projects. Iowa will consider a "variance" based on "considerations" for an access location that presents an unreasonable hardship but that significant deviations require the applicant to petition the director of the DOT to "waive" an administrative rule. In Kansas, the general term is "waiver," but a waiver involving design, operation, or safety is treated as a "variance."

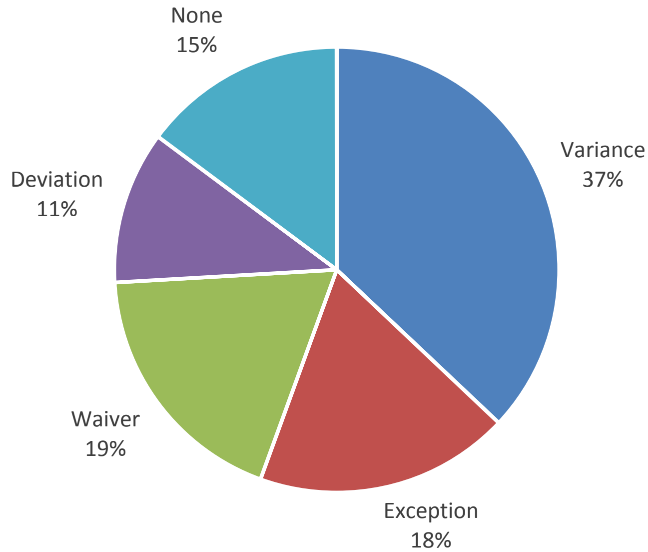

Figure 7. Terminology for a Deviation From Access Management Standards. For 3 states that used multiple terms, Figure 7 was graphed based on the word "deviation" for Connecticut, "variance" for Iowa, and "waiver" for Kansas.

Frequency of Deviation Requests

When asked what percentage of commercial entrance permit requests includes a request for a deviation from access management standards, approximately one-half of the respondents (13 of 27, or 48%) did not provide any indication. (Reasons given for not responding included permitting processes are decentralized, records are not kept, and there is no tracking measure for the information.) Of the 14 remaining responses, 2 were very broad ranges (>50% and "majority"); 3 were narrower ranges (e.g., 5% to 10% or 50% to70%); and 9 were an exact number or a very tight range (<1%). The second column in Table 8 shows the percentage of commercial entrance permits requesting a deviation. Although it does not provide hard numbers for all states, Table 8 provides a relative frequency of exception requests; for example, California probably has fewer requests on a percentage basis than Alabama. The states estimating more than 50% included Alabama, Kansas, Nebraska, Nevada, Utah, Vermont, and Washington State.

Some states that that did provide percentages included a caveat concerning estimation. Although Kansas estimated that its statewide percentage was 50%, the respondent elaborated that permits were recently evaluated in their most populated district over a 5-year period and approximately 58% of the 370 permits were found to have a variance. In Nevada's District II, the respondent stated:

> At least 75% of commercial driveways require at least one deviation letter (per design not meeting standard). The deviation varies from minimum spacing requirement, clear zone conflicts, decel/accel lanes, and not adequately meeting the turning templates for the design vehicle. This occurs mostly because of existing urbanized corridors and conditions.

Table 8. State Deviation Requests, Impact Study Requirements, and Approval Rates

State	Deviation Request %	Impact Study Requirement[a]	Outcome (% Approved)
Alabama	>50	A	Majority [b]
Arkansas	NP	B	NP
Arizona	NP	B	Majority[b]
California	<1	A	Majority[b]
Colorado	NP	B	NP
Connecticut	5-10	B	85
Florida	Majority[b]	A	Majority[b]
Georgia	10-25	A	>50
Iowa	10	B	CBD
Kansas	50	B	91
Illinois	NP	A	NP
Louisiana	NP	A	Majority[b]
Montana	NP	B	NP
Nebraska	75	A	60
North Carolina	NP	B	NP
New Jersey	20	B	50-80
New Mexico	NP	B	NP
Nevada	75	A	Majority[b]
Oregon	NP	A	Majority[b]
South Carolina	NP	C	NP
South Dakota	25	C	85
Tennessee	NP	B	NP
Texas	NP	C	Majority[b]
Utah	60	A	98
Vermont	50	C	NP
Washington State	50-70	A	80-90
Wyoming	NP	A	NP

NP = not provided; CBD = cannot be determined based on response.
[a] For the impact study requirement, A, B, and C are defined as follows: A = "yes," "usually," or "typically" in the response; B = "may" or "depending" in the response; C = no.
[b] The term "majority" was used by these respondents who did not provide a percentage.

Some states also provided additional information even if they could not provide a percentage. Florida and Oregon were two states that did not provide estimates but mentioned that most permit requests do not meet spacing standards. Florida elaborated that the state is obligated to provide reasonable access and encourage interconnected properties by providing median openings and an incentive. Oregon elaborated on two conditions that most commonly occur for which a deviation is not required: (1) if the approach application is the result of a change of use of an approach, or (2) if the approach is for a property with no alternative access and the applicant and developer can agree on a location.

Requirements for Traffic Impact Studies

The third column in Table 8 lists states that require TISs when deviations from access management standards are requested. When asked if a TIS is required, approximately one-half of the responding states (12 of 27, or 44%) responded "yes," "usually," or "typically." Both Nevada and Oregon replied that a TIS is required but discretion can be used to waive the requirement. Similarly, Utah requires a TIS but can use discretion to waive the requirement for low-intensity developments. In California, traffic and design engineering is part of the permit application where sight distance, deceleration, storage, crash concentration, etc., are considered. If the permit is declined, the applicant can request deliberation of an exception.

Almost one-half of the responding states (11 of 27, or 41%) indicated that a TIS may be required depending on the type of development, safety concerns, or specific trip generation rates. Six states provided TIS requirements based on trip generation thresholds such as peak hour volume (PHV), average annual daily traffic (AADT), or level of service (LOS):

1. Arizona: PHV > 100 trips

2. Iowa: AADT > 500 trips or PHV > 100 trips

3. Kansas: AADT > 50 trips

4. Missouri: PHV > 100 trips

5. New Jersey: AADT ≥ 500 trips or PHV ≥ 200 trips

6. New Mexico: PHV ≥ 100 trips or expected LOS will be below applicable LOS standards

7. North Carolina: AADT > 3,000 trips.

Extent to Which Requests Are Approved

No states had definitive data regarding the percentage of requests that have been approved, as was the case that most states did not have data regarding the percentage of entrance permits requesting a deviation. Most respondents (16 of 27 states) provided an answer indicating that the majority of requests for deviations are approved. Arizona mentioned that it is rare that a commercial property is completely denied access, as the regional traffic engineer and districts work hard to negotiate solutions. California had a similar response. Iowa responded “less than 2 per year, estimate,” but that may be the number of approvals granted and without knowledge of the number of requests received, a percentage cannot be determined. No respondents are aware of any studies conducted in their state that analyze the impacts of approved deviation requests. Utah mentioned that they are interested in conducting research on this topic.

Process for Requesting a Deviation

When a deviation request is received, 59% of the responding states (16 of 27) responded that a separate form must accompany a commercial entrance permit, whereas 41% (11 of 27) indicated that requested deviations are included in the commercial entrance permit, typically in a comment field or in check boxes. Separate deviation requests are typically on forms but can also be in letters. In Nevada, applicants must submit a Request for Design Waiver Form as an attachment to the Application for Occupancy of Nevada Department of Transportation Rights-of-

Way. The request for design waiver must include appropriate documentation to support the request. The DOT will consider the following under review:

- exceptional hardship on the applicant if the design waiver is not granted
- safety of the general public
- convenience or welfare of the public.

In Tennessee, applicants must request in writing that an exception to the DOT's policy be made. The request must show why the DOT policy cannot be complied with and the effect the proposed exception will have. All requests for exceptions must be made to the Region Traffic Engineering Office that is handling the proposed entrance permit. The office then forwards potentially acceptable requests to the state traffic engineer's office where a panel of transportation professionals that meets quarterly approves or denies the request.

Most requests in other states go through a review process that incorporates elements similar to those in Tennessee. In Nebraska, an "access control team" meets to discuss and determine if a variance will be approved. Voting members of the team include the roadway design engineer, the planning and project development engineer, the traffic engineer, and the right-of-way manager. In Illinois, the developer must be able to justify the design exception at a coordination meeting with the Federal Highway Administration, the central office, and the district. If approved, a form must be filled out documenting the exception. In Kansas, an access management unit will review the variance request for justification and consistency; then, the district engineer may approve the permit with the variance or deny the permit.

Extent to Which Access Exceptions Have Been Granted by VDOT

Quality of VDOT Access and Land Use Databases

There are two ways to evaluate the quality of the information on VDOT's Access Management Team Site and in LUPS. First, is a given exception request or a given commercial entrance permit request recorded in these databases? Second, to what extent are the fields for a given record complete? (Note that these two databases have not necessarily been in use for the same amount of time; whereas access exception requests generally did not exist before 2010, references to LUPS can be found as far back as 2004 [VDOT, 2004].)

Availability of Records in VDOT Databases

Surveys were distributed to the nine VDOT districts from June 28–July 22, 2016. Responses were received from July 21–September 12, 2016. For each district, the numbers of unlisted denied exception requests, approved exception requests, and commercial land use permits were obtained. Table 9 quantifies the completeness of exception requests (on VDOT's Access Management Team Site) and entrance permit requests (in LUPS).

Table 9. Comparison of Listed and Unlisted Information Based on VDOT District Surveys

District		Listed Denied Requests	Unlisted Denied Requests	Listed Exception Requests	Unlisted Exception Requests[a]	Listed Commercial Entrance Land Use Permits	Unlisted Commercial Entrance Land Use Permits[b]
Bristol		0	0	1	27	155	0
Culpeper		0	1	12	19	157	15
Fredericksburg		0	0	22	5	230	0
Hampton Roads		1	1	22	0	146	0
Northern Virginia	Prince William	0	2	20	10	133	12
	Loudoun	0	2	1	3	219	More than 0[c]
	Fairfax	0	2	17	Roughly 62	504	Unknown[d]
Lynchburg		0	0	21	12	165	0
Richmond		1	0	4	23	337	88
Staunton		0	0	19	18	259	0
Salem		0	0	32	43	235	59
Total		2	8	171	222	2,540[e]	174[e]
Total [f]		10		393		2,714[e]	

[a] "Unlisted" = Not found on VDOT's Access Management Team Site.
[b] "Unlisted" = Not found in the Land Use Permit System.
[c] In the response to the survey, the respondent indicated: "Your LUPS search shows 219 Loudoun entrance permits—this appears to be many fewer entrances than have actually been permitted in your timeframe."
[d] In the response to the survey, the respondent indicated: "It is not possible to determine which of these 100 exception requests have been built or have not been built at this point in time."
[e] If the Northern Virginia District counties of Loudoun and Fairfax are excluded, there are 1,817 listed commercial entrance land use permits, 174 permits that were not listed, and a total of 1,991 permits.
[f] A site may have more than one exception request; for instance, later crash analysis showed that a site at Telegraph Road in the Northern Virginia District has 3 exception requests.

Of the 10 denied exception requests, 80% were unlisted (8 of 10). Of the 393 approved exception requests, about 56% (222 of 393) were unlisted. However, outside two Northern Virginia District counties (where respondents were not sure of the number of unlisted commercial entrance permits), of the 1,846 commercial entrance permits, only about 9% (162 of 1,846) were unlisted. Thus, although the majority of commercial entrance permits are listed in LUPS, the majority of approved and denied exception requests are not listed on the Access Management Team Site.

(Note that there may be more than one request for a given site or entrance. In the Culpeper District, at least 2 of the 19 unlisted exception requests pertain to the same entrance. In the Northern Virginia District's Prince William County, at least 3 of the listed exception requests pertain to the same site. In the Lynchburg District, at least 2 of the 21 listed exception requests pertain to the same entrance.)

Quality of Records in VDOT Databases

The information recorded in the individual records on VDOT's Access Management Team Site varies by individual record. Examples of missing fields (if the form is present) include proposed and required distances, the speed limit, the date of approval or the signature indicating approval, the specific location of the proposed entrance, the type of entrance, and functional classification. For example, in the Northern Virginia District, there are 38 approved requests on the Access Management Team Site. About 18% (7 exception requests) of these are missing either (1) the speed limit along with proposed and required distances, or (2) exception request approval dates. One request, for instance, is missing all of this information. In the Salem District, about 16% (5 of 32) of the exception requests on the Access Management Team Site are also missing speed limits and the required and proposed distances. Each of the 5 exception requests in the Richmond District consists of a summary of information for the exception but does not include an Access Management Exception Request Form. By contrast, other exception requests recorded on the Access Management Team Site consist of not only a completed form but also a satellite image or blueprint of the site and entrance location.

It should be noted that while searching LUPS for the permit for the Albemarle Place commercial entrance exception in the Culpeper District, the researchers discovered that the permit was not a commercial entrance permit as expected but instead was a road construction permit (Alkhadra, 2016c). Because Albemarle Place was planned to be built as a residential and commercial area, it was not found under commercial entrances. Because this failure to uncover Albemarle Place suggested that more permits for located exception requests may exist outside of commercial entrance permits, it was initially suggested that another criterion, "Road Construction," might be needed to locate such permits (Alkhadra, 2016b). However, when the 13 other residential or mixed use entrances with exception requests were searched for in the "Road Construction" permit system, none was found.

Frequency of Exception Requests

As shown by the second and third survey questions, each district was asked to confirm which exception requests have been built (or not built). Thus, for the 393 entrance permit requests shown in Table 9, Table 10 shows the number of requests that have been built or not built based on responses received July-September 2016. Table 10 also shows how this information changes depending on whether one uses only the data collected from VDOT's Access Management Team Site or if one also has access to the additional data provided by the transportation and land use directors. In addition, Table 10 shows the total number of approved exception requests for each VDOT district and the total number of entrances with commercial entrance permits (some of these have been completed and others may have been approved but not constructed). Overall, Table 10 suggests that slightly less than 15% of commercial entrance permit requests (393 of 2,714) entailed an approved request for an exception. (Because most requests are approved, a similar percentage results if one includes the small number of denied requests.) Outside the Northern Virginia District, slightly more than one-half of the exception requests (184 of 318, or 58%) have been built.

As is the case with Table 9, there are caveats with respect to the data. Although the survey questions did not specifically state how to characterize sites that were under construction, some respondents volunteered this information. In the Fredericksburg District, 4 exception requests that were under construction were categorized as not built. Further, there was a single parcel of land that had an exception request, and later this exception request was replaced by 2 different exception requests, none of which has been built. In the Hampton Roads District, the seven listed but not built sites include two sites that the respondent characterized as "under construction."

Table 10. Approved Exception Requests and Commercial Entrance Permits in Each VDOT District[a]

District	Listed			Unlisted[b]			Total	Total Commercial Entrance Permits
	Built			Built				
	Found in LUPS	Not Found in LUPS	Not Built	Found in LUPS	Not Found in LUPS	Not Built		
Bristol	1	0	0	16	0	11	28	155
Culpeper	4	4	4	7	1	11	31	172
Fredericksburg	9	0	13	0	0	5	27	230
Hampton Roads	12	3	7	0	0	0	22	146
Northern Virginia	15	13	10			75[c]	113[c]	At least 868
Lynchburg	7	2	12	9	1	2	33	165
Richmond	1	0	3	6	6	11	27	425
Staunton	9	0	10	8	0	10	37	259
Salem	21	0	11	27	2	14	75	294
Total	79	22	70	73[d]	10[d]	64	393	2,714

[a] Based on survey responses received July-September 2016.
[b] Not found on VDOT's Access Management Team Site.
[c] Rough estimate from respondent.
[d] Excluding the Northern Virginia District.

In the Northern Virginia District, the respondent noted that the results do not include requests that have not been submitted (e.g., one that was incomplete; one with comments that has not been submitted yet; one without comments not submitted yet; one that was grandfathered; one that was incomplete; and one in the Town of Leesburg, which thus does not need to be reviewed); the respondent also noted it was not possible to determine which of the exception requests have been built. (The research team sought to make this determination for the case of the listed exception requests.) In the Lynchburg District, the 21 listed requests include 1 request for another district. In the Staunton District, a customized SharePoint site provided by the Staunton District (VDOT, 2016b) was used by the researchers to tabulate the number of built and unbuilt sites. In the Richmond District, the respondent noted that the district does not track which requests have been built, but the research team sought to determine these through the use of LUPS and Google Maps. In the Salem District, for the two requests not listed, one was a locally administered project and one was not on a VDOT roadway; further, these results include two entrance permit requests under review.

The Nature of Exception Requests

Figure 8 is a histogram of the spacing requested in the 64 exception requests. Of the 36 spacing standards shown in Figure 1, only 5 are repeated more than 3 times: 250; 440; 660; 1,050; and 1,320 feet. These standards are shown in Figure 8; e.g., of the 64 exception requests, 39 involve a request for spacing between 0 and 250 feet away from the existing intersection. By contrast, 3 entail a spacing of between 1,051 and 1,310 feet away from the existing intersection.

A more detailed review of a subset of the exception requests, i.e., those shown in the Northern Virginia District, shows the amount of deviation from the access standard and the type of land use. For instance, the second request entails a deviation of 210 feet from the spacing standard, with the land use being the construction of nine dwelling units.

Table 11 shows considerable variation in the requests in terms of deviation from the standard, land use for which the commercial entrance is sought, number of crashes per year, and proposed mitigation measures.

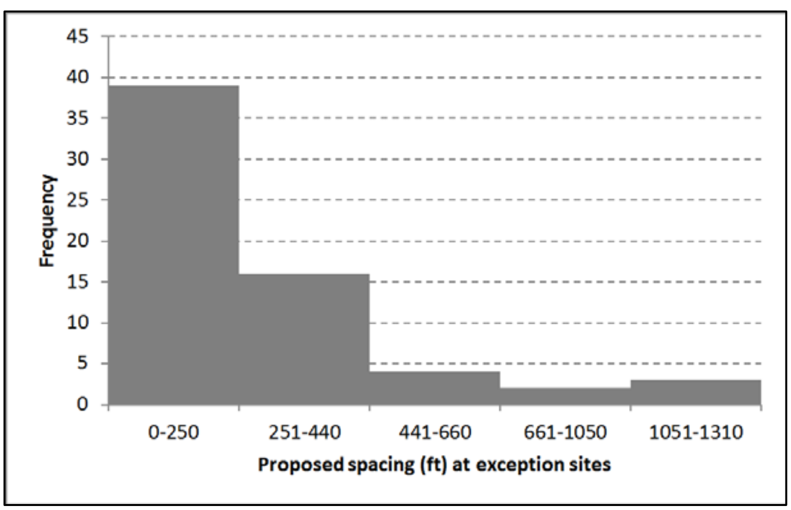

Figure 8. Frequency of Proposed Spacing on Access Management Exception Requests

Table 11. Northern Virginia District Exception Sites Used in Crash Analysis

No.	Functional Class (Speed Limit)	Standard	Deviation	Land Use	Crashes/ Year [a]	Mitigation
1	Local (25 mph)	Corner Clearance	35 ft	35 single-family detached units	5	Proposed entrance moved as far away from adjacent intersection as possible
2	Minor arterial (40 mph)	Spacing	210 ft	9 dwelling units	4	None
3	Principal arterial (55 mph)	Spacing	12 ft	Fuel facility, market, fast food, and 200-bed nursing facility	0	None
4	Principal arterial (55 mph)	Spacing	168 ft	Church and ancillary use development	0	Applicant to eliminate additional access points in conflict with proposed and existing intersection
5	Minor arterial (25 mph)	Spacing	293 ft	6-dwelling unit	0	None
6	Principal arterial (35 mph)	Spacing	38 ft	Walgreens	16	None
7	Minor arterial (45 mph)	Spacing	100 ft	Medical office building (7,000 ft^2)	0	None
8	Principal arterial (35 mph)	Spacing	147 ft	Retail center (19,600 ft^2)	14	Applicant is to remove service drive and convert south entrance into right-in only
9	Minor arterial (40 mph)	Spacing	270 ft	Office building (240,500 ft^2)	5	None
10			145 ft		7	
11	Principal arterial (35 mph)	Spacing	1,030 ft	Costco	3	Applicant will increase vehicle storage in turn lane and affected road through relocation of entrance
12	Local (35 mph)	Spacing	15 ft	Warehouse (zoned I-5)	0	None
13	Major collector (35 mph)	Spacing	80 ft	Park-and-ride lot (729 spaces)	1	None
14			125 ft		0	
15	Principal arterial (35 mph)	Spacing	2,304 ft	Shopping mall	10	None
16	Minor arterial (40 mph)	Spacing	95 ft	167-room hotel	3	None
17	Principal arterial (45 mph)	Spacing	49 ft	Automotive repair facility	5	None
18	Minor arterial (35 mph)	Spacing	210 ft	276-unit adult residential community	0	None
19	Local (30 mph)	Spacing	130 ft	Office/ warehouse in industrial park	0	None
20	Principal arterial (45 mph)	Spacing	177 ft	Electrical substation	5	None
21	Local (25 mph)	Spacing	Unknown	BB&T (bank)	8	Consolidation of 2 entrances across from current private drive
22	Local (25 mph)	Corner Clearance	59 ft	160 town home / condominium dwelling units	1	None
23	Minor arterial (45 mph)	Spacing	40 ft		4	None

[a] Crashes/year is the total number of crashes in the calendar year in which the exception request was accepted.

About one-fourth of the sites in this case show a mitigation measure; note also that the number of crashes per year varies by an order of magnitude: 8 sites show 0 crashes, 12 sites show between 1 and 9 crashes, and 3 sites show between 10 and 16 crashes per year. Note also that although Table 11 shows 23 sites, there are in fact just 20 land development locations: 3 of these land development locations (1 for sites 9 and 10, 1 for sites 13 and 14, 1 for sites 22 and 23) entail two entrances, for which each entrance will entail a separate crash analysis.

Table 11 also shows a range of mitigation measures. For instance, at Site 1 in Table 11 on Little River Turnpike, a mitigation measure was to remove two points with direct access to this route and instead to provide access via a local road (Willow Run Drive). This mitigation measure, however, does not appear to be as dramatic as the mitigation measure in Figure 3—a site with substantial mitigations such that the site did not appear to reflect a true degradation in the spacing standard. Another site—which is not shown in Table 11 as it was ultimately not used—was one known as Village Place, which contains both an access management exception request (which in 2010 was Form AM-2) and a design waiver, Form LD-448 (which appears to have been included in VDOT's list of exceptions [VDOT, 2018] because the form contains information related to the exception request). On the latter form (i.e., Form LD-448), a "mitigation" measure was listed as being to conduct a traffic signal analysis. In short, mitigation measures take a wide variety of forms.

Resolution of Confounding Factors Specific to This Study

Although complete data collection procedures are given in Appendix C, four factors required the development of procedures specific to this study: determination of the date the entrance was considered built, establishment of the crash analysis region, exclusion of atypical exception sites, and determination of suitable comparison sites.

Determination of the Date the Entrance Was Considered Built

The preferred approach for determining the date an entrance was considered built was to use the "completed date" in LUPS. An example of such a permit is shown in Figure 9. (The upper right corner shows that the status of the permit was indeed "completed," and the center shows that this completed date was December 9, 2014.) Note that the completed date differs from the date of approval (July 8, 2014, as shown to the left), the received date (also July 8, 2014), and the expiration date (July 8, 2015). Further, the expiration date does not signify the date construction occurred; it indicates the date by which construction must be completed under this current permit. If applicants do not complete construction by that date, they must request a new land use permit (VDOT, 2017g).

For some exception requests, however, LUPS did not show a completed date for the permit. For example, as shown in Figure 10, there is not a completed date; rather, there is a date that the permit was placed on "active" status. This "active status" was used as the completed date (Alkhadra, 2016d), given that the research team could obtain supporting information such as that shown in Table 12.

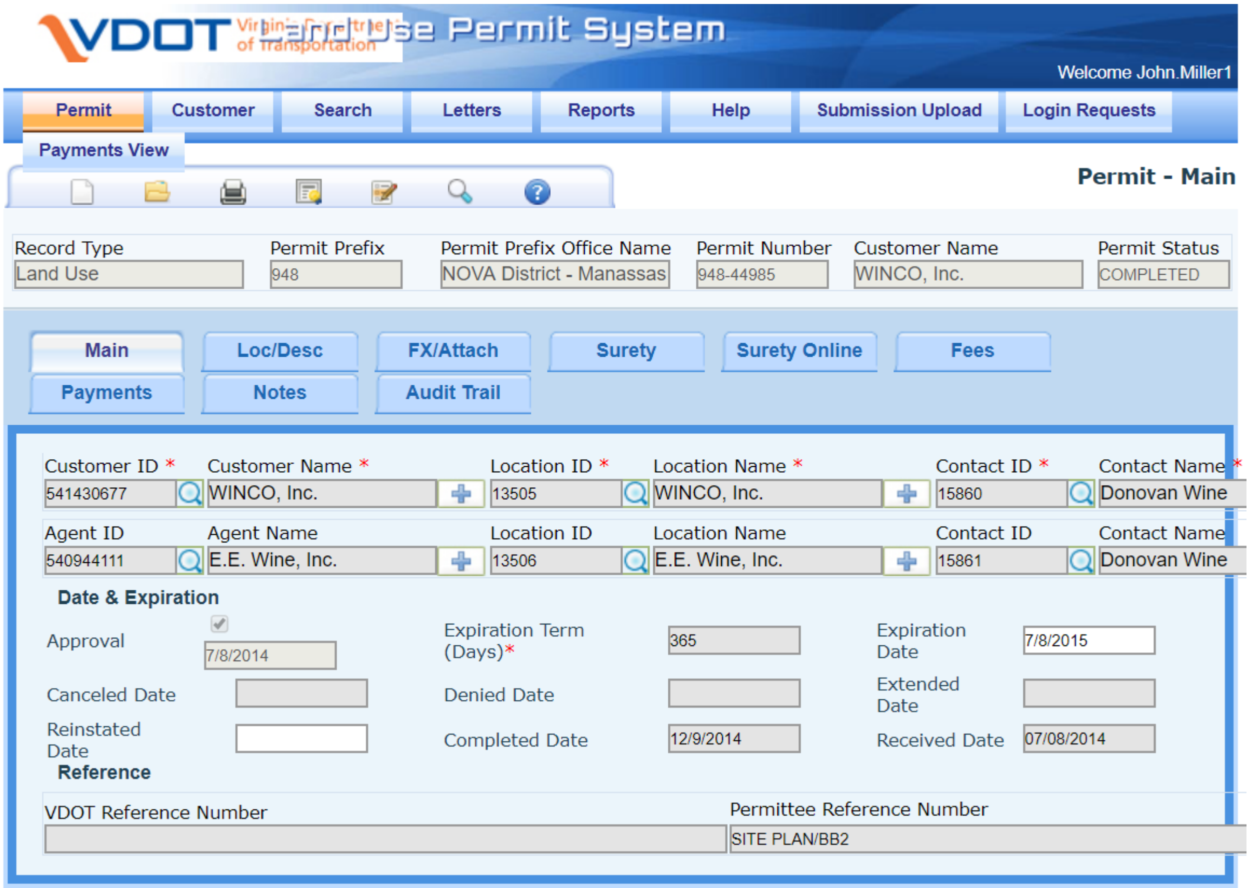

Figure 9. Example of an Exception Request for Which LUPS Shows a Completed Date. Permit No. 948-44985 is shown to have been "Completed" in the upper right corner, and the completed date is December 9, 2014. LUPS = Land Use Permit System.

To be clear, Table 12 shows that many possible dates could be used as the completed date for the exception request described in Figure 10. For example, one could support a date of October 2013 using the argument that the use of the site by construction traffic renders the site operational. An argument against October 2013 could be that that the site should be viewed as operational once it has been developed, at which point one could argue that a date of August or October 2014 (when some homes had been built) or October 2016 should be considered (when all homes had been built). Thus, the research team's decision to use the "active" status as the determinant of the construction date (i.e., when the site became open to construction traffic) can be justified not because it is necessarily the best possible date but rather because it represents an approach that can, to some extent, be replicated consistently for many sites. In fact, VDOT staff noted that there is no firm date in LUPS regarding when an entrance was constructed; rather, staff typically choose a constructed date based on three sources of information: the LUPS inspector notes (e.g., what is shown in Figure 10); the Google Earth database, to which VDOT subscribes; and contacts with the city or county based on when the occupancy permit was issued (Imad Salous, personal communication, November 1, 2016). Local news articles that mentioned the opening date of the exception site were also used where necessary.

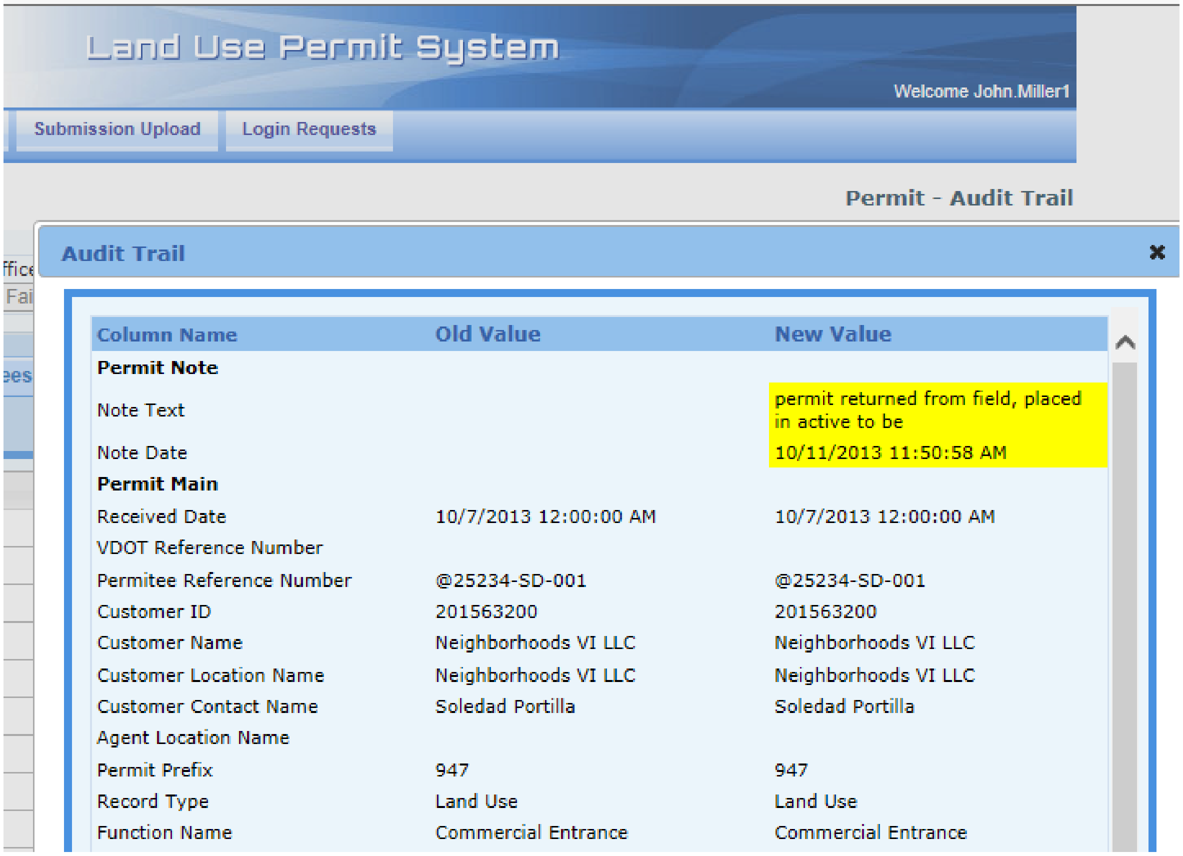

Figure 10. Example of an Exception Request for Which LUPS Does Not Show a Completed Date. Permit No. 947-116849 was placed on "active" status on October 11, 2013. LUPS = Land Use Permit System.

Table 12. List of Possible Dates for the Construction of Exception Request 947-116849

Date	Event	Data Source	No. of Homes	Justification for Month Being Construction Date
November 10, 2011	Exception request submitted	Access Management Exception Request Form	35 planned	None.
March 3, 2012	Exception request approved			
October 9, 2013	Land use permit request approved	LUPS Permit 947-116849	Not stated	Access point is operational for construction traffic.
October 11, 2013[a]	Land use permit request placed in active status			
August 21, 2014	Model home is open and construction is under way	Blog titled "Annandale, VA"[b]	29 planned; 2 built	Even though site is not completely built, some trip generators already exist.
October 17, 2014	Construction is still under way	*The Washington Post* (Hoffer, 2014)	29 planned, 10 sold	
October 26, 2016	Visual inspection	Google Maps	29 homes counted in subdivision	Site has been fully developed.

[a] October 11, 2013, was the construction date used for this exception site.
[b] Within that source is an article by E. Ashford titled "New Houses Sprouting Up on Site of Former Plant Nursery" that was posted on August 23, 2014. However, one reviewer noted that blogs are not an acceptable source, which for future studies would suggest that other dates that do not rely on a blog as a data source would be preferred.

For some exception requests, there was no record available in LUPS. For those cases, Google Earth was used to find an approximate date for the construction of the entrance. For example, as shown in Figure 11, visual observation of the University Mall site (Canfield Street) in year 2016 (*left*) and year 1988 (*right*) shows that the Canfield Street entrance was constructed prior to 1988 (the earliest year for which Google Earth data are available). Thus, for this particular site, without knowing a precise year, one can state only that the entrance was built at some point prior to 1988. (This site was ultimately rejected because it was determined to be completed before the scope of this study.) In other cases, when a Google Earth image from one year showed no entrance and the next Google Earth image 2 years later showed an entrance, one could know only that the entrance was constructed at some point between the 2 years shown. Thus, use of Google Earth provided only an approximate date of construction.

Overall, of the 64 sites, a completion date was determined from LUPS for 39 sites, Google Earth for 19 sites, and other sources such as news articles for 6 sites. In some cases, it was possible to combine information from Google Earth and other sources. For example, Site 13 had been built between October 2013 and May 2015, as the Google Earth image from the former date showed the site was not yet built and the Google Earth image from the latter date showed the site was built. An article by Nachman (2014) supported a built date of July 2014.

Thus, the number of sites for the crash analysis could differ from the number of sites cited by survey respondents. For example, in the Fredericksburg District, at the time the survey was conducted, nine sites were known to be built. An additional five sites for the crash analysis were obtained as follows: (1) one site was under construction (Table F6 in Appendix F, Site 1); (2) Sites 3 and 5 were two exception requests for two separate entrances at one location, and these had been counted as one site by the survey respondents but for the purposes of the crash analysis were two different sites; (3) a similar phenomenon occurred with Sites 16 and 17 where they were two entrances for another location and thus were counted as one site by survey

Figure 11. Use of Google Earth to Determine a Possible Date of Construction. ***Left:*** **Image taken 4/14/2016, © 2017 Google.** ***Right*****: Image taken 4/19/1988, © U.S. Geological Survey. Because the Canfield Street entrance in year 2016 (*****left, black circle indicates the entrance and black lines indicate roughly the extent of the site*****) already existed by 1988 (*****right*****), the research team knew from Google Earth that the site was constructed prior to 1988. This was originally suggested as a comparison site for University Mall (which ultimately was not used for the study, as it was being built).**

respondents but for the purposes of the crash analysis were two different sites; (4) Site 12 had a completed date in LUPS and construction was evident from visual inspection; and (5) Site 13 had been constructed based on visual inspection and a news report (Nachman, 2014) indicating the site had opened.

Establishment of the Crash Analysis Region

Two major methods were used to collect crash data at the site; Figure 12 shows an example of a site at Telegraph Road. The first method was to use a 300-foot buffer from the center of the entrance that was the subject of the exception request. The second method was to include the aforementioned buffer plus any crashes between that buffer and the center of the existing intersection (Hofrichter, 2017). The rationale for the first method was that the use of a 300-foot buffer would cover the "functional area" of the intersection (Rogerson, 2017). A rationale for the second method was that it was possible that crashes related to the exception could extend all the way from the entrance (that was the subject of the exception request) to the existing intersection. Kweon (2017) suggested that comparing these two methods could be useful for determining which entrances required further study. As discussed in Appendix C (see Figure C11), the second method entailed using the white stop bars as the perimeter of the intersection and the median line as the center of the intersection.

Figure 12. Examples of the Two Methods for Collecting Crashes. The exception site entrance (latitude = 38.65743, longitude = -77.28855) is shown with a black triangle in the upper third of the figure. Method 1 uses a 300-foot buffer (black circle). Method 2 includes Method 1 plus any crashes from that buffer to the center of the existing intersection (red rectangle).

For both methods, all crashes contained within the buffer or polygon tool were included unless there was either (1) a grade separation or (2) a non-traversable median the length of the corridor. As an example of Condition 1, Figure 13 (*left*) shows a commercial entrance for a retirement community on Kirby Road. However, Old Dominion Drive does not intersect with Kirby Road; they are grade separated. Thus, such crashes are excluded. As an example of Condition 2, Figure 13 (*right*) shows an entrance for a hotel on Old Keene Mill Road, but only the crashes on the westbound side should be included because of the non-traversable median. Note that for both methods, one must examine attributes such as the Route ID (to exclude crashes on Old Dominion Drive and Amherst Avenue) or the crash document numbers (to exclude crashes on Old Keene Mill Road Westbound) or one must use a rectangular polygon (rather than a circle) to identify the proper crashes.

Note that in the collection of crash data, there can be cases where a single site might have multiple exception requests because the commercial entrance violates spacing standards for two separate intersections. In those situations, the crash data when collected as a 300-foot buffer centered on the site were collected only once. Thus, the unit of analysis was the entrance that was the subject of the exception request, as opposed to the number of violations for the entrance.

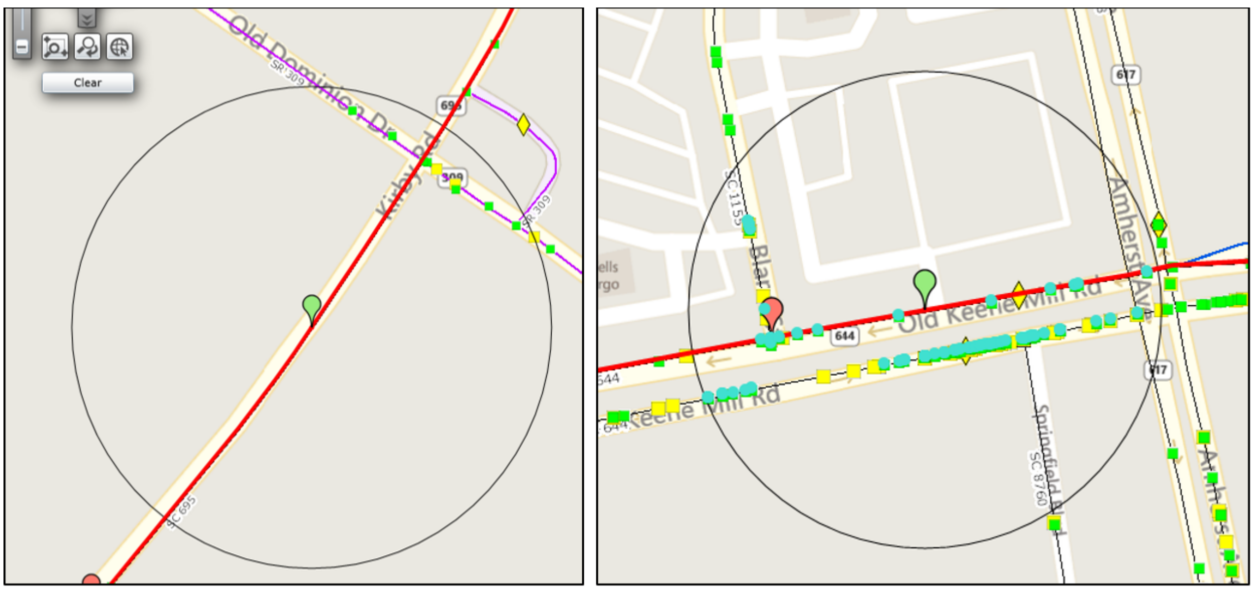

Figure 13. Examples of Excluding Crashes. ***Left:*** **Crashes on Old Dominion Drive are excluded because Old Dominion Drive and Kirby Road are grade separated.** ***Right:*** **Crashes on Eastbound Old Keene Mill Road are excluded because Old Keene Mill Road has a non-traversable median; note also that Amherst Avenue crashes are excluded because Amherst and Old Keene Mill are grade separated.**

Determination of Suitable Comparison Sites

Conceptually, a comparison site should be similar to an exception site, with the only difference being that the comparison site does not entail an exception request. Because of difficulties in finding sufficient numbers of comparison sites, the approach used for selecting comparison sites in this study was to use “tiers” of criteria, which were based on three principles (see Table 13).

Table 13. Criteria for Selecting Comparison Sites

Tier	Characteristic	Guidance	Rationale
1 (Required to be in the same category as the exception site)	Functional class[a]	Must be the same category (local, collector, minor arterial, or principal arterial)	Specified in *Access Management Design Standards for Entrances and Intersections* (VDOT, 2014)
	Speed limit[a]	Must be the same category (30 or below, 35-45, or 50+)	
	Access immediately at the entrance[b]	Must be the same category (full or partial) and hence same type of median	
	Traffic control	Must be the same category (signalized or unsignalized)	
	Evidence of commercial demand	There must be either parking spaces or a website indicating the possibility of commercial traffic at the site	Researchers' judgment that a commercial driveway with no land use will generate no trips
2 (Desirable to be as similar to the exception site as possible)[c]	Median Type (except immediately at the entrance)[b]	Be the same if possible	Median type influences crash risk (Williams et al., 2014)
	Through lanes (sum of both directions)	Be as similar as possible	Number of lanes influences crash risk (Fitzpatrick et al., 2005)
	ADT	Be as similar as possible	ADT is a significant variable that influences crash risk according to the *Highway Safety Manual* (American Association of State Highway and Transportation Officials, 2014)
	Proximity to exception site	Be as close as possible	Researchers' judgment that comparison sites that are closer to exception sites are more likely to have similar geometric and driver population characteristics

[a] As suggested by the technical review panel, an exception can be made if a different functional class or speed limit results in the same spacing standard. For example, Figure 1 showed that for a road with a 40 mph speed limit, the minimum distance between a partial access entrance and an intersection must be 250 ft whether the functional classification is minor arterial or collector. In that instance, for an exception site that was a collector, a comparison site that was a minor arterial would be acceptable.
[b] At the entrance, access control and median type must be identical. For example, if there is a median break at the exception site, there must be a median break at the comparison site. As one moves away from the entrance, it is desirable, but not required, that the median type (no median, traversable median, or non-traversable median) be the same.
[c] Tier 2 criteria are listed in order of importance: the most important is median type and the least important is proximity to the exception site.

1. *The comparison site must be in the same category as the exception site with respect to minimum spacing standards used to define the need for an exception site* (VDOT, 2014). Figure 1 shows these are functional classification, speed limit category, type of access, and type of traffic control.

2. *There must be evidence of demand at the comparison site, such as a parking lot.* (One potential comparison site was ultimately rejected because it was a home

business where the aerial photography did not show any parking or other evidence of trip generation.)

3. *If possible, the comparison site should be similar to the treatment site in terms of number of lanes, ADT, median type, and location*. The first three were chosen because literature (e.g., lanes [Fitzpatrick et al., 2005], ADT [American Association of State Highway and Transportation Officials, 2014], and median type [Williams et al., 2014]) suggests they influence crash risk. The fourth was chosen because the researchers thought that comparison sites that were relatively close to exception sites were more likely to have similar driver and population characteristics.

Thus, a factor is placed in Tier 1 if the factor is in VDOT's *Access Management Design Standards for Entrances and Intersections* (VDOT, 2014). For example, Persaud et al. (1997) suggested that presence of a signal versus a stop sign influences crash risk. That implication alone would have placed traffic control in Tier 2. However, because the *Access Management Design Standards for Entrances and Intersections* (Figure 1) show that whether a given location is signalized or unsignalized materially affects the spacing distance required, that criterion is placed in Tier 1. Table 13 shows the two tiers of criteria: Tier 1 shows the minimum conditions that must be met for a location to be considered a comparison site, and Tier 2 shows additional conditions that are desirable, in case there are multiple candidate comparison sites.

Exclusion of Atypical Exception Sites

There were several reasons for excluding an exception request from further analysis. First, some exceptions were granted but never built. For example, visual inspection of the Village Place Exception Request (located near Route 55 and Route 676 in Gainesville) shows that although the site has been developed, one expected entrance that was included in the site submission was not built. Without this entrance, the site does not appear to violate the spacing standards. Moreover, the developer chose to shift John Marshall Commons Loop Road farther away from the existing Catharpin Road, which could result in future intersections actually meeting access management standards (Figure 14).

An exception might not entail a new entrance but rather it might entail a change in land use at the site, requiring the developers to file an exception request. For example, Lucketts Community Center located near Route 15 and Route 672 in Loudoun County is an example of a commercial business changing the intensity but requesting permission to maintain the existing commercial entrance. In this particular case, the change in land use was a 600-square-foot addition. Although changing the land use at an existing entrance could indeed mean that the site was a suitable exception site (especially if the new land use would generate more trips than the original land use), the access management request stipulates that the additional square footage should not increase vehicular trips. Rather, a change in local laws regarding how buildings are constructed necessitated the exception request, as pointed out in the justification (William H. Gordon Associates, Inc., 2010), which states:

> This expansion does not represent a change in use or increase in existing uses and therefore will not generate additional vehicle trips. It is a limited modification of the existing facility to specifically achieve compliance with current building code criteria.

Figure 14. Example of an Exception Request Never Built. Adapted by Nicholas Zugris in 2017 from a 2010 drawing by Barnes and Johnson, LLC, and aerial imagery, © 2017 Google. Because the original text might be illegible, some of this text was manually added by the Virginia Transportation Research Council (in white boxes) in 2018. For example, for two access points, the original text included the 3 lines of information shown in the lowest white box, indicating that those 2 access points had a required spacing distance of 360 ft and a proposed spacing distance of 321.50 ft, which deviates from the standard by 38.50 ft.

In addition, a request might be excluded because it was not possible to obtain geometric, operational, or crash data. Finally, if the exception request was for a single entrance in violation of two spacing standards, one standard was eliminated such that the duplication of crash data would not affect the results.

Table 14 summarizes how these rules affected the Northern Virginia District. Although a total of 45 access management exception requests were available to the research team, the application of four rules led to eliminating roughly one-half of these requests from further analysis as shown in Table 14; ultimately 23 requests from the Northern Virginia District were analyzed.

1. There was no change to the entrance (despite such a change being requested on the Access Management Exception Request Form).

2. There were insufficient crash data because the site was not built between August 1, 2010, and December 31, 2015.

3. There were difficulties obtaining geometric or operational data (e.g., ADT or speed limits) or crash data (e.g., a facility might not be in VDOT's Roadway Network System and thus have no crash data).

4. There were two requests (each for a separate standard) at the same location, and thus these were treated as one request.

Table 14. Summary of Reasons for Eliminating Certain Northern Virginia District Sites

Rule No.	Rule	No. of Occurrences
1	No change to entrance	5
2	Not in August 1, 2010–December 31, 2015 timeline	10
3	Insufficient geometric, operational, or crash data	9
4	Duplication of crash data from one entrance	4
Total		28[a]

[a] The table shows a total of 28 rejections, 2 of which are repeated, such that there are 26 rejected sites. With 49 sites total, that left 49 −26 = 23 Northern Virginia District exception sites used for the analysis.

Crash Impacts of Access Exceptions

A total of 64 exception sites were identified from four VDOT districts: Northern Virginia (23 sites), Fredericksburg (14 sites), Hampton Roads (12 sites), and Staunton (15 sites). One-half of these (32 sites) had 3 full years of after data; the remaining sites had shorter after periods because of the exception request being completed relatively recently. Most exception sites concerned the spacing standard, although a few concerned the corner clearance standard. (Of the 64 sites that ultimately were used for the analysis, 54 involved a spacing standard and 10 involved a corner clearance standard.)

Complete Dataset (64 Exception Sites)

A paired *t*-test is a hypothesis test that determines if the mean differences between two related datasets are equal to 0 (Statistics Solutions, 2017a). For the crash data collected using Method 1 (e.g., the 300-foot buffers), the paired *t*-test did not show a significant difference in crash rates at the 64 exception sites, whether crashes were normalized by year ($p = 0.73$) or by month ($p = 0.52$). However, this test also requires that the differences in crash rates at each site be normally distributed. Probability plots, such as those shown in Figure 15, suggested that these data were not normally distributed. The National Institute of Standards and Technology (NIST) (NIST, 2013a) indicated that one may determine if a certain dataset is normally distributed with the Anderson-Darling test, where the null hypothesis is that the data follow the specified distribution; with a low *p*-value (<0.01), the assumption of normality was rejected—meaning the paired *t*-test might not be valid.

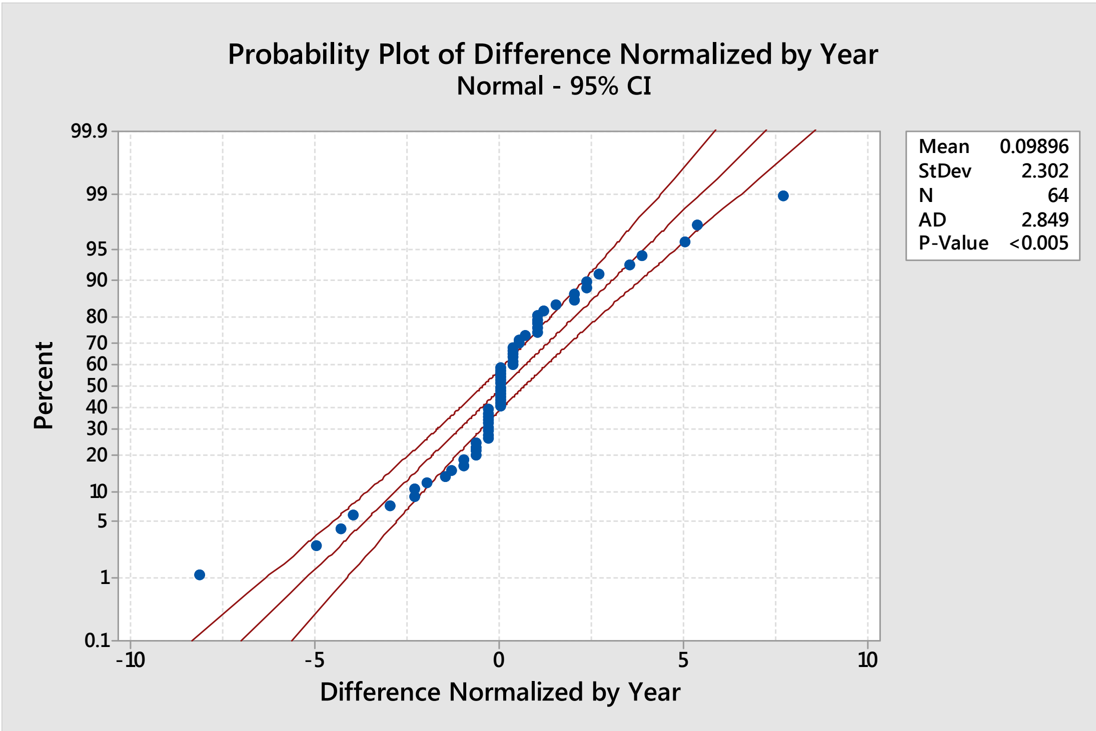

Figure 15. Example of Normal Probability Plots Suggesting Non-Normal Data. CI = confidence interval; StDev= standard deviation; AD = Anderson-Darling test value.

The Wilcoxon signed rank test was also used to determine if there was a change in crash rates for the 300-foot buffers, and this test also showed no significant difference whether the data were normalized by year ($p = 0.63$) or by month ($p = 0.25$). Although this test does not require an assumption of normality, it does require that the data be symmetric, i.e., that they not show substantial skew (NIST, 2013b). Two different tests for skew were applied. One test compares the "Pearson 2 skewness coefficient" (NIST, 2013b), calculated herein as 3 times the difference between the mean and the median, divided by the standard deviation to 2 standard errors for skewness, estimated as the square root of 6 divided by the sample size (Brown, 1997): if the former is smaller than the latter, the data are not skewed. The second test uses Equation 1 (based on 64 sites) to compute the coefficient of skewness (Bai and Ng, 2005) where ideally a value of 0 would indicate no skew; Adams (2017) suggested that an absolute value smaller than 0.5 indicates the data are not skewed. Although both tests suggested normalization by year yields a symmetric dataset, the latter test suggested that normalization by month yielded a skewed dataset. That is, the skew of the monthly data based on Equation 1 is -0.84, which, because its absolute value is between 0.5 and 1.0, would suggest a "modest" amount of skew (Adams, 2017). If the data are truly skewed, an assumption of the Wilcoxon signed rank test would not be met.

$$\frac{\frac{1}{64}\sum_{i=1}^{64}\left(x_i - x_{average}\right)^3}{\left(\frac{1}{64}\sum_{i=1}^{64}\left(x_i - x_{average}\right)^2\right)^{1.5}} \quad \text{[Eq. 1]}$$

Accordingly, the one-sample sign test (Bright Stat, 2016; Statistics Solutions, 2017b)—which does not require an assumption of skew—was executed using crash data collected via Method 1 (the 300-foot buffers). The test showed that there is not a change in crash rates when one changes from the before to the after period, with $p = 1.00$ for normalization by year and $p = 0.78$ for normalization by month.

These results were based on the collection of all crashes using Method 1, i.e., a 300-foot buffer around the exception site (see Table 15). To compare the impacts of using Method 2, i.e., the crashes captured in Method 1 plus any crashes along the roadway up to the centerline of the adjacent intersection, the same three matched-pairs tests were conducted for the 64 exception sites. Although the *p*-values changed, the results were similar: the paired *t*-test showed no significant difference; however, the differences in crash rates at each site were not normally distributed, leading to the need for a non-parametric test. For the Wilcoxon signed rank test, the differences were not significantly different; however, whereas normalization by year appeared to yield a symmetric dataset, normalization by month yielded a skewed dataset based on the application of Equation 1. The one-sample sign test, which requires no assumption about symmetry, showed again that the differences were not significant.

Table 15. Summary of Data Analysis and Hypothesis Testing for Methods 1 and 2

Test	Normalization Period	Method 1 (Crashes Within 300 Feet of the Site)		Method 2 (Crashes Within 300 Feet of the Site to Center of Adjacent Intersection)	
		***p*-value** [a]	**Conclusion (Limitation)**	***p*-value** [a]	**Conclusion (Limitation)**
Paired *t*-test	Year	0.73	No difference (but data are not normal)	0.73	No difference (but data are not normal)
Paired *t*-test	Month	0.52	No difference (but data are not normal)	0.70	No difference (but data are not normal)
Wilcoxon signed rank test	Year	0.63	No difference	0.41	No difference
Wilcoxon signed rank test	Month	0.25	No difference (but data might be skewed)	0.18	No difference (but data might be skewed)
One-sample sign test	Year	1.00	No difference	0.68	No difference
One-sample sign test	Month	0.78	No difference	0.50	No difference

[a] Indicates whether there was a significant difference between crash rates at the 64 exception sites before and after the site was completed. A *p*-value > 0.05 indicates there was no significant difference.

Matched-Pairs Dataset (64 Exception Sites and 64 Comparison Sites)

Although the 64 sites had not shown a significant difference in crash rates, the research team also collected some data for 64 comparison sites, each of which corresponded to 1 of the 64 exception sites. There were two reasons for this additional data collection. First, in case there had been differences in the before-after crashes at the 64 exception sites, the team thought it appropriate to examine comparison sites (e.g., perhaps some factor such as a change in driver population might have caused crash rates everywhere to increase). Second, the team was concerned that there might be a reverse “regression to the mean” phenomenon at the exception sites. (Generally, regression to the mean denotes a situation where crash rates are "artificially high" at a particular site during a before period because of random variation; thus, even without any change to the site being made, crash rates will tend to return to their mean value [Herbel et al., 2011].) A concern is that one might implement a treatment at such a site and incorrectly attribute the reduction in crash rates to the treatment rather than realizing that the change is attributed to random variation. The team wondered if perhaps these exception sites had been approved because they were showing artificially low crash rates; thus, by examining how crash rates changed at corresponding comparison sites, one could address this regression to the mean problem.

Adequacy of the Comparison Sites for the Exception Sites for Basic Before-After Studies

One concern about using the comparison site is whether crash rates at the comparison site are comparable to those at the exception site. The research team had sought to address this issue through the use of the tiered criteria discussed in Table 13, where such criteria included functional class, speed limit, access immediately at the entrance, traffic control, evidence of commercial demand, median type, through lanes, ADT, and proximity of the comparison site to the exception site. Examination of the crash rates showed that the comparison sites were an imperfect but adequate match for the exception sites for basic before-after studies but could be more challenging for multivariate studies.

First, there is an association between the crash rates at the exception sites and the comparison sites during the before period: Spearman's rank correlation coefficient was 0.61 (whether normalized by year or by month), which, being between 0.5 and 1.0, is considered a "large correlation" (Laerd Statistics, 2013). Further, based on the hypothesis that there is no correlation (The Pennsylvania State University, 2017), the p-value is < 0.01, meaning that there was a correlation between crash rates at the comparison sites and crash rates at the exception sites during the before period.

Second, between the before and after periods, just as the crash rates did not change significantly at the exception sites (see Table 15), they did not change significantly at the comparison sites. The paired t-test showed no significant change in crash rates ($p = 0.99$ and $p = 0.85$) for normalization by year and month, respectively, and the one-sample sign test showed p-values of 1.00 for normalization by both month and year.

Change in Crash Rate Ratios at the Comparison Sites and the Exception Sites

An approach adapted from Mokhtarian et al. (2002) was to conduct a matched-pairs analysis to determine whether the ratio of after crash rates to before crash rates at each exception site differed from the same ratio at comparison sites. If the difference in ratios (see Eq. 2) is positive, there was a nominal increase in the crash rates at the exception site relative to the paired comparison site.

$$\text{Difference} = \frac{\text{After crash rate (exception site)}}{\text{Before crash rate (exception site)}} - \frac{\text{After crash rate (comparison site)}}{\text{Before crash rate(comparison site)}} \qquad \text{[Eq. 2]}$$

For the 64 pairs of sites, 31 pairs showed no change in the before crash rate at the exception site or the before crash rate at the comparison site, which would yield an error in applying Equation 2. The 31 pairs of sites excluded from the analysis did not yield a consistent rate of change in crash rates from the before to the after period as follows:

- For 9 pairs, the change from the before to the after period at exception sites and comparison sites was identical: 8 pairs had no crashes, and 1 pair had the same increase at the exception site and the comparison site.

- For 11 pairs, the change in the exception site crash rate was greater than the change in the comparison site crash rate. (This includes two sites where the exception crash rate from the before to the after period was 0 but the comparison site crash rate decreased.)

- For 11 pairs, the change in the comparison site crash rate was greater than the change in the exception site crash rate.

For the remaining 33 pairs of sites, the hypothesis of normality could be rejected ($p < 0.01$ if normalized by year and $p = 0.02$ if normalized by month), suggesting the paired *t*-test might be inadequate to detect differences. That said, when the paired *t*-test was applied, no significant difference in ratios was found, whether normalizing by year ($p = 0.14$) or by month ($p = 0.26$). (The exact value for normalization by year was $p = 0.1449$, so the value with a software package that reported the result to just three decimal places [0.145] could be reported as $p = 0.15$. However, such rounding usually did not affect the results; for example, the exact value for normalization by month was 0.2553, which rounds to 0.26 regardless of the software package used.) The Wilcoxon signed rank test does not require normal data but does require symmetrical data: the month was clearly symmetric since Equation 1 yielded a value of 0.09 (with values of between 0.0 and 0.50 being symmetric [Adams, 2017]); the year was also symmetric but with Equation 1 showing a value of 0.49. The Wilcoxon signed rank test also did not show a significant difference for yearly data ($p = 0.24$) or monthly data ($p = 0.17$). Because the yearly data had been close to the threshold for moderate skew, the one-sample sign test, which does not require an assumption of symmetry, was also applied; this test also did not show a change in these crash rate ratios whether normalized by year ($p = 0.85$) or by month ($p = 0.57$). These findings matched a simple description of the results. Of the 33 paired sites, 15 reflected a higher difference in ratios as per Equation 2 (e.g., a nominal increase in the crash rates at the exception site compared to the comparison site); 13 reflected a lower difference as per Equation 2; 1 showed no difference as the ratio of after crashes to before crashes was the same; and 4 had no reported crashes during the after period.

The results presented here suggest that the allowance of an exception is not associated with a change in crash rates. That is, there was no significant change in crash rates at exception sites from the before to the after period, and when one incorporated comparison sites as per Equation 2, there was not a significant difference in the crash rate ratios for comparison sites versus exception sites.

Adequacy of the Comparison Sites for the Exception Sites for Multivariate Studies

As shown in Appendix F, the most complete negative binomial model indicates presence of an exception site is significant for the before period—that is, prior to the entrance (associated with the exception request) being built. This significance during the before period is surprising for three reasons already stated: (1) the before comparison site crash rates show a strong correlation with the before exception site crash rates (i.e., a correlation coefficient of 0.61, which was also found to be highly significant [$p < 0.01$]); (2) Equation 2 does not show a significant change in crash rate ratios ($p = 0.14$ or $p = 0.26$ depending on whether one normalizes by year or by month); and (3) comparison site crash rates do not show a significant change from the before period to the after period ($p = 0.99$ and $p = 0.85$ based on the paired *t*-test for normalization by year and month, respectively). Given that the comparison sites were explicitly chosen so that during the before period they would be similar to the exception sites, the researchers were initially puzzled by the before period significance of the exception site.

With the help of a hypothetical dataset, it was determined that the explanation appears to be that during the before period, comparison site crash rates have similar ratios to exception site crash rates (meaning they are adequate for before-after studies such as those presented in this report); however, although the ratios of these rates are similar, there are differences between exception site rates and comparison site rates (and such differences affect the analysis in Appendix F). That is, for a hypothetical dataset with four exception sites with before crash rates of 10, 20, 30, and 40 increasing to 11, 22, 33, and 44 during the after period and four respective comparison sites with before crash rates of 1, 2, 3, and 4 increasing to 1.1, 2.2, 3.3, and 4.4 during the after period, the correlation during the before period between exception and comparison sites is perfect (1.0). Further, Equation 2 shows that the crash rate ratios between the exception and comparison sites are the same ($p > 0.05$). However, if one performs a paired *t*-test on the differences in exception and comparison crash rates during the before period (e.g., 10 versus 1; 20 versus 2; 30 versus 3; and 40 versus 4), there will be a significant difference between the exception site crash rates and the comparison site crash rates ($p = 0.03$).

Indeed, this was the case with the 64 comparison and exception sites during the before period: there is a significant difference between the comparison site crash rates and the exception site crash rates based on the paired *t*-test ($p = 0.02$ whether normalized by year or by month). Thus, it is not surprising that the most detailed negative binomial model in Appendix F also showed that presence of an exception request (during the before period) was significant. Further, this observation of comparison sites having different crash rates than exception sites during the before period is evident only when data are collected from all four districts. Initially, when comparison sites from only the Northern Virginia District were available, there was no difference between comparison site crash rates and exception site crash rates during the before period based on a paired *t*-test ($p = 0.14$), and Table F13 also shows a non-significant *p*-value during the before period. Investigation of the three other districts individually (Fredericksburg, Hampton Roads, and Staunton) also gave non-significant *p*-values of 0.34, 0.13, and 0.11, respectively, based on a paired *t*-test that compared before comparison site crash rates to before exception site crash rates.

That said, the detailed modeling in Appendix F suggests that exception requests are not associated with a change in crash risk because the significance level for exception requests did not change from the before period (e.g., prior to the entrance being built) to the after period (after the entrance has been constructed). Further, the coefficient for presence of an exception request remained relatively constant from the before period to the after period. However, the detailed modeling in Appendix F also suggests that for future studies, it may be relatively difficult to find suitable comparison sites that are identical in every respect to exception sites, especially in terms of crash rates.

A 150-Foot Buffer for the Reduced Dataset (23 Exception Sites Only)

Although data collection Methods 1 and 2 were the primary interest for this study, upon examination of the results, the TRP asked if it was possible to consider a third method—collection of crash data using a smaller radius at the exception site. An advantage of Method 1 relative to Method 2 was that Method 1 helps avoid the impact of other factors; that is, use of Method 2 could mean that "what is happening at the offending intersection could get confounded with what is happening at the compliant intersection" (O'Leary, 2017). However, after results were obtained from Methods 1 and 2, it was also pointed out that possibly a 300-foot buffer could nonetheless include crashes unrelated to the entrance (Hofrichter, 2017). Accordingly, for a subset of the sites, the research team later used a third method that was similar to Method 1 but that included a 150-foot buffer.

Accordingly, for the 23 exception sites only, i.e., those in the Northern Virginia District, crash data were collected within 150 feet of the entrance that was the subject of the exception request. The results were similar to those obtained when the 64 exception sites were used (see Table 15):

- The paired *t*-test showed that there was no change in before and after crash rates, whether normalized by year ($p = 0.59$) or by month ($p = 0.89$); however, the assumption of normality does not hold.

- The Wilcoxon signed rank test also showed no significant change whether normalized by year ($p = 0.59$) or by month ($p = 0.76$).

- The one-sample sign test also showed no significant change whether normalized by year ($p = 0.61$) or by month ($p = 0.61$).

The crash data used throughout this process had also excluded only the month in which construction of the exception site was completed. The TRP had asked what might happen if one excluded not just that month but also the month prior to completion of construction and the month following completion of construction. With the use of the 23 sites and performance of the Wilcoxon signed rank test with the crash data normalized by month, this new timeframe (of excluding the before month and after month) and use of the 150-foot buffer showed no significant change in crash rates at the 23 sites ($p = 0.84$). As noted previously, the original timeframe (of excluding only the month in which construction was completed) and use of the 150-foot buffer also showed no significant change in crash rates at the 23 sites ($p = 0.76$).

CONCLUSIONS

1. *The criteria used by states to establish spacing standards are not consistent.* Of the 27 states that responded to a survey (see Appendix E), 9 (including Virginia) use roadway classification, 10 (including Virginia) use speed limit, 10 (not Virginia) use area type, and 4 (not Virginia) use cycle length. Except for Virginia, no states use both speed limit and roadway classification yet exclude other criteria. For example, Alabama uses only one criterion (speed) whereas North Carolina uses speed, roadway type, and area type.

2. *Virginia does not appear to have more restrictive spacing standards than other states based on the few cases for which a direct comparison can be made*. For example, for a principal arterial with a speed limit of 45 mph, Virginia's spacing standard for signals is equal to that of 2 or 3 states, less restrictive than that of 13 or 14 states, and more restrictive than that of 2 states. (The range is the result of 1 state, Vermont, having different standards for urban and rural locations.)

3. *A minority (15%) of Virginia access permit requests entail a request for a deviation from access management standards*. For the multiyear period analyzed (July 1, 2011, to the distribution of the survey in July 2016), the researchers estimate that a total of 2,713 entrance permits were sought. Roughly 15% (i.e., 403) of these entailed an access management request (with 393 of those requests being approved).

4. *Compared to other states for which this information is available, a relatively small percentage of entrance permits in Virginia entail an exception request.* About one-half of the respondents indicated they could not provide this information, and the other 14 respondents provided percentages ranging from less than 1% (California) to as high as 75% (Nebraska and Nevada). Of the 14 states for which this percentage is available, Virginia's percentage of 15% is the fourth lowest.

5. *In Virginia, exception permit requests are rarely (3%) denied*. A total of 10 denials were found (1 each in the Culpeper and Richmond districts and 2 each in the Hampton Roads District, Prince William County, Loudoun County, and Fairfax County). Given that 393 exception requests were approved, most exception requests seem to be negotiated instead of simply being denied. In at least one district, for instance, alternatives and mitigations are discussed instead of an outright denial being issued (Joseph, 2016). In addition, although not many exception requests were denied, the majority of those that were denied were not listed on VDOT's Access Management Team Site.

6. *The VDOT databases vary in terms of completeness*. Outside two counties in the Northern Virginia District for which this information could not be determined, VDOT's Access Management Team Site contains slightly less than one-half (43%) of the access management requests, and the LUPS database contains most (91%) of the land use permit requests. As shown in the two rightmost columns of Tables 9 and 10, in eight of the nine VDOT districts, more exception requests existed than were recorded on the Access Management Team Site.

7. *At sites where an exception request was granted, there was not a significant change in crash rates before the entrance was completed and after the entrance was completed.* Based on 64

exception sites in four VDOT districts, crash rates did not change significantly after the exception site was constructed, whether only integer years of data were used ($p = 0.63$) or a more complete dataset was used that included portions of a year ($p = 0.78$). (These p-values are based on the tests with the most statistical power for which key assumptions definitely hold: for normalization by year, that was the Wilcoxon signed rank test, but for normalization by month, that was the one-sample sign test.)

8. *There is not a significant difference in the ratio of after crash rates to before crash rates at exception sites and comparison sites*. Based on the same dataset described in Conclusion 7, where, for each of 64 exception sites, a comparison site (where no entrance had been built) was identified, the Wilcoxon signed rank test showed no significant difference in the ratio of after crash rates to before crash rates between exception sites and comparison sites ($p = 0.24$ when only integer years of data were used or $p = 0.17$ when a more complete dataset was used that included a portion of the year).

9. *The exception requests reflect relatively diverse situations.* Of the 23 Northern Virginia District exception requests that were reviewed in detail, the crash rates at the sites varied by an order of magnitude; the roadways ranged from the highest functional class (a principal arterial) to the lowest functional class (a local facility); deviations from the standards ranged from 12 to 1,030 feet; and some type of mitigation was proposed for about one-fifth of the sites. The only consistency was that almost all exception requests pertained to the spacing standards.

RECOMMENDATIONS

1. *VDOT's Office of Land Use should ask VDOT's Information Technology Division (ITD) to implement a customized module in LUPS that was developed by the Office of Land Use.* This customized module, in addition to instructions for its use, is shown in Appendix D.

2. *VDOT's Office of Land Use should notify the district transportation and land use directors to direct the permit specialists in their district to indicate whether the permit required an exception request when they enter commercial entrance permits into LUPS.* This can be accomplished with the use of the customized module developed by LUPS management in accordance with the instructions provided in the section of Appendix D titled "Entering Exception Request Information Into LUPS."

3. *VDOT's Office of Land Use, in consultation with the district transportation and land use directors and other district staff, should periodically monitor the proportion of commercial entrance permits requiring an exception.* This can also be accomplished with the use of the customized module developed by LUPS management in accordance with the instructions provided in the section of Appendix D titled "Using LUPS to Query Commercial Entrance Permits."

4. *VDOT's Office of Land Use should update the Access Management Exception Request Form to include latitude and longitude for each proposed entrance*. If the latitude and longitude

are recorded to five decimal places, the location in the database will be within 4 feet of its real-world location. This latitude and longitude provides another way to link information from two different databases: the exception requests from VDOT's Access Management Team Site and LUPS.

BENEFITS AND IMPLEMENTATION

Benefits

Access management spacing standards exist in part because they reduce crash risk by reducing vehicular conflict points. The reason for implementing Recommendations 1, 2, 3, and 4 is to ensure that these standards continue to be met or, if they cannot be met, that mitigations tend to minimize the impact on crash risk. Recommendation 1 creates a software application; Recommendation 2 populates this software application with data; Recommendation 3 uses these data to perform monitoring; and Recommendation 4 provides another mechanism for linking datasets in case there is an unforeseen problem with certain records that are used in the first two recommendations.

Overview of Benefits

The benefit of implementing Recommendation 1 is that VDOT will have a single database with the ability to delineate land use permits by (1) those where an exception request was not needed and (2) those where an exception request was needed. Such a single database if populated with data as per Recommendation 2 makes queries easier for VDOT staff as per Recommendation 3 to develop when they seek to compare crash risk at sites with or without an exception request.

The benefit of implementing Recommendation 2 is that the database created in Recommendation 1 will now be maintained. In short, Recommendation 2 (along with Recommendation 1) will make monitoring of exception requests easier to accomplish by linking the Land Use Permit System (LUPS) database with the Access Management Exception Request database. Note that this study is not the first Virginia effort to recognize the benefits of such a linkage. VDOT's Staunton District has developed a SharePoint site that maintains for each exception request a LUPS permit number and an indication as to whether the permit has been completed (i.e., built) (Figure 16). The innovations to LUPS that are being developed by LUPS management in concert with this and the earlier recommendation would support such queries statewide.

Date Submitted	Jurisdiction	Residency	Routes	Type Of Exception	Reason For Exception	Land Use Permit Issued	Land Use Permit Num	Land Use Permit Complete
5/21/2013	County of Augusta	Harrisonburg Residency	250	AM-E: Exception to Commercial Entrance shall not be located within the functional area of intersection	4.) Not enough property frontage to meet spacing standard, but applicant does not want a partial access right-in/right-out entrance	Yes	854-48509	Yes
6/28/2016	County of Augusta	Harrisonburg Residency	1340, 11	AM-E Exceptions to Spacing Standard	4.) Not enough property frontage to meet spacing standard, but applicant does not want a partial access right-in/right-out entrance	No		No

Figure 16. Excerpt of a Customized SharePoint Site for Access Permits Developed by the Staunton District. The figure was modified to enhance readability.

The benefit of implementing Recommendation 3 is that it enables VDOT routinely to monitor the efficacy of its access management exception process, which is a fundamental part of maintaining these standards. If exceptions remain relatively low compared to the number of entrance permits granted, this can be a sign that the spacing standards are continuing to be met. Conclusions 3, 7, and 8 of this study indicated that exceptions are relatively low and that at the sites where exceptions were allowed, there was not a significant change in crash rates. However, Conclusion 6 noted that the databases needed to monitor periodically the exception process are not complete, meaning monitoring such as that performed in this study could require substantial resources in the future.

The benefit of implementing Recommendation 4 is that it provides an alternative mechanism for linking exception requests and land use permits. Perfect execution of Recommendations 1 and 2 would eliminate the need for Recommendation 4, but at this point it provides a backup way of performing this linkage should that backup way be needed.

Monetization of Benefits

Recommendations 1, 2, and 3 make it feasible to monitor periodically the exception process. The benefit of implementing these recommendations depends on which of two situations will occur in the future: (1) access exceptions do not lead to an increase in crash risk or (2) access exceptions do lead to an increase in crash risk. If Situation 1 occurs, the benefits of a monitoring program are difficult to monetize because there are several possible reasons for requesting an exception: an adjacent landowner may refuse to allow an easement that otherwise would allow the spacing standard to be met, locality requirements such as landscaping may make meeting the spacing standard infeasible, or there may be site-specific factors such as the need to relocate utilities. One might further argue that these benefits are currently being realized by VDOT's access exception process (and hence without the study's recommendations). If, however, Situation 2 occurs or is at risk of occurring, the benefit of these recommendations is that they would allow decision-makers to modify the exception process until there is no longer an increase in crashes. It is possible to estimate, very roughly, the benefits for Situation 2 as follows:

- If, in the future, access exceptions were to contribute to an increase in crash risk, the benefits of monitoring access exceptions (and thus stopping them when crashes increased) may be calculated by monetizing the impact of the crashes eliminated. Because a majority of crashes appeared to be property damage only (PDO) crashes, a conservative approach for estimating the crash-related benefits appears to be to use PDO crash impacts.

- Viewing Table 9 in the report as representing roughly 5.5 years of data (January 1, 2011–June 30, 2016), the 2,714 total entrance permits therein represent 493 permits per year. Given further that roughly 15% of these permits entail an exception request, one might expect exceptions to be present in potentially 15% of 493 = 74 exception requests per year. Although presence of an exception was not significant ($p = 0.63$), when one sums the before and after rates from the 64 exception sites (see Appendix D), there is a nominal increase (from 164.7 to 170 crashes per year) when all sites are combined. Adjusting this difference (6.3 crashes at 64 sites) to reflect the 74 exception requests that are expected annually yields a difference of about 7.3 crashes. In its prioritization of transportation projects, Virginia's Smart Scale process (Commonwealth Transportation Board, 2016) refers the reader to work by Council et al. (2005) with respect to cost estimates for crashes. Council et al. (2005) reported that without knowing other details of the crash, the unit crash costs for a PDO crash are $7,438 in 2001 dollars, which, after adjusting for inflation (Bureau of Labor Statistics, 2017), is about $10,251 per crash.

- Thus, the benefits of a monitoring process if crashes were to increase and then the monitoring process were to stop such an increase would be approximately (7.3 crashes) x ($10,251) = $74,832 per year.

To be clear, these benefits are subject to assumptions regarding both the cost of crashes and any future crash impacts. For example, with regard to the cost of crashes, a more recent source than Council et al. (2005) suggested that the unit cost of a PDO crash is $42,298 in 2010 dollars (Blincoe et al., 2015), which, after adjusting for inflation to year 2017 (Bureau of Labor Statistics, 2017), is about $47,374 per crash. The disparity results in part because Blincoe et al. (2015) noted that many crashes that are coded as "O" in the KABCO scale, which corresponds to a PDO crash, do actually involve an injury. If these two sources (Blincoe et al., 2015; Bureau of Labor Statistics, 2017) are used, the annual benefits of the recommendations under Situation 2 are (7.3 crashes)($47,374) = $346,871. Generally, crash severity plays a large role in benefit-cost calculations; one recent study, for instance, showed how the benefit-cost ratio climbed from roughly 1.0 to 10.0 if the type of crash changed from “possible injury” to “incapacitating injury” (Dougald, 2015).

In short, the benefits have a wide range—$70,000 to $350,000—should the exception process in the future lead to an increase in crash risk. To be clear, the crash-exception relationship has been analyzed for only the one Virginia sample included in the study: 64 sites. Table 10 suggests that at the time the survey was conducted, there were between, roughly, 184 and 259 built exception sites, meaning that this study analyzed between 25% and 35% of the sites. (The “roughly” results because although a majority of land developments had one entrance exception request, Table 1 showed that a few land development locations [i.e., 15% of the land development locations in Table 1] had two entrance requests. Further, some sites had short after periods. It is possible that a different, larger sample could yield different aggregate results.)

Implementation

Current Status

Recommendation 1—that is, VDOT’s Office of Land Use’s request to ITD to deploy the customized modules developed by LUPS management and shown in Appendix D—has already been implemented.

Recommendations 2 and 3 can be implemented after ITD has deployed the customized module in LUPS noted in Recommendation 1.

Following a meeting between the Office of Land Use and the transportation land use directors in December 2017, Recommendation 4 was implemented.

Interim Implementation of Recommendations 2 and 3

Until the application noted in Recommendation 1 is developed, VDOT’s Office of Land Use will ask the transportation and land use directors to submit exception requests in a timely manner.

In theory, because the exception reports are not complete (see Table 9), there are three practices that the Office of Land Use can encourage districts to pursue in tracking exception requests, where “exception requests” refers exclusively to those in Appendix D (and not to design waivers using Form LD-448 or design exceptions using Form LD-440). First, keep VDOT’s Access Management Team Site (VDOT, 2016a) up to date by entering every exception request. Second, ensure each exception request includes a completed form and satellite imagery of the site. Third, encourage districts to include the word “denied” in the title of access exception request forms that ultimately were not accepted. However, each of these practices requires effort, and without a clear benefit of keeping the access management request information updated, it may not be realistic to expect such practices to be carried out. By implementing a stronger connection between LUPS and the Access Management Team Site, however, as is expected once Recommendations 2 and 3 are under way, it may be easier for district staff to keep this information updated.

Future Implementation of Recommendations 2 and 3

Recommendations 2 and 3 will initially be undertaken by VDOT's Office of Land Use once the customized module is available. These recommendations will be supported through customized modules developed by LUPS management based on the database integration needs identified during the course of this study. Instructions for using LUPS in following these two recommendations are given in Appendix D. The customized modules can help ensure it is possible to link access exceptions and permits (see Figure 17). With these customized modules in place, long-term implementation of Recommendation 2, following notification from the Office of Land Use, would rest with the district transportation and land use directors. Implementation of Recommendation 3 would initially rest with VDOT's Office of Land Use.

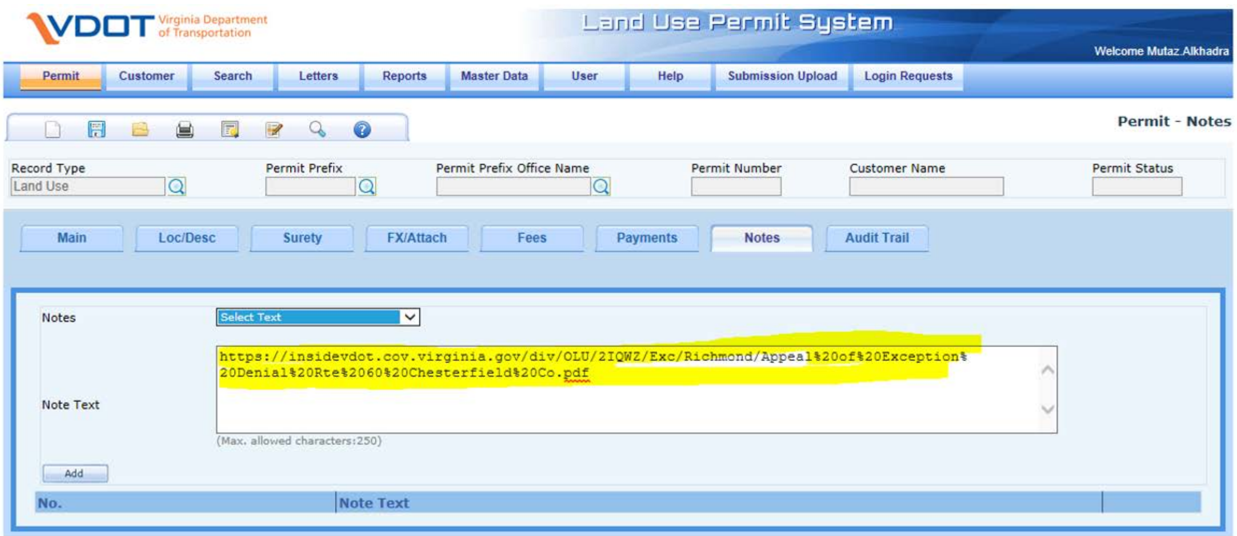

Figure 17. Example of Linking an Access Exception Request to LUPS. LUPS = Land Use Permit System. Figure courtesy of Alkhadra (2017b).

FUTURE RESEARCH NEEDS

The results of this study also suggest two related, but distinct, future research needs. One concerns the sampling that was undertaken—an ideal study would have examined 100% of the exception sites, compared to this study that analyzed roughly one-fourth to one-third of the exception sites. (The exact percentage is not certain because in some cases, the number of built versus unbuilt exception sites is not known.) It is possible that a study that examined the entire sample of built sites, especially with longer after periods, might yield different results.

Second, this study focused on aggregate crash impacts, treating each exception site in a uniform manner where the total crashes within a certain distance of the site was obtained. It may be the case that some exception sites are fundamentally different from others in terms of the degree to which they deviate from the access standard, the resultant geographic distribution of crashes at the site, and the types of crashes observed. Thus, a more disaggregate study that somehow analyzed individual crash patterns at individual sites (while recognizing the inherent variability in crashes) might also be appropriate.

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APPENDIX A

DEVELOPMENT OF THE SURVEY INSTRUMENT FOR A REVIEW OF STATE PRACTICES FOR DEVIATIONS FROM ACCESS MANAGEMENT POLICIES

The initial draft of the survey had 5 questions and was shared with the TRP, who had detailed knowledge of access management principles and practices in Virginia. Based on comments from the TRP, the survey was expanded to 12 questions. The survey was then provided to one TRP member with survey expertise, and based on the comments of that member, a tentative final survey was developed. Collectively, the TRP had several major suggestions:

- Organize the questions such that certain non-technical, high-level questions are posed first in order to "set the stage." For example, start with the term "policies" and then move to the more detailed term "standards." Similarly, ask respondents basic questions (e.g., "do you have access standards") before asking for details about those standards.

- Simplify the terminology as much as possible; for example, clarify that the survey uses the term "deviation" for consistency but recognizes that states may use other terms such as "exceptions" or "variances." Rather than using the term "the state," since this is directed to a respondent, use the term "your state."

- Force each question to address one key concept. For example, rather than asking about minimum spacing standards for intersections and crossovers in the same sentence, break this question into two parts: one for intersections and one for crossovers.

- Ask if an engineering study is required when making an exception request. That is, although knowing that a form must be completed is helpful, it is critical to find out if an engineering study is required.

- Clarify that when a response requires detailed information, it is appropriate to provide a web link or some other published document—and further clarify that the provision of contact information is desired but voluntary. Clarify also that although precise numbers are desirable, rough estimates are acceptable provided the respondent indicates this in the response.

- Provide sample answers from Virginia, but offer them in a separate document so that respondents have it as a resource but are not confused by the extra information. Further, when providing the answer from Virginia, do not simply indicate a "no" response. For example, Virginia has not conducted safety studies of exception sites and we should explain that although we have not completed safety studies, we are considering doing so depending on what we learn in the first phase of our research.

- For respondents who do look at Virginia's standards, clarify that Category C ("Spacing from Full Access Entrances . . .") refers *not* just to commercial entrances but also to T-intersections. Also note that Category B includes two commercial entrances opposite each other.

After these revisions were made, the tentative survey was shown to the TRP again. There were a couple of minor grammatical and cosmetic changes to the survey (e.g., in Question 9, the phrase was changed from "what percentage are" to what percentage is") and the response for Virginia Question 7 was altered to clarify that Virginia does not require a traffic engineering study. Then, the survey was reviewed by the TRP member with survey expertise, who identified some grammatical and wording changes that were needed such as pointing out that respondents do not have to retype their state spacing standards if these are documented (Question 4) or changing the phrase "give to" to "use for" (Question 5).

Several grammatical errors or wording problems were addressed. For example, in Question 3, rather than asking where access management standards are published, the question was altered to ask where these standards could be obtained. The question was also altered to focus on access standards for commercial entrances to be consistent with the introductory paragraph. An addendum to Question 6 was altered to read "(If this process is documented, you are welcome to send us a link or the document if that is easier than typing an answer to the question)," and a similar change was made as suggested to Question 4 in order to clarify that respondents had the choice of answering the question directly or, as suggested by an earlier reviewer of the survey, sending a link or document if that would be easier for the respondent. A second round of review by the editor that focused on the answers also changed some of the grammar in terms of punctuation, clarifying that the Virginia requests for access deviations require the submittal of a completed form, and also led to the addition of a note of thanks for respondents taking the time to complete the survey.

When the survey was provided to the TRP, one additional concern was over the wording of Question 5, which had asked "What *term(s)* does your state use for a request from a commercial developer to deviate from your state's access management standards for a commercial entrance (emphasis added)?" The concern was that some might interpret the word "term" to refer to conditions; one suggestion was to replace the word "term" with the word "nomenclature," but another TRP member was concerned that "nomenclature" might make the survey confusing, suggesting that the word "word" could be used instead of "nomenclature." Ultimately, the survey used the word "terminology" in Question 5, with the caveat that if the responses of the first two respondents indicated confusion, the survey question would be revised. (This was feasible because the survey was administered to recipients one at a time by the research team initially contacting them by telephone.)

The final survey instrument follows, with its native formatting.

Review of State Practices for Deviations from Access Management Policies

Introduction

Access management concerns the spacing and design of road entrances, street intersections, median openings, and traffic signals. The Virginia Department of Transportation is conducting a short survey on states' access management policies for commercial entrances (including entrances for residential subdivisions). Our specific interest is how states grant deviations from access management standards. Survey Questions 1-4 pertain to the standards for your state. Survey Questions 5-12 pertain to how your state addresses requests to deviate from these standards. (We use the term "deviation" here, but some states may use terms such as "exception" or "variance.") We welcome your answers by email, phone, or fax. We have attached a sample survey response from our own agency (the Virginia Department of Transportation) to clarify the types of information we are seeking.

Survey Questions

1. Does your state have standards related to access management?

2. Do your state's access management standards apply to commercial entrances?
   (*Note:* Throughout this survey the term "commercial" may include entrances for residential subdivisions.)

3. Where may these access management standards for commercial entrances be obtained?
   (Please provide link to web address, if applicable.)

4. What are your state's minimum spacing standards for the following:
   a. intersections (signalized and unsignalized)
   b. median crossovers
   c. commercial entrances?

   (If these standards are documented, you are welcome to send us a link or the document if that is easier than typing an answer to the question.)

5. What terminology does your state use for a request from a commercial developer to deviate from your state's access management standards for a commercial entrance?

6. When a developer of a commercial property wants to deviate from your state's access management standards for a commercial entrance, what process must the developer follow to obtain approval?
   (If this process is documented, you are welcome to send us a link or the document if that is easier than typing an answer to the question.)

7. Does your state require that a traffic engineering study accompany a request for a deviation?

8. What percentage of commercial entrance permit requests includes a request for a deviation from your state's access management standards?
   (If it is not possible to provide an exact percentage, please give an estimate and indicate in your response that the percentage is an estimate.)

9. Of the requests for a deviation from your state's access management standards for a commercial entrance, approximately what percentage is approved?

(If it is not possible to provide an exact percentage, please give an estimate and indicate in your response that the percentage is an estimate.)

10. Has your state performed any analysis of the safety impacts of allowing deviations from your state's access management standards for commercial entrances?

11. Do you have a publicly accessible archive of your state's requested access management deviations for commercial entrances that we could view? If yes, please provide the web link.

12. Optional but extremely helpful: Whom from your state may we contact for additional information? (We would welcome the person's name, phone number, and email address.)

Please Direct Responses to

Lance.Dougald@vdot.virginia.gov (email) or 434-293-1974 (phone) or 434-293-1990 (fax) or
Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903 (address)

OR

John.Miller@vdot.virginia.gov (email) or 434-293-1999 (phone) or 434-293-1990 (fax) or
Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903 (address)

We thank you for your time—this information is quite helpful to us. We would also be glad to provide you with a summary of the responses; if so, please give us either an email address or a physical mailing address.

APPENDIX B

REVIEW OF STATE PRACTICES FOR DEVIATIONS FROM ACCESS MANAGEMENT POLICIES: SAMPLE VIRGINIA ANSWERS

This document shows how Virginia would have completed the survey and is offered in case it helps clarify the information sought from your state.

1. **Question:** Does your state have standards related to access management?

   Example response for Virginia: Yes.

2. **Question:** Do your state's access management standards apply to commercial entrances? (*Note:* Throughout this survey the term "commercial" may include entrances for residential subdivisions.)

   Example response for Virginia: Yes.

3. **Question:** Where are these access management standards published? (Please provide link to web address, if applicable)

   Example response for Virginia: The complete set of access management requirements in Virginia is documented in the Virginia Administrative Code (24VAC30-73) and is available at this site: http://www.virginiadot.org/info/access_management_regulations_and_standards.asp.

   The design standards are in Appendix F of Virginia's *Road Design Manual,* and Appendix F is available at this site: http://www.extranet.vdot.state.va.us/locdes/Electronic_Pubs/2005%20RDM/AppendF.pdf

4. **Question:** What are your state's minimum spacing standards for the following:
   a. intersections (signalized and unsignalized)
   b. median crossovers
   c. commercial entrances?

   (If these standards are documented, you are welcome to send us a link or the document if that is easier than typing an answer to the question.)

   Example response for Virginia: Virginia's spacing standards are shown on the next page. Virginia has different standards depending on whether the spacing refers to a signalized intersection, an unsignalized intersection, a crossover (e.g., a break in the median), or an entrance (e.g., connection between a commercial establishment and the roadway). Further, for crossovers and entrances, the standards depend on whether the crossovers and entrances permit full access or directional access. Note that Category C is for T-intersections, not just commercial entrances, just as Category B includes two commercial entrances opposite each other. Note also that Virginia's standards depend on highway functional classification and the speed limit.

Minimum Spacing Standards for Commercial Entrances, Intersections, and Median Crossovers					
Highway Functional Classification	Legal Speed Limit (mph)①	Minimum Centerline to Centerline Spacing (Distance) in Feet			
		Spacing from Signalized Intersections to Other Signalized Intersections ② *a*	Spacing from Unsignalized Intersections & Full Median Crossovers to Signalized or Unsignalized Intersections& Full Median Crossovers ③ *b*	Spacing from Full Access Entrances & Directional Median to Other Full Access Entrances and Any Intersection or Median Crossover ④ *c*	Spacing from Partial Access One or Two Way Entrances to Any Type of Entrance, Intersection or Median Crossover ⑤ *d*
Principal Arterial	≤ 30 mph 35 to 45 mph ≥ 50 mph	1,050 1,320 2,640	880 1,050 1,320	440 565 750	250 305 495
Minor Arterial	≤ 30 mph 35 to 45 mph ≥ 50 mph	880 1,050 1,320	660 660 1,050	355 470 555	200 250 425
Collector	≤ 30 mph 35 to 45 mph ≥ 50 mph	660 660 1,050	440 440 660	225 335 445	200 250 360

[a] This standard refers to the distance between traffic signals. (Virginia's administrative code defines an intersection as any of the following: (1) an at-grade crossing of two highways; (2) a crossover; or (3) an "at-grade connection," such as a commercial entrance and a highway.
[b] If there is no median, an at-grade intersection and a full crossover are the same. If there is a median, a full crossover is a median that permits left, right, and through movements. This category includes two commercial entrances opposite each other.
[c] A full access entrance is an entrance that allows left-in, left-out, right-in, and right-out movements. This category applies to commercial entrances and T-intersections.
[d] A partial access entrance has movements limited to (1) right-in only; (2) right-out only; or (3) both right-in and right out; with any of these combinations, left-in movements may be allowed or prohibited.

5. **Question:** What terminology does your state use for a request from a commercial developer to deviate from your state's access management standards for a commercial entrance?

   Example response for Virginia: Such a request is called an access management exception. Virginia uses a different term, a "waiver," if the request comes from the state (e.g., if Virginia wanted to build a new facility that did not meet standards, the request to do so would be called a waiver)—and that is not part of this study.

6. **Question:** When a developer of a commercial property wants to deviate from your state's access management standards for a commercial entrance, what process must the developer follow to obtain approval?
   (If this process is documented, you are welcome to send us a link or the document if that is easier than typing an answer to the question)

Example response for Virginia: *A summary of the process is this:* to request an exception, the developer submits a completed Access Management Exception (AME) Request Form to the district transportation and land use director. *For details of the full process,* see the subsection titled "Exceptions/Waivers to the Spacing Standards/Access Management Requirements" shown on page F-29 of a document titled "Appendix F. Access Management Design Standards for Entrances and Intersections," which is available at this link: http://www.extranet.vdot.state.va.us/locdes/Electronic_Pubs/2005%20RDM/AppendF.pdf.

7. **Question:** Does your state require that a traffic engineering study accompany a request for a deviation?

   Example response for Virginia: A traffic engineering study may be performed that indicates how the exception request will affect highway operations and safety. For example, for one Virginia request, impacts such as vehicle delays, the relocation of U-turns, and spacing were documented as part of the exception request. Please note, however, that not all exception requests include a traffic engineering study, so a blanket response of "Yes" to this question may overstate the extent such studies are required.

8. **Question:** What percentage of commercial entrance permit requests includes a request for a deviation from your state's access management standards?
   (If it is not possible to provide an exact percentage, please give an estimate and indicate in your response that the percentage is an estimate in your response.)

   Example response from Virginia: It is not possible to give an exact percentage for the entire state. However, based on data as of August 8, 2016, it is possible to give an estimate based on a portion of the state. Based on data from six (Bristol, Culpeper, Fredericksburg, Richmond, Staunton, and Salem) of Virginia's nine construction districts, Virginia knows the total number of exception requests was 180 for the period 2011-2016. Further, the total number of entrance permits granted (for commercial and residential developments) was 1,397. Thus about 13% (i.e., 180/1397) of entrance permits in Virginia entailed a request for a deviation from access management standards. (Note that not all of these requests were necessarily approval.)

9. **Question:** Of the requests for a deviation from your state's access management standards for a commercial entrance, approximately what percentage is approved?
   (If it is not possible to provide an exact percentage, please give an estimate and indicate in your response that the percentage is an estimate.)

   Example response for Virginia: Based on the same partial dataset noted in the response to Question 8 (i.e., based on 6 of Virginia's 9 construction districts as of August 8, 2016), of the 180 exception requests received over the past 5 years, 176 (approximately 98%) were approved.

10. **Question:** Has your state performed any analysis of the safety impacts of allowing deviations from your state's access management standards for commercial entrances?

Example response for Virginia: No. However, we are considering conducting such a study within the next 18 months, depending on the information we receive from this survey and VDOT staff.

11. **Question:** Do you have a publicly accessible archive of your state's requested access management deviations for commercial entrances that we could view? If yes, please provide the web link.

    Example response for Virginia: We have an internal SharePoint site, accessible only to internal VDOT staff, that records the exceptions each district provided to our Office of Land Use. The Office of Land Use can make these exceptions available upon request. The internal link (available only to persons within VDOT) is here:
    https://insidevdot.cov.virginia.gov/div/TMPD/LNDV/AccessMgmt/SitePages/Home.aspx.

12. **Question:** Optional but extremely helpful: Whom from your state may we contact for additional information? (We would welcome the person's name, phone number, and email address.)

    Example response for Virginia: For more information about access management in general, you may contact Brad Shelton (brad.shelton@vdot.virginia.gov, 804-786-1893). For more information about this particular survey, you may contact Lance Dougald (lance.dougald@vdot.virginia.gov, 434-293-1974) or John Miller (john.miller@vdot.virginia.gov, 434-293-1999).

APPENDIX C

METHODS FOR OBTAINING TRAFFIC AND GEOMETRIC DATA

To perform crash analyses, one needs to obtain traffic and geometric data at exception sites and comparison sites in a consistent manner, as documented in this appendix. The first portion of this appendix discusses how to collect data elements at each site. The second portion discusses ways to identify candidate comparison sites.

Data Elements Common to All Exception and Comparison Sites

As an illustration for how to obtain these data, Figure C1 shows a potential site from the Northern Virginia District, at University Mall on Route 123 in Fairfax County, for which a spacing standard exception was sought because of the site's proximity to the Braddock Road / Ox Road intersection. Figure C1 shows three roadway components common to all exception sites: (1) the commercial entrance, (2) the affected road, and (3) the adjacent road.

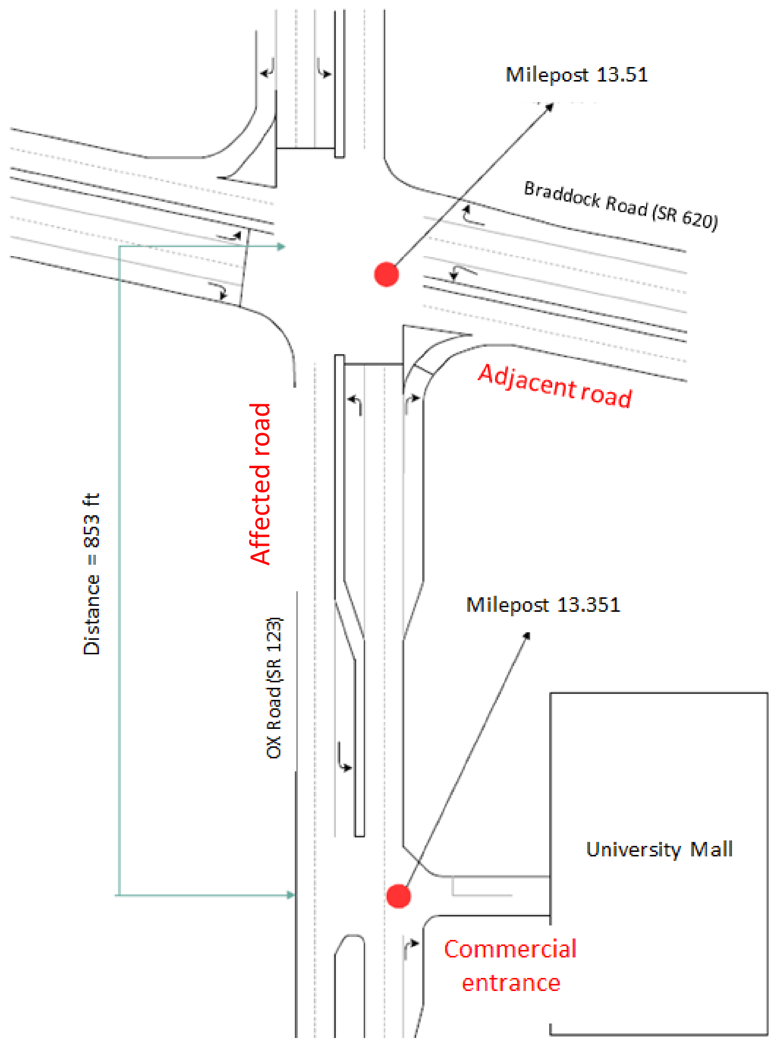


Figure C1. University Mall Exception Site and Labeled Components

Four data sources are used to gather data: (1) VDOT's Roadway Network System (RNS), (2) VDOT's Roadway Inventory Management System (RIMS), (3) Google Maps, and (4) Google Earth. The 20 data elements required are as follows:

1. Name of exception request
2. Route
3. Type of exception
4. Affected road
5. Adjacent road
6. Date of construction
7. Milepost of intersection (affected road)
8. Average daily traffic (ADT)
9. Speed limit
10. Crash data
11. Functional class
12. Sidewalk
13. Bike path
14. Total number of through lanes, median type, and facility type
15. Intersection type
16. Traffic control
17. Dedicated turn lane
18. Corridor length
19. At-grade intersections (within 0.5 miles)—time permitting
20. At-grade intersections (within 300 feet).

In theory, Item 19 has overlap with Item 20, since crashes within 300 feet of a point are also within 0.5 miles of a point. However, because these will be obtained using GIS tools available through VDOT where one specifies the radius, it is easier to collect the crashes through two separate efforts.

1. Name of Exception Request

Figure C2 shows a map of exception sites in Virginia that were constructed within the date range of January 9, 2012, to November 4, 2016, as indicated by the "completed" date in LUPS. The window on the left of the map shows the exception request name. To access the maps, a log-in to Google Maps is required. The Google map with all Virginia sites and the Google map with only Northern Virginia District sites can be found at the following URLs, respectively.

- https://www.google.com/maps/d/viewer?mid=1It5zFOSGWCSKVzcLIt2iYqvmjHU&ll=37.89172442898062%2C-79.35584949999997&z=7
- https://www.google.com/maps/d/viewer?mid=1dhZWLU_oO8UvSZBicgVXFo5UDOE&ll=38.824362359336575%2C-77.50481180000003&z=10

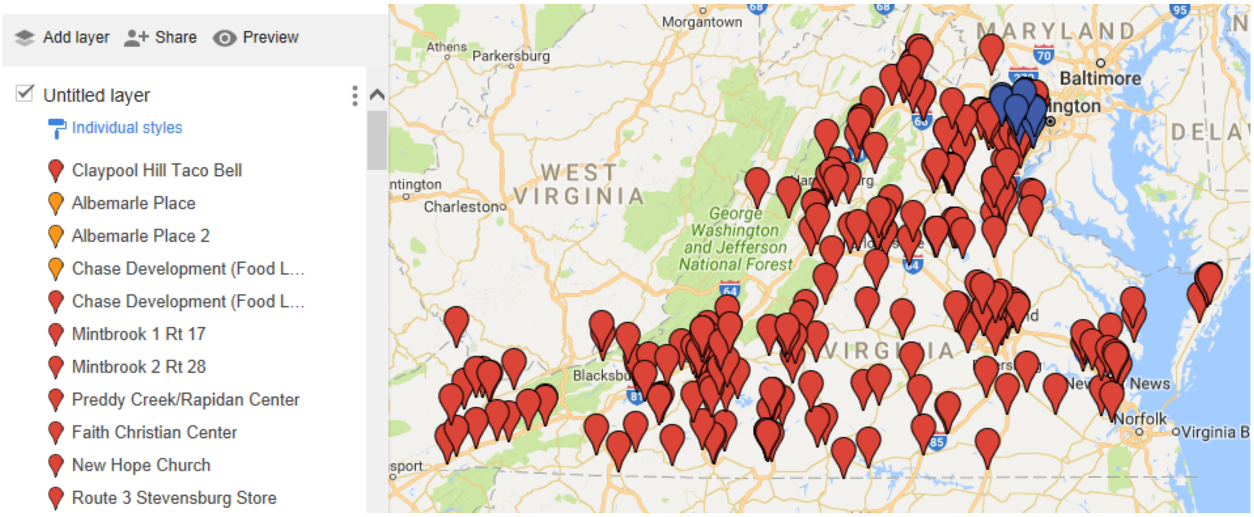


Figure C2. Exception Sites in Virginia Constructed Between January 9, 2012, and November 4, 2016. Map Data © Google, INEGI.

By clicking on an exception request name in the box, the location is highlighted in the map. Figure C3 shows the location of University Mall.

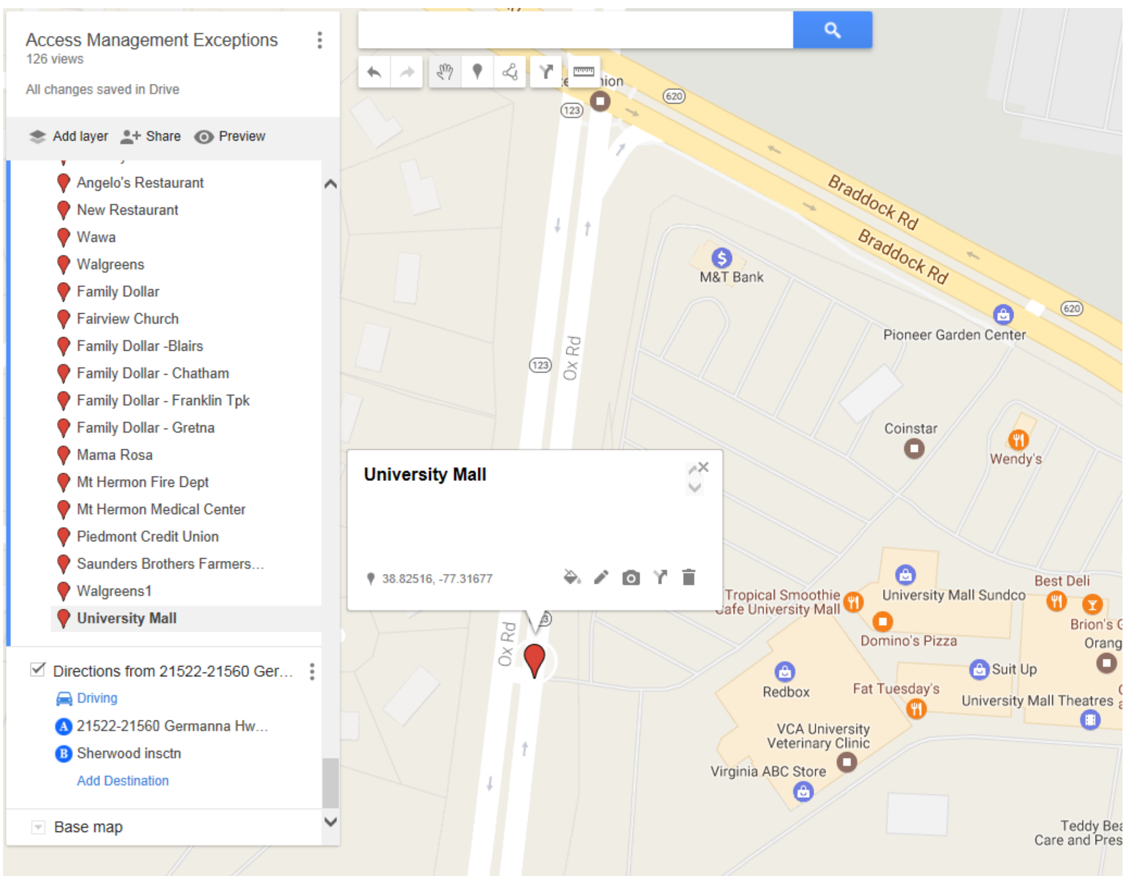


Figure C3. Location of the University Mall Entrance on Ox Road. Map Data © 2017 Google.

2. Route

Indicate the VDOT route number for the affected road.

3. Type of Exception

From documentation in LUPS, note the type of exception (e.g., corner or spacing).

4. Affected Road

Provide name of affected road.

5. Adjacent Road

Provide name of adjacent road.

6. Date of Construction

For exception sites, the date of construction is typically found in LUPS under the field "completed date." If not found in LUPS, more investigation will be needed such as using Google Earth historical aerial imagery or finding local news reports on the site's progress.

For comparison sites, use Google Earth to find an approximation. For example, University Mall has a candidate comparison site also located on Route 123 where it intersects Canfield Street. Thus, enter the street name (Canfield Street) and county name (Fairfax) in the search bar as shown in Figure C4.

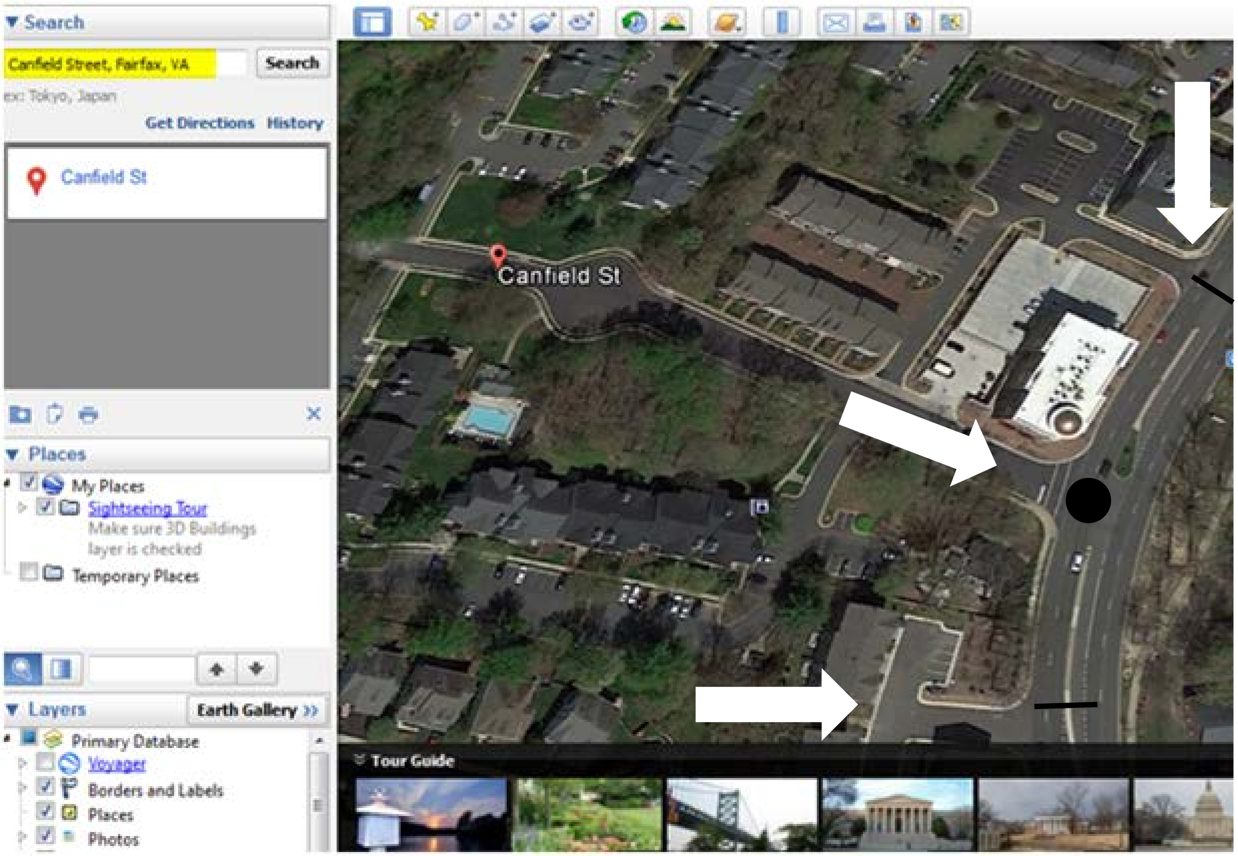


Figure C4. Google Earth Screenshot of Canfield Street Entrance on Route 123. Image taken 4/14/2016, © 2017 Google. Black circle to the right side indicates the entrance, and the black lines above and below the circle indicate roughly the extent.

Select the clock icon  in the menu bar and then scroll through the date bar to go back in time. Because Canfield Street is visible in the 1988 map (see Figure C5), the entrance was constructed prior to 1988.

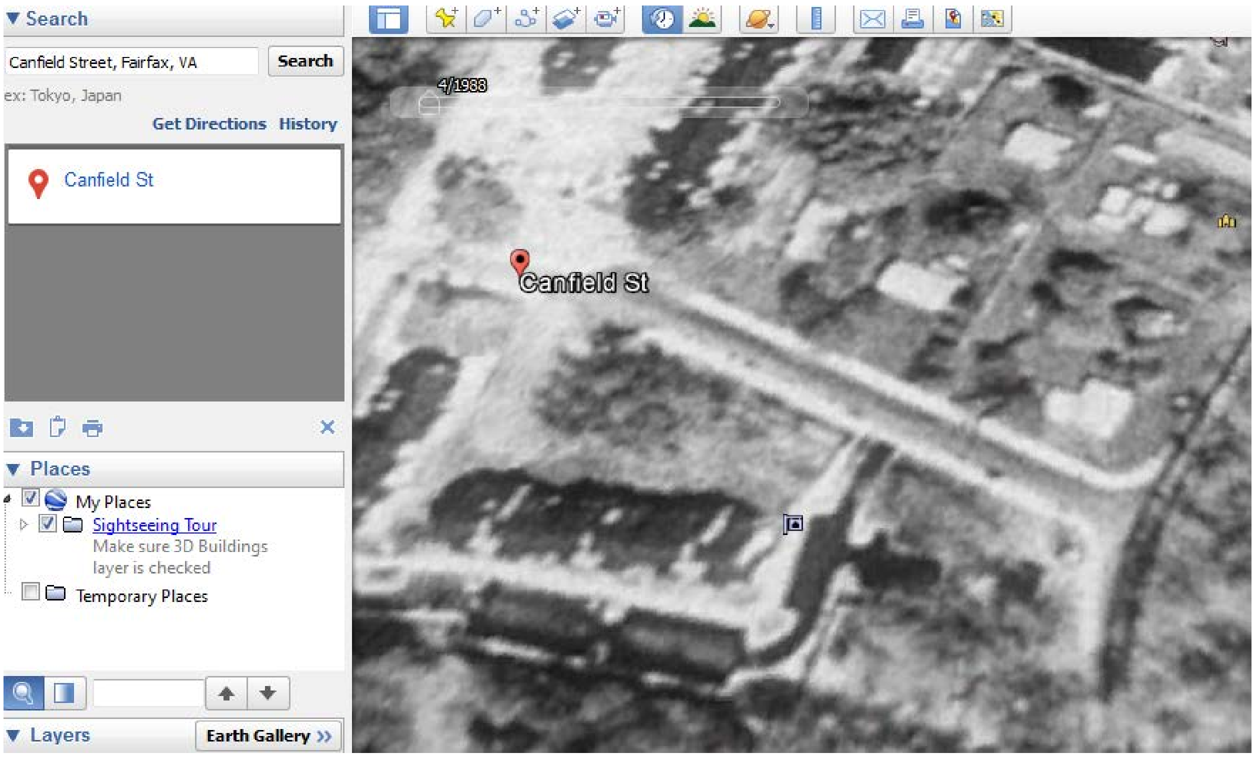


Figure C5. Google Earth Screenshot of Canfield Street Entrance in 1988. Image taken 4/19/1988, ©U.S. Geological Survey.

7. Milepost of Intersection (Affected Road)

From VDOT's Roadway Network System (http://rns/app/rns.aspx), the following steps are undertaken to obtain milepost:

1. Select advanced search.
2. Select traffic.
3. Select location search tab.
4. Enter VDOT District (Northern Virginia (09)) and route number of affected road (123).
5. Select refresh route list.
6. Select any direction (N, W, S, E) from the route list dropdown menu.
7. Select distance from intersection.
8. Find start intersection (the commercial entrance and affected road intersection [93: 13.351 Miles]) and end intersection (the affected road and adjacent road intersection [94: 13.510 Miles: Braddock Road; Rte 620 E. Fairfax County]).

If the start intersection is not listed in RNS, select the closest intersection and proceed to click on "Show Map." Taking this action will open the VDOT Integrator (2017e) in a new tab (henceforth this is known as "Integrator.") Open Integrator and follow these steps to obtain milepost:

1. Select  icon in map pan/zoom tool.
2. Select aerial.

3. Pan/zoom to commercial entrance.
4. Adjust the milepost manually in the start mile textbox under the route selector tab until the green pin is visually in the centerline of start intersection.

8. Average Daily Traffic (ADT)

From the same page on RNS that milepost data are found, the following steps are performed to find ADT. (Note that these procedures were used during the period December 2016–July 2017 such that ADT was obtained, as shown in Figures C6 and C7. However, a recent alteration to Integrator means that as of roughly October 9 or 10, 2017 [the researchers could not recall exactly which date this change first transpired], ADT was not visible from this step.)

1. Select show on map (this will show the affected road segment between mileposts in Integrator).
2. Select layers tab.
3. Select VDOT map from dropdown menu.
4. Select traffic count under VDOTLayers.
5. Right click road segment between pins on map.
6. Select identify visible layers.
7. Select traffic count in dropdown menu.
8. Scroll to ADT.

To find ADT on the adjacent road and commercial entrance (if available), right click on those road segments and follow Steps 5 and 6. Figures C6 and C7 show the resulting RNS screenshots of the process for the affected road (SR 123) and adjacent road (SR 620), respectively. The entrance at University Mall is privately owned; therefore, commercial entrance ADT data are not available.

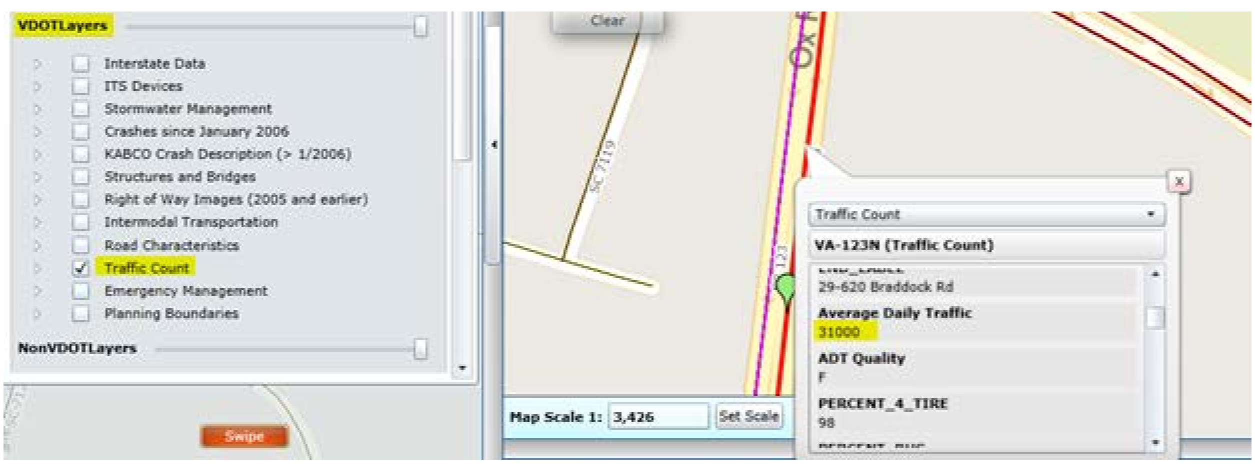


Figure C6. RNS Screenshot of Average Daily Traffic (ADT) on University Mall's Affected Road

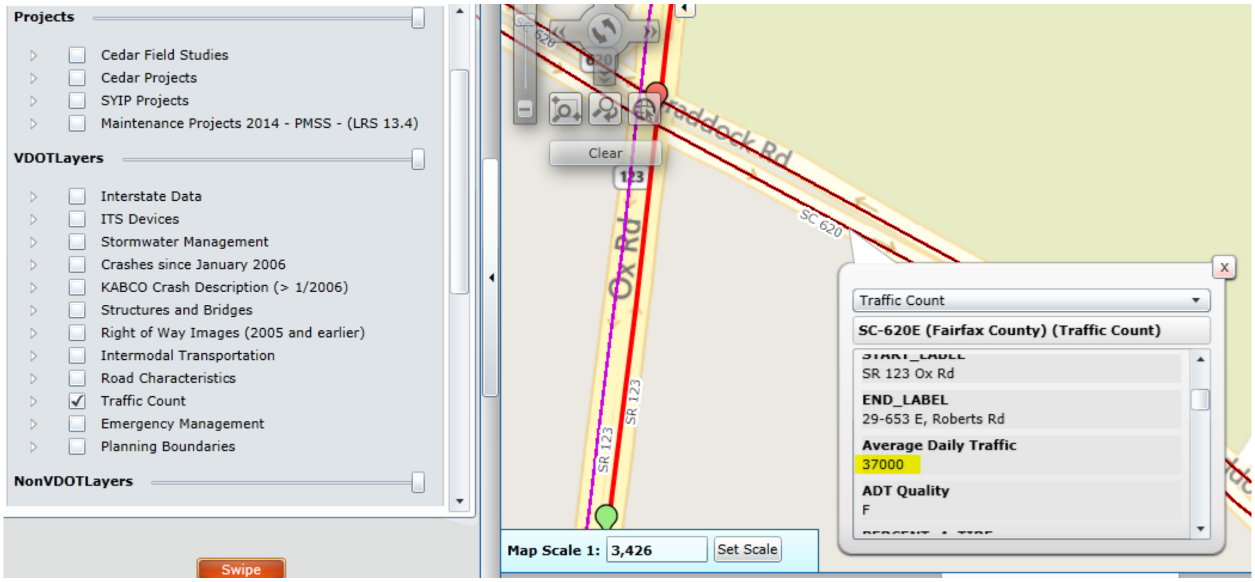


Figure C7. RNS Screenshot of Average Daily Traffic (ADT) on University Mall's Adjacent Road

9. Speed Limit

Continuing in RNS, the following steps are performed to find speed limits:

1. Select road characteristics under VDOTLayers.
2. Right click affected road segment.
3. Select identify visible layers.
4. Select speed limit (cars) in dropdown menu.
5. Scroll to car_speed_limt.

To find speed limits on the adjacent road and commercial entrance (if available), right click on those road segments and follow Steps 3 through 5. RNS screenshots of the affected and adjacent road speed limits for University Mall are shown in Figures C8 and C9, respectively.

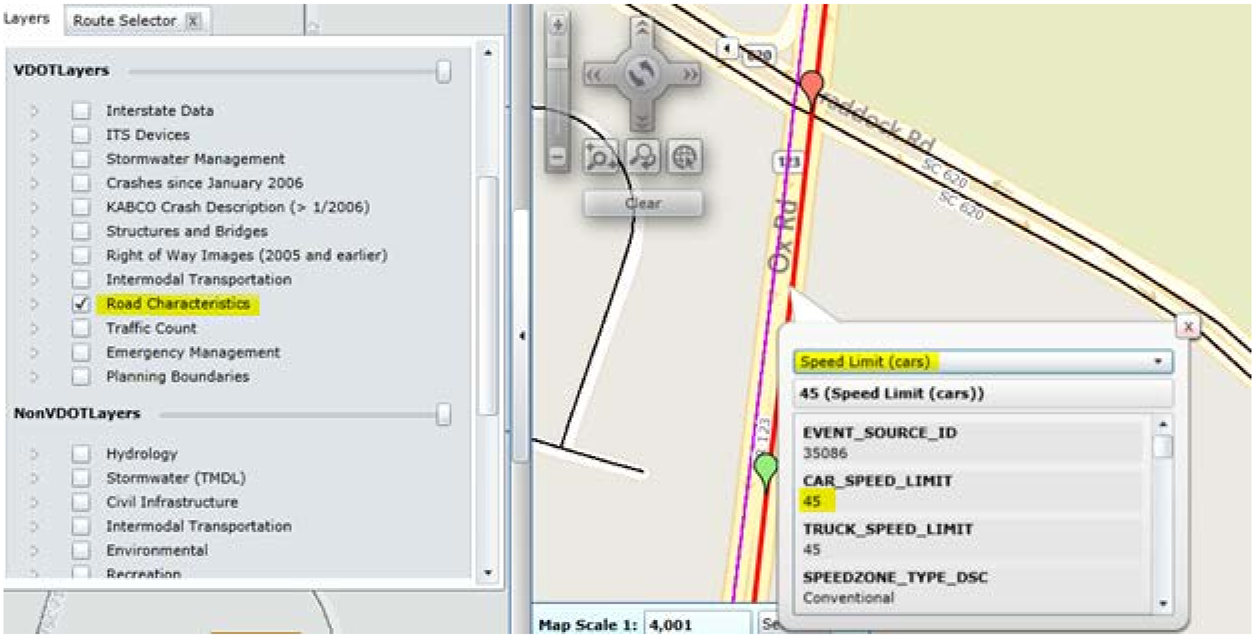


Figure C8. RNS Screenshot of Speed Limit for University Mall's Affected Road

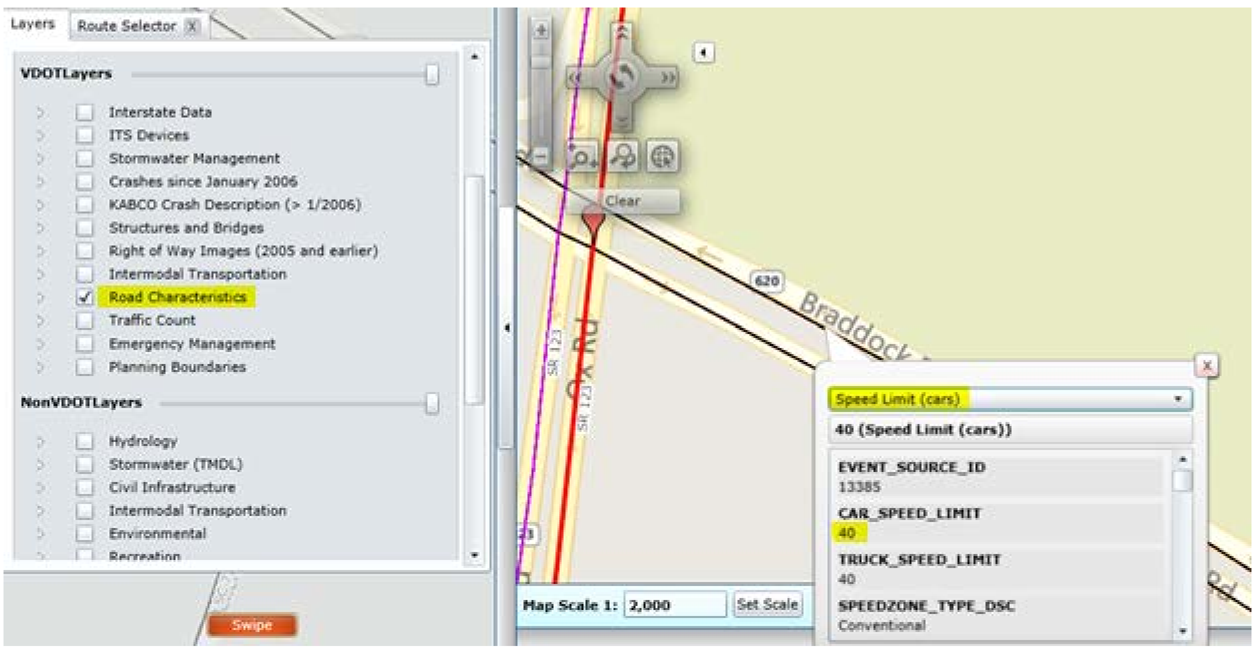


Figure C9. RNS Screenshot of Speed Limit for University Mall's Adjacent Road

10. Crash Data

Method 1

Continuing in RNS, the following steps are performed to find crashes for spacing standard exceptions:

1. Under the layers tab, select “Crashes.” Note that this step will result in five categories of crashes, and as of October 12, 2017, the layer is titled “Crashes since January 2006.” Note also that in the upper left corner of the screen, there are multiple “maps” that can be chosen; select the RNS map.
2. Select  icon in map pan/zoom tool.
3. Select aerial. Now zoom in directly to the point and make sure it is what you want. Then, change from aerial to street view and zoom in a bit more until the road (in black) is not overlapped by the RNS road (in red). Select analysis and then buffer in the toolbar.
4. Select buffer on point.
5. Click select point.
6. Place point at midpoint of the commercial and affected road intersection (see Figure C10).

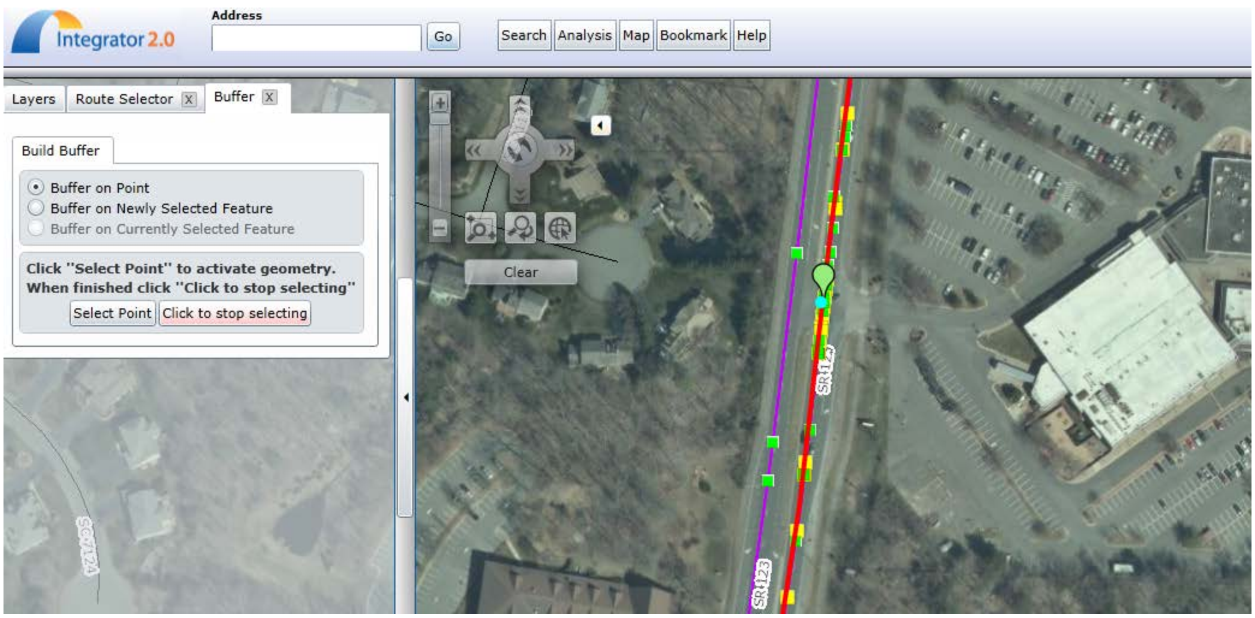


Figure C10. RNS Screenshot of Buffer Point (Blue Dot) at Midpoint of the Commercial and Affected Road Intersection. In aerial mode for visual representation. Use Street View during analysis.

7. Select “Click to stop selecting.”
8. Select “Create new buffer.”
9. Select buffer input layers:
   — non-pedestrian fatality
   — non-pedestrian injury
   — pedestrian fatality
   — pedestrian injury
   — property damage only.
10. Set buffer distance to 300 feet.
11. Select run.
12. Select “Run Report.”
13. Click OK in the reports viewer pop-up window.

14. Select  to export to Excel.
15. Open Excel, select all cells, and unclick “merge and center.”
16. Delete columns G&H.
17. Custom sort & filter by column F (crash dates), sort A to Z, and select “Sort anything that looks like a number, as a number.”
18. Select all entries from January 1, 2000, to present.
19. Cut and paste into new sheet in data table (sheet name—Site No.).

Method 2

A special note is applicable for using Method 2, discussed in the body of the report, to collect crashes. When collecting crashes with Method 2, a consistent method of establishing a crash region within an intersection is to use white stop bars as the perimeter of the intersection and the median line or strip as the center of the intersection. Within Integrator, the measure tool is used to mark the location of the stop bars and centerline, thereby delineating the boundary before using the polygon tool to collect the crashes. Figure C11 shows this process in establishing the Method 2 crash region where the shaded region represents the polygon’s capture area.

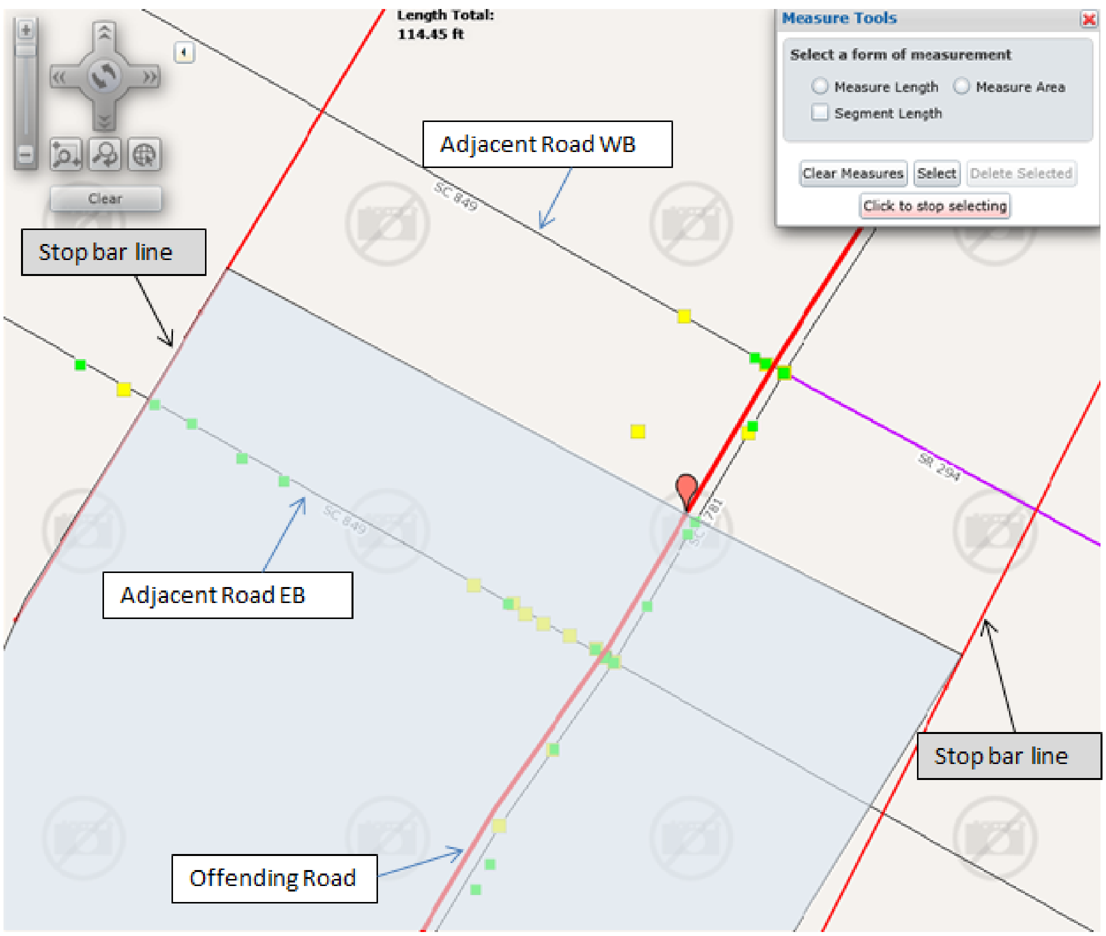


Figure C11. Method 2 Crash Region Example. Adapted from Integrator.

11. Functional Class

Go to VDOT's Roadway Inventory Management System (RIMS) at http://rims/ and perform the following procedures:

1. Select "Search" on main page.
2. Select district: Northern Virginia.
3. Select residency: Fairfax.
4. Enter route name/number for affected road: 123.
5. Select search route.
6. Select route (you may then select either direction).
7. Select milepoint in quick filter menu.
8. Enter milepoint range as found in *Milepost* section.
9. Select apply.
10. Select inventory tab.
11. In event layers menu, select functional class.

Figure C12 shows the resulting RIMS screenshot upon completion of the steps. Note the functional class of the affected road is principal arterial.

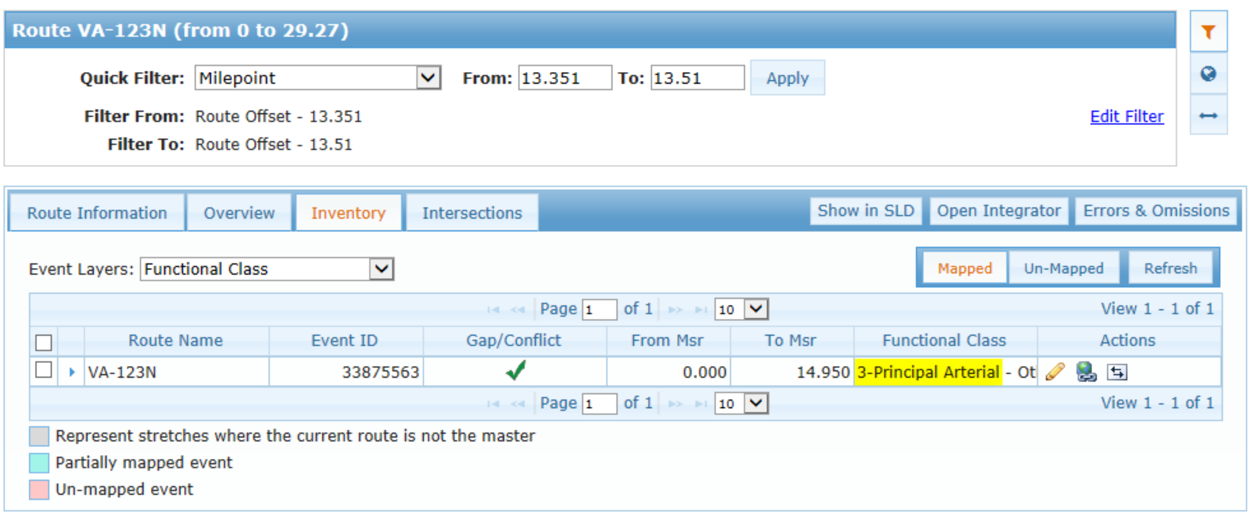


Figure C12. RIMS Screenshot of Functional Class for University Mall's Affected Road

12. Sidewalk

Continuing in RIMS, select sidewalk in the event layers menu and note the description as shown in Figure C13.

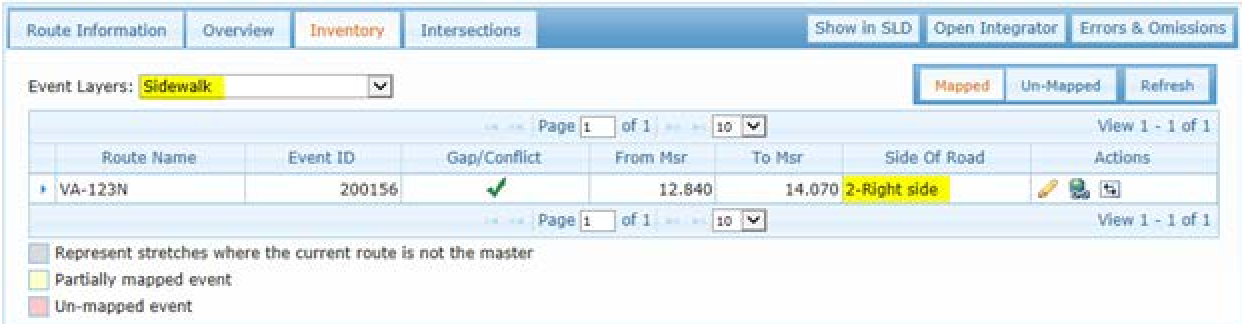


Figure C13. RIMS Screenshot of Sidewalk Description for University Mall's Affected Road

13. Bike Path

Continuing in RIMS, select bicycle accommodations in the event layers menu and note the description as shown in Figure C14.

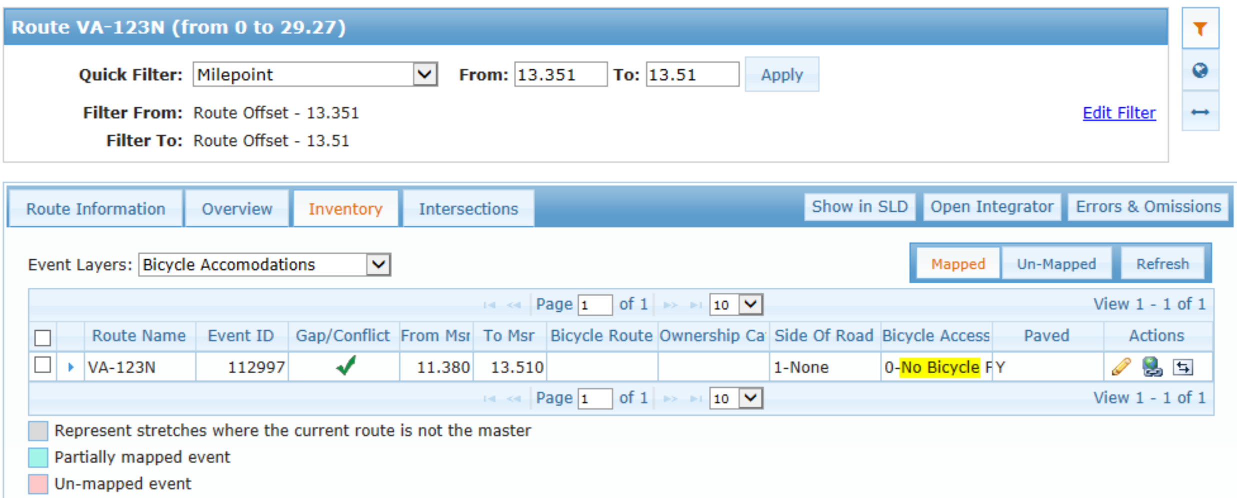


Figure C14. RIMS Screenshot of Bike Path Description for University Mall's Affected Road

14. Total Number of Through Lanes, Median Type, and Facility Type

In the Inventory tab of RIMS, select travelway in the event layers menu. Figure C15 shows the resulting page. The total number of through lanes, median type, and facility type for University Mall's affected road is 4, raised, and two-way divided, respectively.

Figure C15. RIMS Screenshot of Total Through Lanes, Median Type, and Facility Type for University Mall's Affected Road

To find the number of through lanes for the adjacent road and commercial entrance (if available), perform a separate search following the first 11 steps described previously for finding *functional class* and replace functional class with travelway in Step 12. To find the milepoint segment in RIMS, follow the steps for *Milepost* as described previously using RNS. For University Mall, use the adjacent road route number (SR 620) in the location search tab and then locate by "Distance from Intersection" the affected road (Ox Road, SR 123). The milepost segments to use in RIMS are 12.052 (Ox Road, VA123S) and 12.060 (Ox Road, VA123N). Figure C16 shows the resulting RIMS screenshot to find total number of through lanes for the adjacent road.

Figure C16. RIMS Screenshot of Total Through Lanes for University Mall's Adjacent Road

15. Intersection Type

Use Google Maps to identify intersection type of the commercial entrance and affected road intersection. Describe the intersection based on number of "legs" (typically 3 or 4) and whether it is a partial access (right turn in, right turn out) or full access (right and left turns in and out).

16. Traffic Control

Use Google Maps (and Street View if needed) to identify traffic control at the intersections of the affected road / adjacent road and commercial entrance / affected road. Figure C17 shows the Google Maps Street View of University Mall's affected (Ox Road) and adjacent road (Braddock Road) intersection, which is signalized. Figure C18 shows the Street View image of the commercial entrance and affected road (Ox Road) intersection, which is stop controlled.

Figure C17. Google Street View of Affected and Adjacent Road Intersection. Image Data © 2017 Google.

Figure C18. Google Street View of Commercial Entrance and Affected Road Intersection. Image Data © 2017 Google.

17. Dedicated Turn Lane

Use Google Maps and Street View to determine the number of dedicated turn lanes into the commercial entrance from the affected road. As shown in Figure C19, University Mall has two dedicated turn lanes on Ox Road into the commercial entrance.

Figure C19. Dedicated Turn Lanes Into the Commercial Entrance From the Affected Road. Map Data © 2017 Google.

18. Corridor Length

Length was determined based on the difference in mileposts (in Integrator) between the entrance (that was the subject of the exception request) and the location of the adjacent (offended) intersection. When the entrance was a private road and hence not on the VDOT network (and thus not in Integrator), the milepost in Integrator of the exception entrance had to be manually estimated.

19. At-Grade Intersections (Within 0.5 Miles)

Because of time limitations, these data were initially selected for the exception sites only. In RIMS, select the Intersections tab and re-adjust milepoints to account for ±0.5 miles on the affected road measured from the commercial entrance intersection. In the case of University Mall, the milepost of the commercial entrance intersection is 13.351; therefore, enter 13.851 and 12.851 in the from/to fields. Figure C20 shows the resulting RIMS screenshot. At-grade intersections are counted in the turn direction column. Labels of “BOTH” should be counted as two intersections, and blank “LT” or “RT” labels should be counted as one intersection. Figure C20 shows that for University Mall, the total number of at-grade intersections along the affected road within 0.5 miles in either direction of the commercial entrance is 13. Sometimes there may be more than one page of results. Adjust the number of results per page accordingly using the dropdown menu.

Route Information | Overview | Inventory | Intersections | Show in SLD | Open Integrator | Errors & Omissions

Page 1 of 1 | 10 | View 1 - 8 of 8

Route	Street	Measure	Turn Direction	Actions
Ox Rd	Ox Rd	12.86		Google | Integrator | Zoom To
Portsmouth RD SC-4406 E/W	Portsmouth Rd	12.88	BOTH	Google | Integrator | Zoom To
Ames ST SC-4405 E/W	Ames ST SC-4405 E/W	12.96	BOTH	Google | Integrator | Zoom To
Marlborough RD SC-4401 E/W	Marlborough Rd	13.04	BOTH	Google | Integrator | Zoom To
Braddock RD SC-620E	Braddock RD SC-620E	13.51	BOTH	Google | Integrator | Zoom To
Braddock RD SC-620W	Braddock RD SC-620W	13.519	BOTH	Google | Integrator | Zoom To
Kelley DR SC-1090 E/W	Kelley Dr	13.69	LT	Google | Integrator | Zoom To
Mason Park CT	Mason Park CT	13.73	RT	Google | Integrator | Zoom To

Page 1 of 1 | 10 | View 1 - 8 of 8

Search

Figure C20. RIMS Screenshot of Number of At-Grade Intersections on the Affected Road Within a 0.5-Mile Radius of the Commercial Entrance Intersection

20. At-Grade Intersections (Within 300 Feet)

Because of time limitations, these data were initially selected for the exception sites only.

Use Google Maps to determine the number of at-grade intersections on the affected road within a 300-foot radius of the commercial entrance. The measurement tool within Google Maps can be accessed by left clicking the midpoint of the commercial entrance and then right clicking to enable the mapping features menu. Figure C21 (*left*) shows how the tool is used to measure a distance that is 300 feet south of the commercial entrance. Figure C21 (*right*) shows the 300-foot range (600 feet total) as measured both south and north of the commercial entrance. The intersections within the 600-foot range should be counted and labeled as (1) number of single unit driveways, (2) number of multiple unit entrances, and (3) road intersections (including the adjacent road). For University Mall, the number of intersections within the measured distances is one multi-unit entrance.

For a single family detached dwelling unit only, a driveway with two entrances (e.g., a circular driveway) would be counted as a single entrance, with the rationale being that the number of vehicles using that driveway is so low that it can be treated as a single entrance. However, for an apartment building with two entrances to the parking lot, the number of entrances is counted as two, with the rationale being that it is quite possible both entrances could be used at the same time, given the larger number of vehicles using an apartment building.

Figure C21. ***Left:*** **Google Measurement Tool.** ***Right:*** **Single Multi-Unit Entrance Within a 300-Foot Radius of the Commercial Entrance on the Affected Road. Map Data © 2017 Google.**

Choosing Comparison Sites

For each exception site, at least one comparison site should be identified that best matches the exception site. The first subsection illustrates how to use visual inspection to identify candidate comparison sites. The second subsection illustrates how to apply detailed criteria to identify and then select comparison sites.

Identifying Comparison Sites (Simplified Examples)

Potential comparison sites in relation to the University Mall exception site are shown in Figure C22 and labeled (1a) the intersection of Route 123 and Canfield Street; (1b) the intersection of Route 123 and the entrances to One God Ministry Church and Commonwealth Health Rehab Center; and (1c) the intersection of Route 123 and Middlegate Road / Flora Lee Drive. Comparison sites will not have an affected road as previously; however, for data gathering purposes, references in this report to "affected road" when describing exception sites correlate to the roadway that the comparison site entrance intersects.

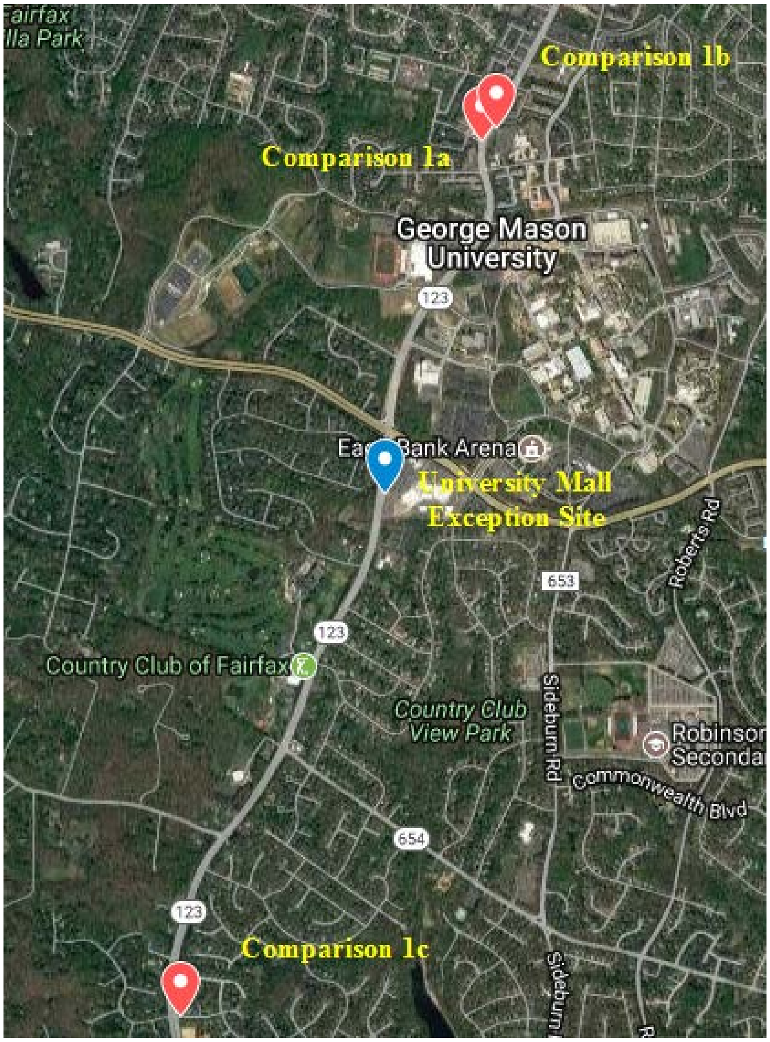


Figure C22. University Mall Exception Site and Its 3 Comparison Sites. 1a: The intersection of Route 123 and Canfield Street; 1b: the intersection of Route 123 and the entrances to One God Ministry Church and Commonwealth Health Rehab Center; 1c: the intersection of Route 123 and Middlegate Road / Flora Lee Drive. Imagery © 2017 Google, Map Data © 2017 Google.

Figure C23 shows a different exception site than the University Mall used in the previous section: a Callaway subdivision entrance on Route 2458 in Annandale that required a corner clearance exception because of its proximity to the Little River Turnpike / Willow Run Drive intersection. Note the labeling of the three roadway components: (1) the commercial entrance, (2) the affected road, and (3) the adjacent road.

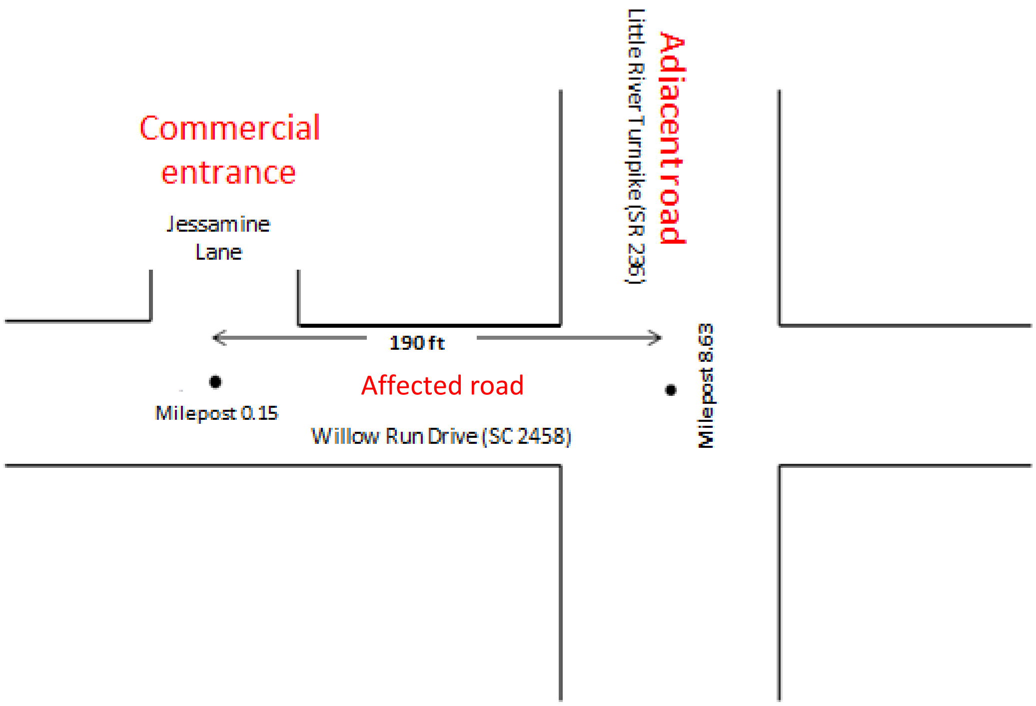


Figure C23. Callaway Subdivision Exception Site and Labeled Components

Potential comparison sites for the Callaway subdivision are shown in Figure C24 and labeled (2a) the Denude Med entrance on Medford Drive; (2b) the College Warehouse Building entrance (Warehouse Drive) on Lake Drive; and (2c) the CVS entrance on Woodburn Drive.

Figure C24. Callaway Subdivision Exception Site and Its 3 Comparison Sites. 2a: the Denude Med entrance on Medford Drive; 2b: the College Warehouse Building entrance (Warehouse Drive) on Lake Drive; 2c: the CVS entrance on Woodburn Drive. Imagery © 2017 Google, Map data © 2017 Google.

Selecting Comparison Sites: Detailed Examples

A third exception site is the Lucketts Community Center. The site requires a deviation from the corner clearance standard because there is 120 feet between the entrance on Route 662 (Lucketts Road) and Route 15; the required spacing is 305 feet (Figure C25, *left*). Ideally, a comparison site would be as shown in Figure C25 (*right*), where mythical Route 999 also intersects Route 15. On this mythical Route 999, there is another commercial location, with demand characteristics similar to those of the Lucketts Community Center. In fact, the only difference between the comparison site and the existing site is that this mythical community center intersect intersects Route 999 at least 305 feet away from Route 15.

Table C1 shows the application of the criteria for selecting three potential comparison sites for the Lucketts Community Center exception site. The last six rows of Table C1 also show additional information needed to replicate these results: the exception type, entrance location, location of the nearest existing intersection, distance from the commercial entrance to the existing intersection, latitude, and longitude. Approximately 5 hours were required to identify and collect the information shown in the three comparison sites, with approximately one-half the time devoted to finding the comparison sites.

Table C1 shows several challenges that can potentially result from choosing comparison sites. First, it may be more difficult to find appropriate comparison sites. Although the Northern Virginia District is generally considered urban, the Lucketts exception site in Loudoun County is a relatively rural site: a search for nearby businesses may reveal home business locations rather than larger establishments. Second, when one expands beyond a few miles from the exception site location, more candidate comparison sites become available, such as the first comparison site (Village Winery). However, the ADT on that road (160) is considerably lower than that at the exception site (1,800). Further, the comparison site's adjacent road (Route 665) will likely have a lower volume than the exception site's adjacent road (Route 15). Third, some data on local facilities are missing— notably, except for the school speed limits, speed limit data do not appear within VDOT databases (e.g., RNS, Integrator, and RIMS) for the three comparison sites.

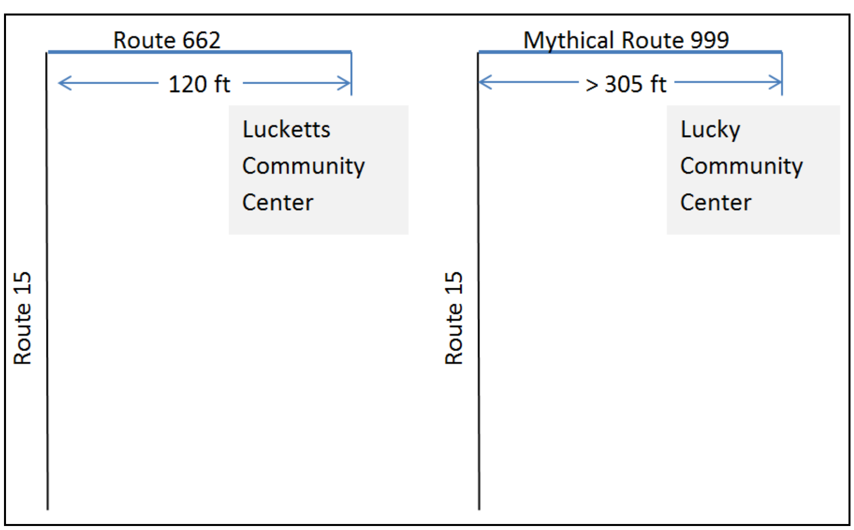


Figure C25. Lucketts Community Center Exception Site (*left*), and Ideal Comparison Site (*right*)

Table C1. Application of Comparison Site Criteria to the Lucketts Community Center

Tier	Characteristic	Exception Site	Comparison Site 1	Comparison Site 2	Comparison Site 3
1	Functional class	Local	Local	Local	Local
	Speed limit[a]	30 mph from the application	Not certain but likely 55 mph[b]	Not certain but likely 55 mph[b] (A school shows a temporary 25 mph limit)	Not certain but likely 55 mph[b] (A school shows a temporary 25 mph limit)
	Access immediately at the entrance	Full	Full	Full	Full
	Traffic control	Unsignalized	Unsignalized	Unsignalized	Unsignalized
	Evidence of commercial demand	Community Center (visible parking lot of roughly 60 spaces)	Village Winery and Vineyards (2014) indicates this business attracts traffic	Unknown business (visible parking lot of roughly 160 spaces)	Possibly a healthcare business (visible parking lot of roughly 120 spaces)
2	Median type (except immediately at the entrance)	Undivided	Undivided	Divided	Undivided
	Through lanes (sum of both directions)	2	2	4	2
	ADT	1,800	160 (VDOT, 2017b)	3,100	220 (VDOT, 2017b)
	Proximity to exception site	0.0 miles (Loudoun)	4.19 miles (aerial distance) (Loudoun)	24.86 miles (aerial distance) (Prince William)	5.14 miles (aerial distance) (Loudoun)
N/A	Exception type	Corner clearance	Corner clearance	Corner clearance	Corner clearance
	Entrance location	Route 662	Route 666	Route 3829	Route 740
	Nearest intersection	Routes 15 & 662	Routes 666 & 665	Routes 15 & 3829	Routes 15 & 740
	Distance from entrance to intersection	120 ft	358 ft	741 ft	1,168 ft
	Latitude	39.21573	39.18753	38.85813	39.14327
	Longitude	-77.53399	-77.60353	-77.64033	-77.54966
	Problems with comparison site (relative to the exception site)		• ADT on affected road is low • Adjacent intersection is not Route 15.	• Difference in number of lanes • Median is divided • Location is far away	• ADT is low • The site has two entrance points
	Decision with comparison sites		Reject as ADT is too low	Use if more than 1 site is necessary.	Use (best of the 3 sites)

[a] For roads in the local functional class only, differences in the speed limit category are tolerable because the design standards for local facilities are not affected by speed limits. However, roadways of similar speed limits are nonetheless preferable to roads with different speed limits.

[b] Speed limits for these roads are not available from the Integrator or RNS databases (VDOT, 2017d, e). Because unsigned secondary roads (roads numbered 600 and above) have a statutory speed limit of 55 mph (VDOT, 2017g), these facilities are believed by the research team to have a 55 mph speed limit. (An exception to this rule is secondary roads that have fewer than 4 lanes and are within a business or residence district; such roads have a speed limit of 25 mph (§ 46.2-874). However, the *Code of Virginia*, although using these terms, does not define a "business or residence district." One person familiar with speed limit databases in Virginia pointed out that determination of whether one is in such a district is a matter of engineering judgment (Curtis Myers, personal communication, June 19, 2017).

Figure C26 shows the exception site and the three comparison sites. A mitigating factor with comparison Site 3 appears to be that although the ADT is low, most of the ADT on that site appears attributable to the particular site, as VDOT (2017) shows that vehicle counts on Route 740 drop from 220 to 40 once beyond the site. Accordingly, it appears that Site 3 may be used if only one comparison site is required, which would be the case if a matched-pairs comparison is performed. However, if a more detailed approach (Wood and Porter, 2013) is used, Site 2 may be tolerable. It appears that Site 1 should be rejected given the very low volume on the facility.

Figure C26. Aerial Photos of Exception Site and 3 Comparison Sites. For Comparison Site 3, Imagery ©2017 Commonwealth of Virginia, DigitalGlobe, USDA Farm Service Agency, Map Data © 2017 Google. The other figures are based on Integrator (VDOT, 2017e).

APPENDIX D

DETAILS FOR USING THE LAND USE PERMIT SYSTEM (LUPS) WITH ACCESS EXCEPTION REQUESTS

Recommendations 1, 2, and 3 in the body of the report refer to a customized module developed by LUPS management.

Entering Exception Request Information Into LUPS

Commercial entrance permits that entail an exception request may be entered into LUPS using the following four steps based on that customized module:

1. Access LUPS by entering http://lups (see top of Figure D1).

2. Select permit/new permit (see bottom of Figure D1).

3. Select FX/attach and then select "CE-ER-Commercial Entrance Exception Request/provide link" (see Figure D2). Note that if there is not an exception request, the user would simply have chosen "CE-commercial entrance," which is also shown in Figure D2.

4. Select "CE-ER-Insert link to doc in the work description." Then, insert the hyperlink for the exception request (see Figure D3).

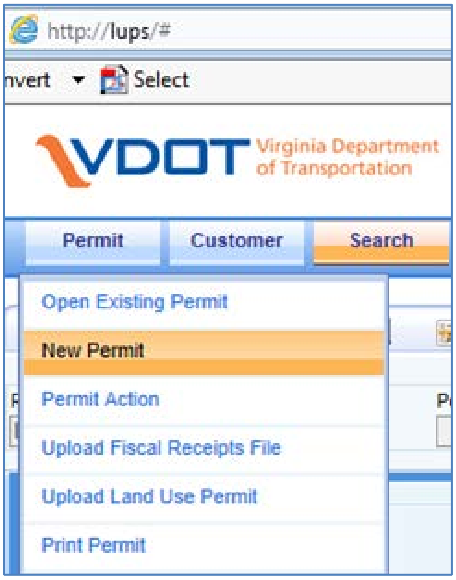


Figure D1. Accessing the Land Use Permit System (LUPS) to Enter Permit Data

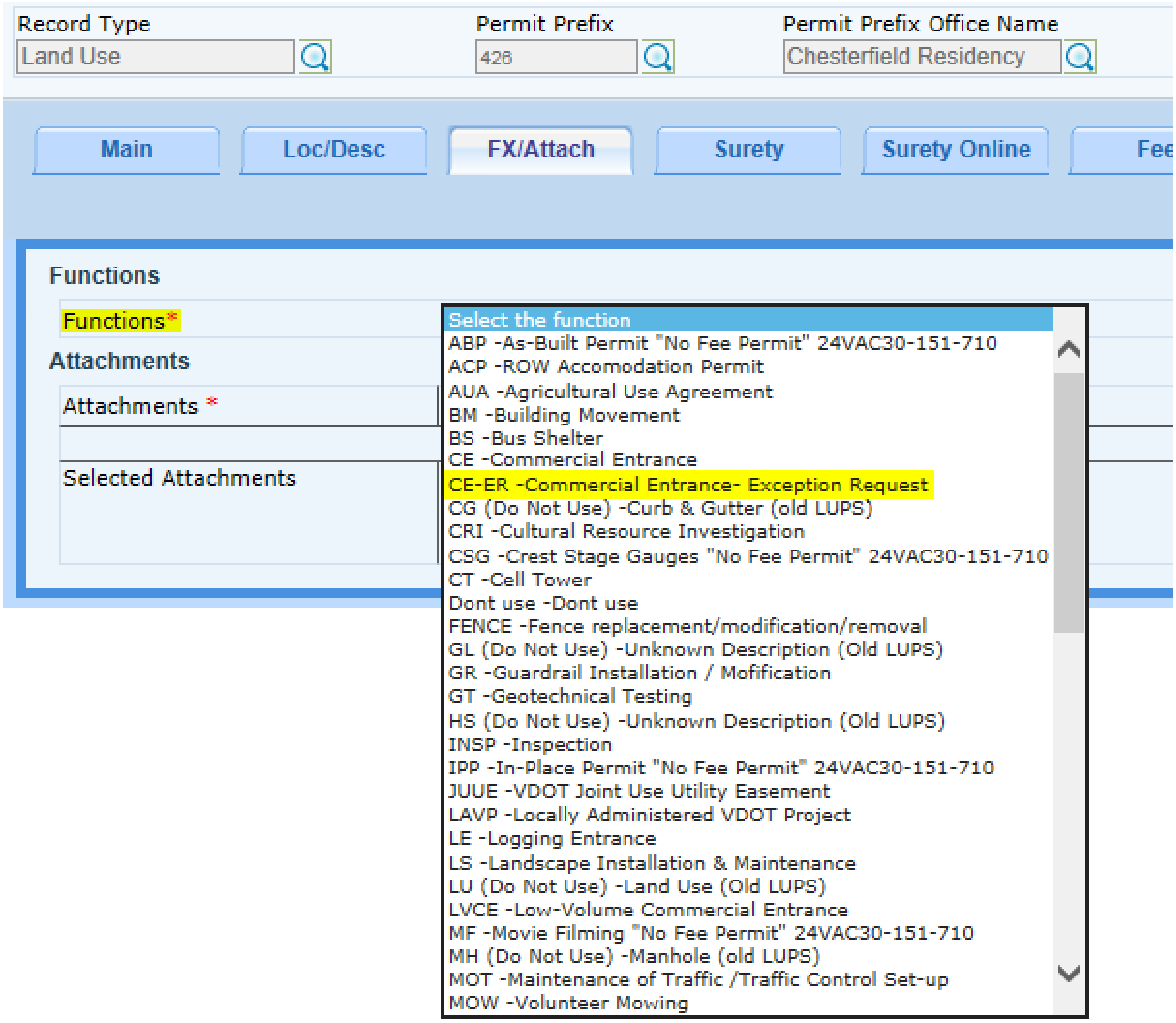


Figure D2. Entering a Permit for a Commercial Entrance. The user selects "CE-Commercial Entrance" if there is not an exception request. If there is an exception request, the user selects "CE-ER-Commercial Entrance Exception Request" in order to provide a link, as shown in Figure D3.

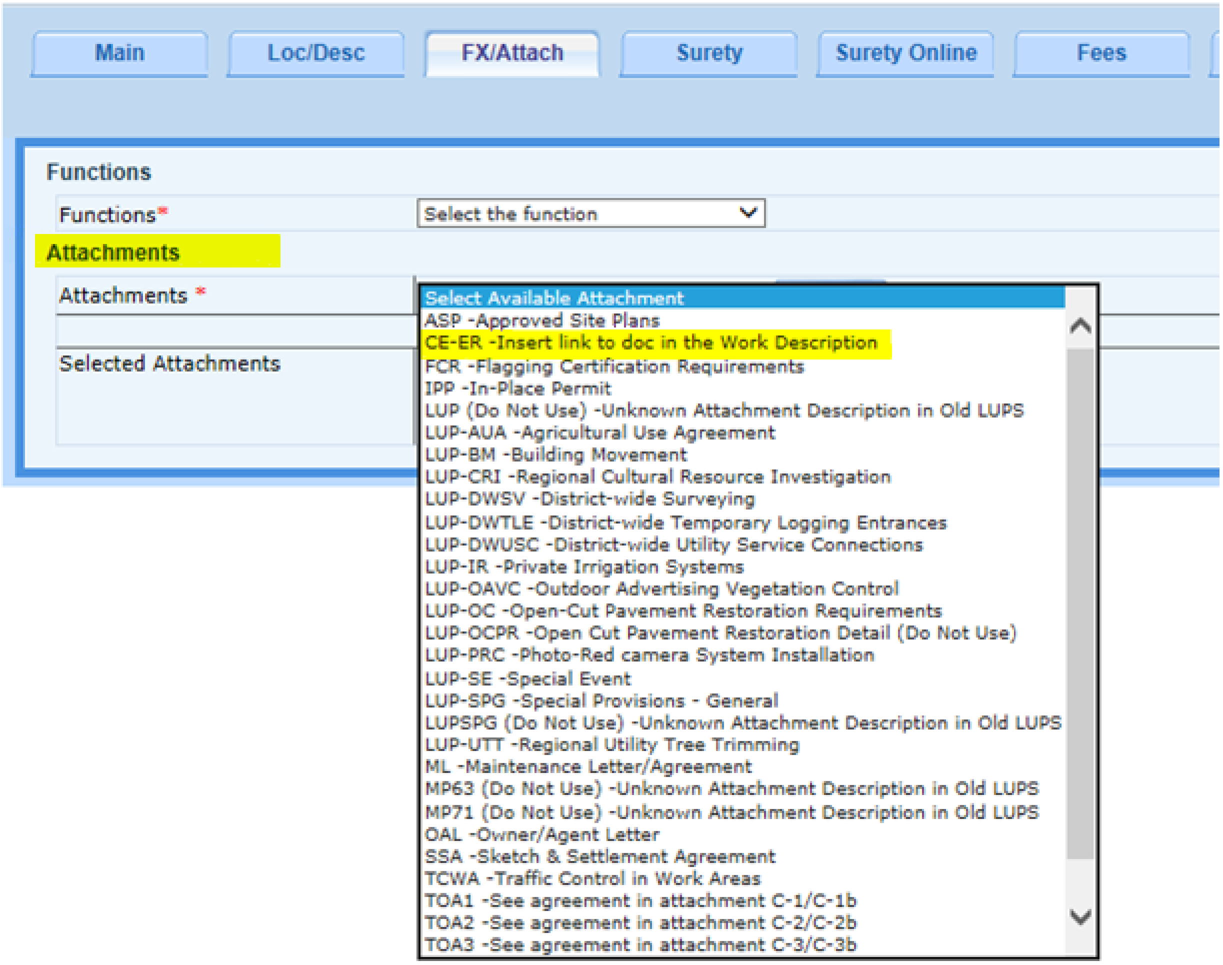


Figure D3. Adding a Link to an Access Management Exception Request

Using LUPS to Query Commercial Entrance Permits

Related to Recommendation 3, one may then determine which commercial entrance permits in LUPS require an exception request through five steps (where the fifth step is optional) based on the customized module in LUPS:

1. Access LUPS and select reports/view adhoc reports (Figure D4).

2. Under reports, select "Access Exception Requests Report" and then press "View Report" (Figure D5).

3. Under function name, select both "Commercial Entrance" and "CE-ER1" (Figure D6).

4. Enter an "Approval Date From," enter an "Approval Date to," select all route types, and select all permit statuses (Figure D7).

5. If desired, limit the results to one particular district (Figure D8). If statewide results are desired, this step may be skipped.

The results will be a listing of commercial entrances, including those that entail an exception request, for each district. For example, Figure D9 shows the results for the Staunton District. (At this point in time, Figure D9 simply shows all commercial entrance permits, but in the future, Figure D9 will distinguish those commercial entrances that did not require an exception request from those that do require an exception request.)

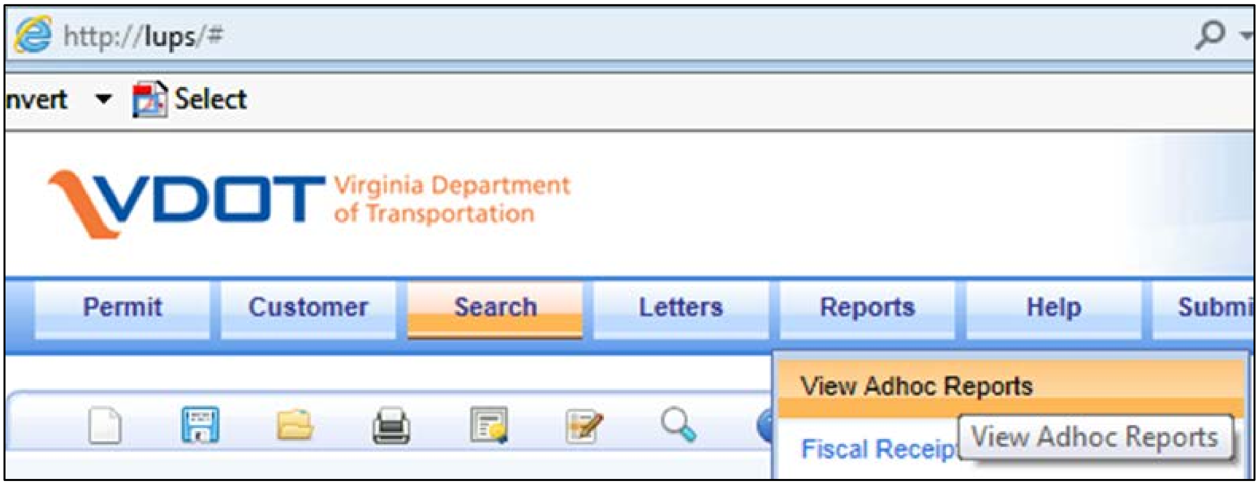


Figure D4. Accessing the Land Use Permit System (LUPS) to View Reports

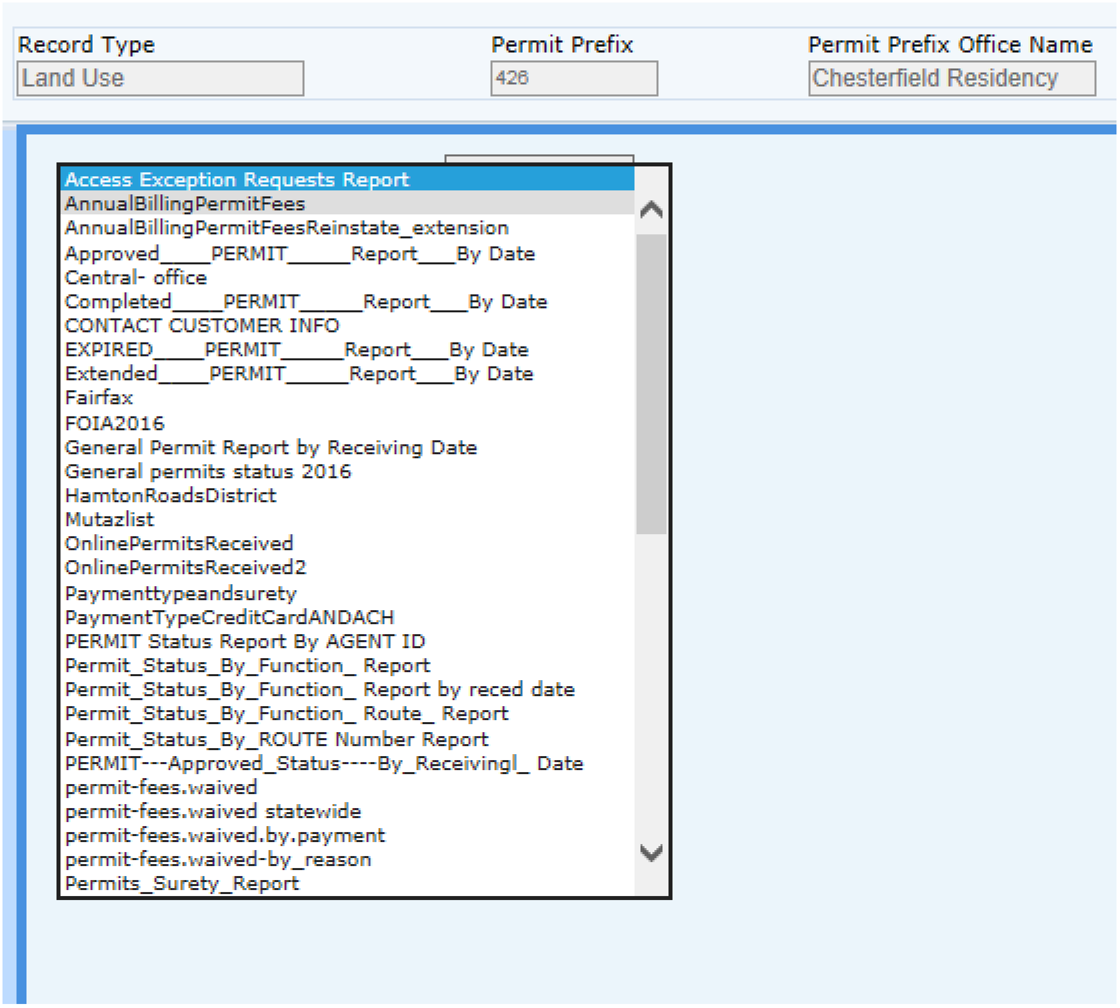


Figure D5. Changing the Report Type to "Access Exception Requests Report"

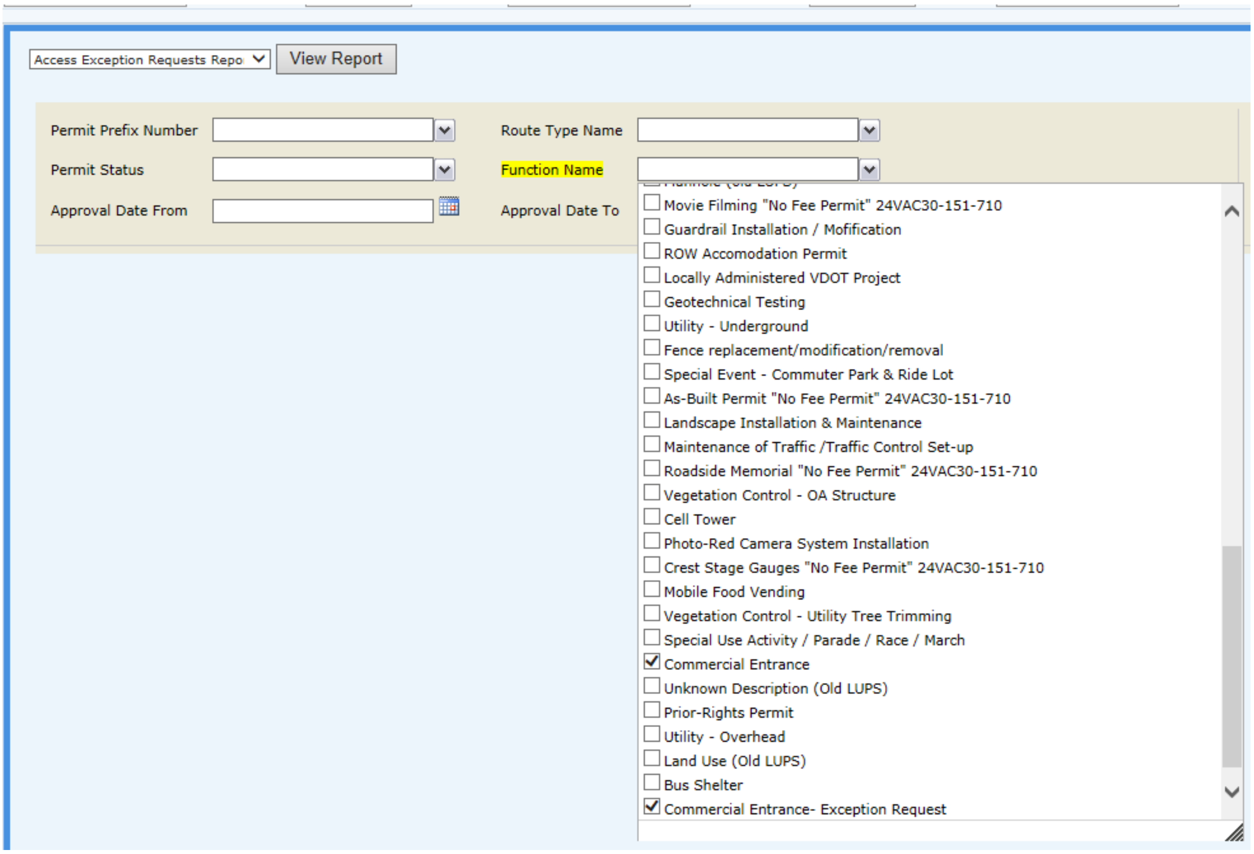


Figure D6. Selecting "Commercial Entrance" and "Commercial Entrance- Exception Request" Under Function Name

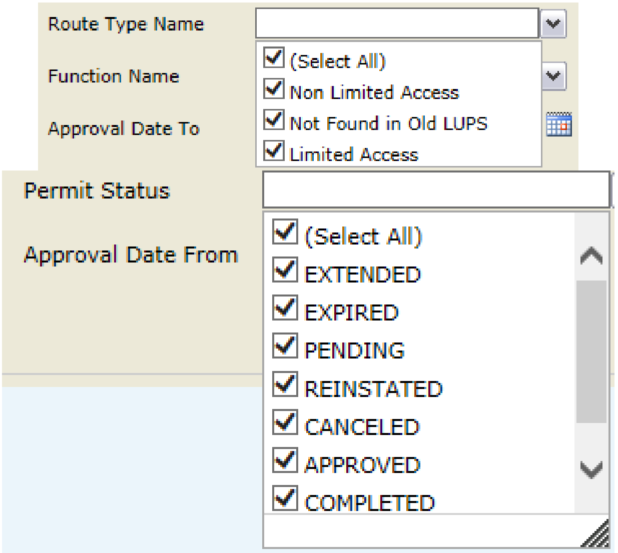


Figure D7. Setting Customer ID to Null, Selecting All Route Types, and Selecting All Permit Statuses

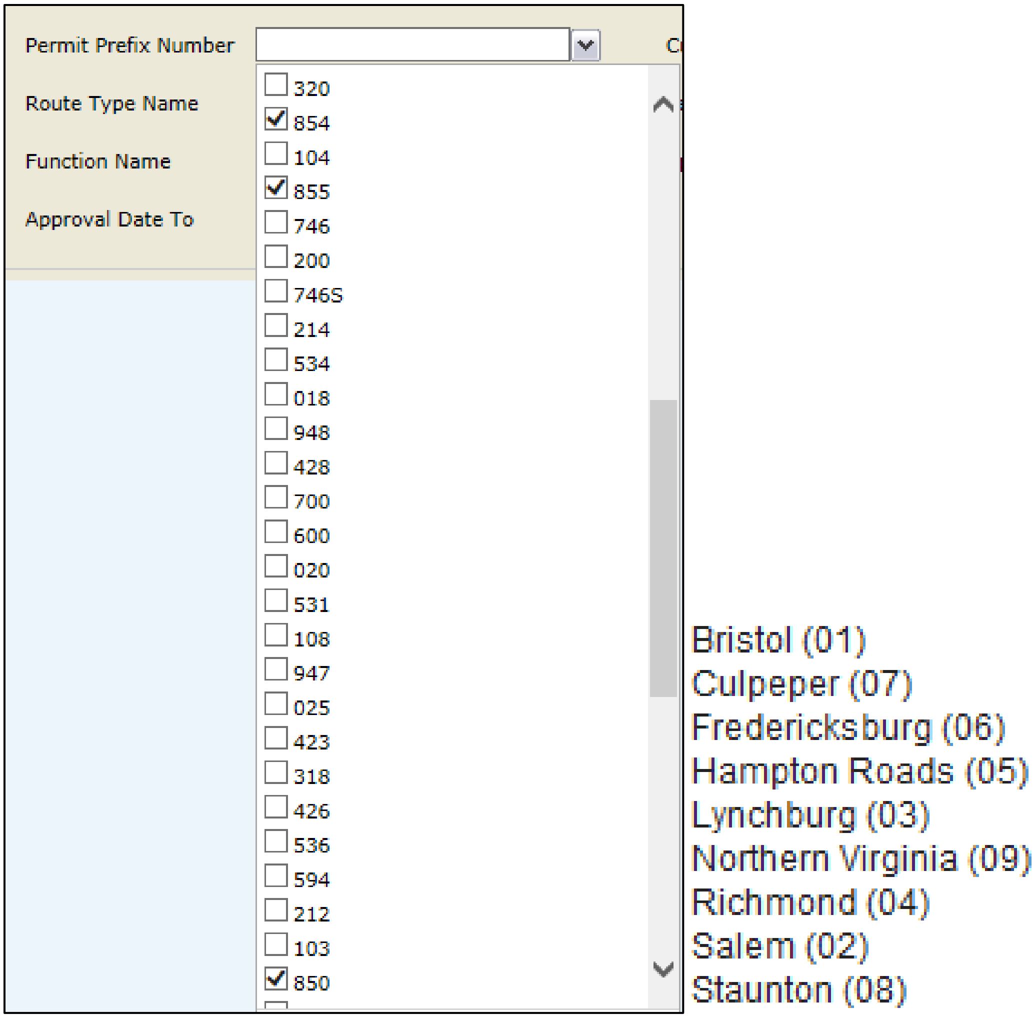
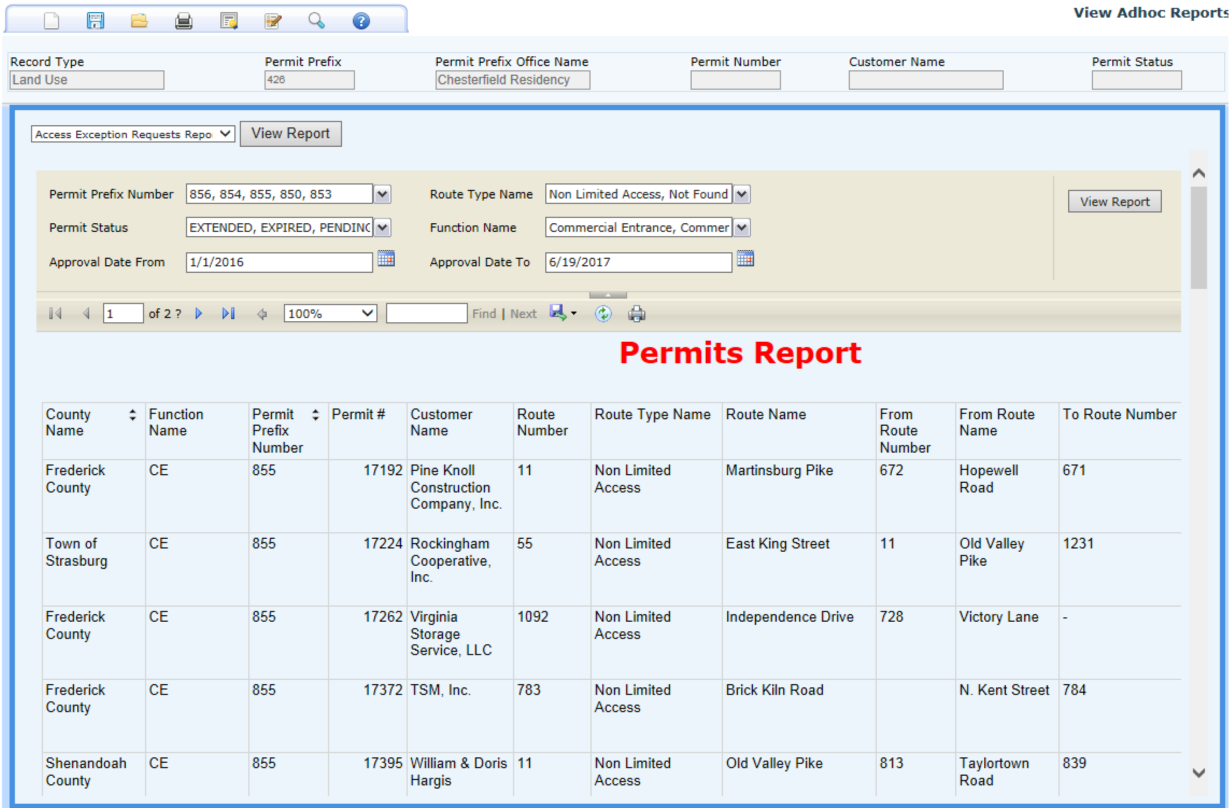


Figure D8. Limiting the Results to One District. For example, checking all permit prefixes that begin with "8" will limit results to the Staunton District.



County Name	Function Name	Permit Prefix Number	Permit #	Customer Name	Route Number	Route Type Name	Route Name	From Route Number	From Route Name	To Route Number
Frederick County	CE	855	17192	Pine Knoll Construction Company, Inc.	11	Non Limited Access	Martinsburg Pike	672	Hopewell Road	671
Town of Strasburg	CE	855	17224	Rockingham Cooperative, Inc.	55	Non Limited Access	East King Street	11	Old Valley Pike	1231
Frederick County	CE	855	17262	Virginia Storage Service, LLC	1092	Non Limited Access	Independence Drive	728	Victory Lane	-
Frederick County	CE	855	17372	TSM, Inc.	783	Non Limited Access	Brick Kiln Road		N. Kent Street	784
Shenandoah County	CE	855	17395	William & Doris Hargis	11	Non Limited Access	Old Valley Pike	813	Taylortown Road	839

Figure D9. Results for the Staunton District

APPENDIX E

SPACING STANDARDS OF OTHER STATES

Table E1. Signalized Spacing Standards From States Using Only Area Type and/or Classification Criterion

State	Area Type	Classification (Roadway or Area)	Spacing (ft)
Georgia	Urban Rural		1,320 2,640
Montana	Urban Rural	Major, Non-freeway	2,650 5,280
	Urban Rural	Minor	1,320 5,280
Nebraska	Rural/Urban	Undeveloped	1,000
Oregon	Urban Rural		2,640 5,280
South Carolina		Major Arterial Minor Arterial Collector Local	2,640 1,320 1,320 1,320
South Dakota	Urban/Rural	Expressway	2,640
	Urban	Free Flow Intermediate Developed Fringe	2,640 2,640 1,320 1,320
Utah	Urban Rural	System and Regional Priority	2,640 5,280
	Rural Urban	Regional Importance	2,640 1,320
	Rural Urban	Community Importance	1,320 1,320
Vermont	Urban Rural		1,320 2,460
Washington State		Class 1 Class 2 Class 3 Class 4 Class 5	5,280 2,640 2,640 2,640 1,320

Table E2. Spacing Standards From States With Signal Cycle Length and Speed Criteria

State	Cycle Length (sec)	Speed (mph)	Spacing (ft)
Illinois and New Jersey	60-150	25	1,100-2,640
		30	1,320-2,640
		35	1,540-2,640
		40	1,760-2,640
		45	1,980-2,640
		50	2,200-2,640
		55	2,430-2,640
Kansas	60-120	25	1,100-2,200
		30	1,320-2,640
		35	1,540-3,080
		40	1,760-3,520
		45	1,980-3,960
		50	2,200-4,400
		55	2,420-4,840
		60	2,640-5,280
		65	2,860-5,720
Nevada	60-180	20	880-2,640
		25	1,110-3,300
		30	1,320-3,960
		35	1,540-4,620
		40	1,760-5,280
		45	1,980-5,940
		50	2,200-6,600
		55	2,430-7,260
		60	2,640-7,920
		65	2,860-8,580

Table E3. Unsignalized Intersection or Full Median Spacing Standards

State	Roadway Functional Class	Area Type	Speed (mph)	Spacing (ft)
Tennessee		Urban Rural		440-880 880-1,760
Rhode Island		Rural Suburban/Urban		2,640 1,320
Arkansas		Suburban/Urban Rural		1,320 2,640
Arizona		Urban Rural		660 1,320
Georgia		Rural Urban		1,320 1,000
Illinois		Rural New Rural Existing Urban Existing		5,280 2,640 1,320/500[a]
Nebraska		Rural Undeveloped Urban		1,000 600
Utah	S-R R-S R-PU R-U C-R C-U O F-FR			1,000 660/500[b] 660/350[b] 350/200[b] 300/150[b] 300/150[b] 300/150[b] 660/NA
Washington State	Class 1 Class 2 Class 3 Class 4 Class 5			1,320 660 330 250 150
Kansas	B	Undeveloped Developed CBD	35-70 20-60 20-35	350-1,075 115-740 85-205
	C and D	Undeveloped Developed CBD	35-70 20-60 20-35	255-730 85-485 65-165
	E	Undeveloped Developed CBD	35-70 20-60 20-35	190-605 65-420 40-125
North Carolina			>45 ≤45	2,000 1,200
Vermont			20 25 30 35 40 45 50 55	115 155 200 250 305 360 425 495

[a]Expressway: 6 lanes / 4 lanes.
[b]Minimum street spacing / minimum driveway spacing.

Table E4. Oregon's Unsignalized Intersection or Full Median Spacing Standards

Roadway Functional Class	Area Type	Speed (mph)	Spacing (ft)
Regional, District, and Unclassified Highways (ADT ≤ 5,000)	Rural and Urban	≤25	150
		30-35	250
		40-45	360
		50	425
		≥55	650
State Highways (ADT ≤ 5,000)	Rural	≤25	550
		30-35	770
		40-45	990
		50	1,100
		≥55	1,320
	Urban	≤25	150
		30-35	250
		40-45	360
		50	1,100
		≥55	1,320
	Unincorporated Urban	≤25	350
		30-35	425
		40-45	750
		50	1,100
		≥55	1,320
State Highways ADT > 5,000	Rural	≤25	550
		30-35	770
		40-45	990
		50	1,100
		≥55	1,320
	Urban	≤25	350
		30-35	500
		40-45	800
		50	1,100
		≥55	1,320
Regional Highways ADT > 5,000	Rural	≤25	450
		30-35	600
		40-45	750
		50	830
		≥55	990
	Urban	≤25	250
		30-35	350
		40-45	500
		50	830
		≥55	990
District and Unclassified Highways	Rural	≤25	400
		30-35	400
		40-45	500
		50	550
		≥55	700
	Urban	≤25	250
		30-35	350
		40-45	500
		50	550
		≥55	700

Table E5. Restrictive or Partial Median Spacing Standards

State	Roadway Classification or Area Type	Entrance Type	Speed (mph)	Spacing (ft)
Alabama	2- Lane Rural	Right In	≤45 >45	125 440
		Right Out	≤45 >45	125 660
		Right In/Right Out	≤45 >45	250 660
	All Other	Right In	≤45 >45	250 440
		Right Out	≤45 >45	250 660
		Right In/Right Out	≤45 >45	275 660
Florida	Class 2	Restrictive with Service Roads	≤45 >45	660 1,320
	Classes 3-4	Restrictive and Non-Restrictive	≤45 >45	440 660
	Classes 5-6	Restrictive and Non-Restrictive	≤45 >45	245 440
	Class 7	Restrictive and Non-Restrictive	≤45 >45	125
Texas			≤30 35 40 45 ≥50	200 250 305 360 425
South Carolina	ADT ≥ 2000 (or > 50 peak hour trips)		30 35 40 45 ≥50	160 220 275 325 400
	ADT < 2000		30 35 40 45 ≥50	75 125 175 225 275
Georgia			25 30 35 40 45 50 55 60 65	125 125 150 185 230 275 350 450 550

APPENDIX F

VIRGINIA CRASH RATES AND NEGATIVE BINOMIAL MODELS

Crash Rates

Tables F1 through F11 show the crashes, normalized by year and by month, for each district and each method used in this study. The number of crashes per year will not necessarily be equal to the number of crashes per month because the former uses integer years only (in an effort to minimize seasonal disparities between the before and after period) whereas the latter can include a portion of a year (in an effort to maximize the quantity of data analyzed). The small numbers associated with the monthly data mean that others replicating these results may obtain slightly different *p*-values than those given in the report because of rounding. A more extreme instance of this discrepancy occurred with the ratio analysis based on Equation 2 in the body of the report, which is repeated here as Equation F1: when only Northern Virginia data are used, the paired *t*-test shows no significant difference with a *p*-value of 0.58 (if exact values are used), whereas a *p*-value of 0.48 is obtained (when the rounded values shown in Tables F1 and F2 are used). Another instance was where the use of 150-foot buffers showed no significant change in before-after crashes at 23 Northern Virginia District sites: a *p*-value of 0.89 is obtained with exact values compared to a *p*-value of 0.90 based on the rounded data in Table F4.

$$\text{Difference} = \frac{\text{After crash rate (exception site)}}{\text{Before crash rate (exception site)}} - \frac{\text{After crash rate (comparison site)}}{\text{Before crash rate(comparison site)}} \qquad \text{[Eq. F1]}$$

Table F1. Crash Rates at Northern Virginia District Exception Sites (Method 1)

	Crashes per Year			Crashes per Month		
Site	**Before**	**After**	**Difference**	**Before**	**After**	**Difference**
2	3.333	2.000	-1.333	0.278	0.167	-0.111
3	0.667	3.000	2.333	0.056	0.188	0.132
4	0.000	1.000	1.000	0.000	0.063	0.063
5	1.000	1.500	0.500	0.083	0.125	0.042
6	3.333	11.000	7.667	0.278	0.650	0.372
7	5.000	10.000	5.000	0.417	0.650	0.233
9	0.000	0.000	0.000	0.000	0.000	0.000
11	13.667	5.500	-8.167	1.139	0.545	-0.593
14	0.000	1.500	1.500	0.000	0.115	0.115
15	13.667	11.333	-2.333	1.139	0.917	-0.222
16	2.667	0.333	-2.333	0.222	0.028	-0.194
17	4.000	1.000	-3.000	0.333	0.111	-0.222
18	5.667	5.333	-0.333	0.472	0.444	-0.028
20	0.333	0.000	-0.333	0.028	0.000	-0.028
21	0.667	1.000	0.333	0.056	0.050	-0.006
22	0.333	0.000	-0.333	0.028	0.000	-0.028
24	14.000	12.000	-2.000	1.167	1.333	0.167
26	3.667	6.333	2.667	0.306	0.528	0.222
31	3.000	2.333	-0.667	0.250	0.194	-0.056
32	9.667	5.667	-4.000	0.806	0.472	-0.333
33	0.000	0.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000
35	7.333	9.333	2.000	0.611	0.722	0.111

Table F2. Crash Rates at Northern Virginia District Comparison Sites (Method 1)

	Crashes per Year			Crashes per Month		
Site	Before	After	Difference	Before	After	Difference
2	1.000	0.667	-0.333	0.083	0.056	-0.028
3	1.667	3.000	1.333	0.139	0.250	0.111
4	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	1.500	1.500	0.000	0.125	0.125
6	1.000	2.000	1.000	0.083	0.150	0.067
7	10.667	9.000	-1.667	0.889	0.850	-0.039
9	0.000	0.000	0.000	0.000	0.000	0.000
11	2.000	2.500	0.500	0.167	0.242	0.076
14	0.333	0.500	0.167	0.028	0.038	0.011
15	9.333	12.000	2.667	0.778	1.000	0.222
16	1.000	2.333	1.333	0.083	0.194	0.111
17	11.000	5.667	-5.333	0.917	0.472	-0.444
18	8.000	6.667	-1.333	0.667	0.556	-0.111
20	0.000	0.000	0.000	0.000	0.000	0.000
21	0.667	1.000	0.333	0.056	0.050	-0.006
22	0.667	0.000	-0.667	0.056	0.000	-0.056
24	7.000	4.000	-3.000	0.583	0.333	-0.250
26	1.667	3.000	1.333	0.139	0.250	0.111
31	1.000	2.000	1.000	0.083	0.167	0.083
32	2.667	1.000	-1.667	0.222	0.083	-0.139
33	0.000	0.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000
35	3.667	5.667	2.000	0.306	0.472	0.167

Table F3. Crash Rates at Northern Virginia District Exception Sites (Method 2)

	Crashes per Year			Crashes per Month		
Site	Before	After	Difference	Before	After	Difference
2	2.333	2.000	-0.333	0.194	0.167	-0.028
3	0.667	3.000	2.333	0.056	0.250	0.194
4	1.000	0.000	-1.000	0.083	0.063	-0.021
5	3.667	5.500	1.833	0.306	0.458	0.153
6	3.333	11.000	7.667	0.278	0.650	0.372
7	10.333	13.000	2.667	0.861	1.000	0.139
9	0.000	0.000	0.000	0.000	0.000	0.000
11	13.000	7.000	-6.000	1.083	0.515	-0.568
14	1.333	3.000	1.667	0.111	0.231	0.120
15	13.667	11.333	-2.333	1.139	0.944	-0.194
16	8.000	2.333	-5.667	0.667	0.194	-0.472
17	4.000	1.000	-3.000	0.333	0.083	-0.250
18	5.667	6.333	0.667	0.472	0.528	0.056
20	0.333	0.000	-0.333	0.028	0.000	-0.028
21	2.667	4.000	1.333	0.222	0.350	0.128
22	0.667	1.000	0.333	0.056	0.150	0.094
24	22.333	19.000	-3.333	1.861	1.583	-0.278
26	3.667	6.333	2.667	0.306	0.528	0.222
31	3.000	3.000	0.000	0.250	0.250	0.000
32	9.667	6.333	-3.333	0.806	0.528	-0.278
33	0.000	0.667	0.667	0.000	0.056	0.056
34	0.000	0.000	0.000	0.000	0.000	0.000
35	7.333	9.333	2.000	0.611	0.778	0.167

Table F4. Crash Rates at Northern Virginia District Exception Sites (150-foot Buffer)

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
2	0.000	0.000	0.000	0.000	0.000	0.000
3	0.667	0.000	-0.667	0.056	0.000	-0.056
4	0.000	0.000	0.000	0.000	0.000	0.000
5	0.333	0.500	0.167	0.028	0.042	0.014
6	3.333	11.000	7.667	0.278	0.650	0.372
7	2.333	7.000	4.667	0.194	0.400	0.206
9	0.000	0.000	0.000	0.000	0.000	0.000
11	0.667	0.000	-0.667	0.056	0.000	-0.056
14	0.000	0.000	0.000	0.000	0.000	0.000
15	7.000	5.667	-1.333	0.583	0.472	-0.111
16	2.333	0.333	-2.000	0.194	0.028	-0.167
17	2.000	0.000	-2.000	0.167	0.000	-0.167
18	2.000	1.667	-0.333	0.167	0.139	-0.028
20	0.333	0.000	-0.333	0.028	0.000	-0.028
21	0.667	1.000	0.333	0.056	0.150	0.094
22	0.000	0.000	0.000	0.000	0.000	0.000
24	8.333	7.000	-1.333	0.694	0.583	-0.111
26	1.667	2.667	1.000	0.139	0.222	0.083
31	0.667	0.000	-0.667	0.056	0.000	-0.056
32	0.000	0.000	0.000	0.000	0.000	0.000
33	0.000	0.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000
35	1.000	2.000	1.000	0.083	0.167	0.083

Table F5. Crash Rates at Northern Virginia District Exception Sites (150-foot Buffer, Omit 3 Months[a])

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
2	0.000	0.000	0.000	0.000	0.000	0.000
3	0.667	0.000	-0.667	0.056	0.000	-0.056
4	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.500	0.500	0.000	0.042	0.042
6	3.333	11.000	7.667	0.278	0.650	0.372
7	2.333	7.000	4.667	0.194	0.400	0.206
9	0.000	0.000	0.000	0.000	0.000	0.000
11	0.667	0.000	-0.667	0.056	0.000	-0.056
14	0.000	0.000	0.000	0.000	0.000	0.000
15	7.000	5.667	-1.333	0.583	0.472	-0.111
16	2.333	0.333	-2.000	0.194	0.028	-0.167
17	2.000	0.000	-2.000	0.167	0.000	-0.167
18	2.000	1.667	-0.333	0.167	0.139	-0.028
20	0.333	0.000	-0.333	0.028	0.000	-0.028
21	0.667	1.000	0.333	0.056	0.150	0.094
22	0.000	0.000	0.000	0.000	0.000	0.000
24	8.333	7.000	-1.333	0.694	0.583	-0.111
26	1.333	2.667	1.333	0.111	0.222	0.111
31	0.667	0.000	-0.667	0.056	0.000	-0.056
32	0.000	0.000	0.000	0.000	0.000	0.000
33	0.000	0.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000
35	1.000	2.000	1.000	0.083	0.167	0.083

[a]Unlike all other tables, in which only the month of construction was omitted from the crash rate calculations, this table omitted the month prior to the month of construction and the month following the month of construction.

Table F6. Crash Rates at Fredericksburg District Exception Sites (Method 1)

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
1	1.000	4.500	3.500	0.083	0.346	0.263
2	8.000	8.000	0.000	0.667	0.944	0.278
3	11.333	7.000	-4.333	0.944	0.789	-0.155
5	3.000	3.000	0.000	0.250	0.421	0.171
6	1.000	0.667	-0.333	0.083	0.056	-0.028
8	17.000	12.000	-5.000	1.417	1.000	-0.417
9	5.667	9.500	3.833	0.472	0.792	0.319
11	0.333	1.333	1.000	0.028	0.111	0.083
12	0.667	0.000	-0.667	0.056	0.000	-0.056
13	0.000	0.500	0.500	0.000	0.034	0.034
14	1.667	7.000	5.333	0.139	0.421	0.282
15	0.000	0.333	0.333	0.000	0.028	0.028
16	0.000	0.000	0.000	0.000	0.000	0.000
17	0.333	0.000	-0.333	0.028	0.000	-0.028

Table F7. Crash Rates at Fredericksburg District Exception Sites (Method 2)

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
1	1.000	4.500	3.500	0.083	0.346	0.263
2	8.333	8.000	-0.333	0.694	0.667	-0.028
3	11.333	7.000	-4.333	0.944	0.789	-0.155
5	3.000	3.000	0.000	0.250	0.421	0.171
6	1.000	0.667	-0.333	0.083	0.056	-0.028
8	17.000	12.000	-5.000	1.417	1.000	-0.417
9	7.000	10.500	3.500	0.583	0.875	0.292
11	1.667	2.333	0.667	0.139	0.194	0.056
12	0.667	0.000	-0.667	0.056	0.000	-0.056
13	0.000	0.500	0.500	0.000	0.034	0.034
14	1.667	7.000	5.333	0.139	0.421	0.282
15	0.000	0.333	0.333	0.000	0.028	0.028
16	0.000	0.000	0.000	0.000	0.000	0.000
17	0.333	0.000	-0.333	0.028	0.000	-0.028

Table F8. Crash Rates at Hampton Roads District Exception Sites (Method 1)

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
1	0.667	3.000	2.333	0.056	0.250	0.194
2	0.333	1.000	0.667	0.028	0.100	0.072
3	0.667	1.000	0.333	0.056	0.100	0.044
4	3.000	3.333	0.333	0.250	0.278	0.028
5	2.000	0.500	-1.500	0.167	0.063	-0.104
6	0.667	0.000	-0.667	0.056	0.000	-0.056
7	0.000	0.333	0.333	0.000	0.028	0.028
8	0.000	2.000	2.000	0.000	0.167	0.167
9	0.333	0.000	-0.333	0.028	0.000	-0.028
10	0.667	0.000	-0.667	0.056	0.000	-0.056
11	1.333	1.000	-0.333	0.111	0.083	-0.028
13	0.000	0.000	0.000	0.000	0.000	0.000

Table F9. Crash Rates at Hampton Roads District Exception Sites (Method 2)

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
1	1.000	3.000	2.000	0.083	0.250	0.167
2	0.667	1.000	0.333	0.056	0.100	0.044
3	0.667	1.000	0.333	0.056	0.100	0.044
4	3.000	3.333	0.333	0.250	0.278	0.028
5	2.000	0.500	-1.500	0.167	0.063	-0.104
6	0.667	0.000	-0.667	0.056	0.000	-0.056
7	1.000	2.000	1.000	0.083	0.167	0.083
8	1.000	3.333	2.333	0.083	0.278	0.194
9	0.333	0.000	-0.333	0.028	0.000	-0.028
10	0.667	0.000	-0.667	0.056	0.000	-0.056
11	1.333	1.000	-0.333	0.111	0.083	-0.028
13	0.000	0.000	0.000	0.000	0.043	0.043

Table F10. Crash Rates at Staunton District Exception Sites (Method 1)

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
1	0.667	0.667	0.000	0.056	0.056	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000
3	1.667	2.667	1.000	0.139	0.222	0.083
4	1.667	0.667	-1.000	0.139	0.056	-0.083
5	1.667	0.667	-1.000	0.139	0.056	-0.083
6	0.333	0.000	-0.333	0.028	0.000	-0.028
7	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000
9	0.333	0.000	-0.333	0.028	0.000	-0.028
13	0.000	1.000	1.000	0.000	0.083	0.083
15	6.333	7.500	1.167	0.528	0.625	0.097
16	0.333	0.667	0.333	0.028	0.056	0.028
17	0.000	1.000	1.000	0.000	0.083	0.083
18	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000

Table F11. Crash Rates at Staunton District Exception Sites (Method 2)

Site	Crashes per Year			Crashes per Month		
	Before	After	Difference	Before	After	Difference
1	0.667	0.667	0.000	0.056	0.056	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000
3	1.667	2.667	1.000	0.139	0.222	0.083
4	1.667	0.667	-1.000	0.139	0.056	-0.083
5	1.667	0.667	-1.000	0.139	0.056	-0.083
6	0.333	0.000	-0.333	0.028	0.000	-0.028
7	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000
9	0.333	0.000	-0.333	0.028	0.000	-0.028
13	0.000	1.000	1.000	0.000	0.083	0.083
15	6.333	7.500	1.167	0.528	0.625	0.097
16	0.333	1.000	0.667	0.028	0.083	0.056
17	0.000	1.000	1.000	0.000	0.083	0.083
18	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000

Negative Binomial Models

Overview

An initial experiment with the 23 Northern Virginia District exception and comparison sites (see Tables F1 and F2) was to develop a negative binomial regression model to forecast crashes per year (when collected via Method 1, i.e., 300-foot buffers at crash sites). The motivation for this approach was twofold: (1) to test whether there might be a tendency to allow exceptions at sites that had recently shown an unusually low crash rate (because of chance) but that otherwise had a higher crash rate, and (2) to experiment with a more powerful model that accounted for other factors not considered in the models described in the body of the report, such as speed limit or number of lanes. This experiment followed a method employed by Porter and Wood (2012) in which one seeks to forecast crashes as a function of multiple explanatory variables (such as speed limit or number of lanes). In this method, another independent variable is whether the site is an exception or comparison site during an after period—that is, after the site had been constructed. A variety of models were considered, three of which are presented herein, and these results appear consistent with those reported in the body of the report in that based on this particular dataset, presence of an exception request does not appear to be associated with a significant change in crash frequency. If comparison and treated sites were selected in a perfect manner, then ideally during the before period, the variable exception request will be highly insignificant (e.g., $p = 1.0$). During the after period, if this exception request period remains insignificant, then exception requests are not associated with a change in crash risk; by contrast, if this variable changes from an insignificant to a significant value, then exception requests are associated with a change in crash risk. After this analysis was performed with only the 23 Northern Virginia pairs of exception and comparison sites, the analysis was expanded to include all 64 pairs of sites in the Northern Virginia, Fredericksburg, Hampton Roads, and Staunton districts.

The negative binomial regression model is a more general form of the Poisson model (Molla and Muniswamy, 2012). The negative binomial distribution starts with a Poisson distribution and adds a multiplicative random effect (θ) in order to model overdispersion, where θ is assumed to follow a gamma distribution with parameters α and β. The mean is α/β, the variance is α/β^2, and $\alpha = \beta^2 = 1/\sigma^2$. The density function of the negative binomial distribution is given in Equation F2. The negative binomial distribution has mean μ and variance $\mu(1+\sigma^2\mu)$. If $\sigma^2 = 0$, the distribution reduces to the Poisson distribution (Rodriguez, 2013).

$$P(Y=y) = \frac{\Gamma(\alpha+y)}{y!\Gamma(\alpha)} \frac{\beta^{\alpha}\mu^{y}}{(\mu+\beta)^{\alpha+y}} \quad \text{[Eq. F2]}$$

Development of a Simple Model Based on Northern Virginia Data

To determine whether a model was feasible, two initial test models, one for the before period and one for the after period, were developed based on just four explanatory variables: presence of an exception request, natural log of ADT, natural log of the distance to the nearest intersection in feet, and presence of a full access intersection. The dependent variable is the number of crashes per year within a 300-foot buffer of the site. The reason for choosing these four variables is that they did not appear to be correlated, having a correlation of no more than 0.40. In the resultant model for the after period (see right of Table F12), the log of ADT had a *p*-value of 0.01(during the before period) and a p-value of 0.03 (during the after period), which suggested the variable was appropriate, as one would expect ADT to be significant. It was surprising, however, that for the before period, the exception request had a *p*-value of 0.23; because the exception request was not yet implemented, it would have been preferable, in terms of having identical comparison and exception sites, for the exception request to have a *p*-value of 1.00 during the before period. That said, Table F12 showed it should be feasible to develop a model with these data.

Table F12. Negative Binomial Regression (Simple Model)

Item[a]	**Before Period**		**After Period**	
	Estimate	***p*-value**	**Estimate**	***p*-value**
Intercept	-2.528	0.15	-1.774	0.28
Exception request	0.432	0.27	0.423	0.23
Ln(ADT)	0.379	0.01	0.308	0.03
Ln(Distance to nearest intersection (ft))	-0.074	0.82	-0.125	0.67
Full access	0.312	0.52	0.697	0.12
Dispersion parameter[b]	1.116		0.9083	
Log-likelihood of the fitted model	-103.39		-103.97	
Akaike information criterion (AIC)	218.78		219.95	

[a] The first 4 rows are independent variables used to forecast the crash rates. The fifth item (dispersion parameter) results from model calibration and is reported from SAS. The last 2 items (log-likelihood and Akaike information criterion) are goodness-of-fit measures.

[b] The dispersion parameter reported by SAS is the inverse of the dispersion parameter reported by R; the dispersion parameter reported by SAS is used herein. This was determined by the research team by comparing R and SAS results and is documented by Pesta (2017).

Development of a Full Model for Northern Virginia Without Scaling

A negative binomial regression model was then built using additional input data for both the before period and the after period. The results from this model are shown in Table F13. Similar results were obtained using two different software packages: R and SAS. Both sets of results are presented in Table F13, and although there are slight differences in some coefficients and significance levels, the interpretation of these results is the same.

Both Tables F12 and F13 include the Akaike information criterion (AIC), computed as 2(Number of variables including the intercept plus the dispersion parameter) - 2(log-likelihood). For the after period in Table F13, the log-likelihood of the model was -84.62; with 12 variables, an intercept, and a dispersion parameter; the AIC is 2*14-2*(-84.62) ≈ 197.25. Because the models in Table F13 have AIC values that are closer to 0 than the models in Table F12, the models in Table F13 have a nominally better fit than the test model.

Table F13. Negative Binomial Regression (Full Model) for Northern Virginia

Item	Before Period[a]		After Period[a]	
	Estimate	***p*-value**	**Estimate**	***p*-value**
Intercept	-6.041	0.03	-5.171 (-5.172)	<0.01
Exception request	0.264	0.35	0.308	0.10
Ln (ADT)	0.348	0.12 (0.15)	0.439	0.01
Ln(Distance to Nearest Intersection (ft))	0.029	0.91	0.011 (0.010)	0.94
Presence of a median	1.418	0.02	0.538	0.28
Total number of through lanes	-0.092	0.31	0.079	0.23
Speed limit ≤ 30 mph	4.619	<0.01	2.881	<0.01
Speed limit 35 to 45 mph	3.190	<0.01	1.376	0.02
Traffic control is a signal	0.662	0.20 (0.18)	0.563	0.09
Functional class is principal arterial	-0.264	0.76	-0.568	0.34
Functional class is minor arterial	-0.906	0.24 (0.22)	-1.431	0.01
Functional class is collector	-1.837	0.06 (0.05)	-1.782	0.03
Full access	-0.209	0.66 (0.65)	0.126	0.69
Dispersion parameter[b]	0.223		0.0000 (0.0001)	
Log-likelihood of a null model[c]	-107.251		-107.371 (-107.372)	
Log-likelihood of the fitted model	-85.325		-84.62	
Log-likelihood of the maximum achievable model[d]	-61.09 (-58.92)		-52.33 (-51.36)	
Akaike information criterion (AIC)	198.65		197.25	
McFadden pseudo R^2[e]	(0.20)		(0.21)	
Deviance	48.4667 (52.81)		64.5778 (66.52)	
Pearson chi-square statistic	48.0170 (43.86)		70.6789 (45.50)	

[a] Values in parentheses reflect results obtained from execution of the model in R; values outside parentheses reflect results from execution of the model in SAS. Values are the same if no parentheses are shown. Execution of the model in R yielded similar results with one exception: the Pearson chi-square statistic is different for the after period (45.50 rather than 70.68). However, the inferences based on that statistic do not change.
[b] The dispersion parameter is read directly from SAS and R. However, the dispersion parameter reported by R is the inverse of the dispersion parameter reported by SAS. After this inversion is taken into account, the parameters are identical for the before period and similar (0.0000 versus 0.0001) for the after period.
[c] The log-likelihood of a null model is estimated by executing a model with no parameters.
[d] The log-likelihood of a maximum achievable model is inferred from the relationship that deviance (which is reported by SAS) is equal to twice the difference between the log-likelihood of the maximum achievable model and the log-likelihood of the fitted model.
[e] The McFadden pseudo R^2 reported herein is based on the R software, which presumes a perfect model having a log-likelihood of 0. The general formula for determining the pseudo R^2, which is the ratio of the difference between the log-likelihoods of the fitted and null models to the difference between the log-likelihoods of the perfect and null models (Shtatland et al., 2000), thus simplifies to unity minus the ratio of the log-likelihoods of the fitted and null models. SAS does not report a pseudo R^2, but a different result for the McFadden pseudo R^2 will be obtained if one uses the "maximum achievable model" (UCLA Institute for Digital Research and Education, 2017a), which is calculated from the SAS estimate for the deviance, to estimate the log-likelihood of a perfect model.

Further, the likelihood ratio test suggests that the models in Table F13 have a statistically better fit than the models in Table F12. The likelihood ratio test compares twice the difference in the log-likelihood values for each model to the chi-square statistic based on the difference in the degrees of freedom between the two models. For example, twice the difference in the log-likelihood values for the after period, based on Tables F12 and F13, is 2*(-84.62 + 103.97) = 38.7. One compares this to the chi-square statistic associated with 13 - 5 = 8 degrees of freedom; since the former is larger than the latter ($p < 0.01$), the difference is significant.

For the after period, the independent variables of ADT, speed limit, and functional class were significant. Traffic control ($p = 0.09$) and presence of an exception request ($p = 0.10$) were not significant at the 95th percentile level but were significant at the 90th percentile level. For the after model, it is surprising that presence of a median has a positive (rather than a negative) coefficient, as the model would suggest presence of a median is associated with an increase in crash risk.

As the dependent variable is the natural log of the crash rates, the exponential function is used to interpret the independent variables (UCLA Institute for Digital Research and Education, 2017b). For instance, because presence of an exception request has a coefficient of 0.308, the model indicates that the expected number of crashes per year increases by exp (0.308) = 1.36 if this term is statistically significant.

Development of a Full Model for Northern Virginia With Scaling

The research team was not aware of a firm rule for determining the necessary number of samples to fit a negative binomial regression model. However, unlike the hypothesis testing performed in the study (e.g., the paired *t*-test or the Wilcoxon signed rank test) or the small models in Table F12, the models in Table F13 have a large number of variables (12) not including the intercept. Given the relatively small sample size of 46 (from 23 comparison sites and 23 exception sites) compared to this large number of variables, the team reviewed additional literature to identify any additional modeling concerns beyond the likelihood ratio tests used previously. The literature suggested two possibilities applicable to the models in Table F13:

1. One concern is the ratio of the deviance to the degrees of freedom associated with the after period model in Table F13 (UCLA Institute for Digital Research and Education [2017a]). (Deviance is twice the difference between the log-likelihood of the fitted model and the log-likelihood of a perfect model that replicated each observed data element; Table F13 shows this to be 2*(-52.331 minus a negative 84.62) = 64.58.) With 46 samples – (12 variables plus an intercept) = 33 degrees of freedom, the ratio is 64.58/33 = 1.96. The UCLA Institute for Digital Research and Education (2017a) suggested that this ratio should be close to 1.0 and that when this is not the case, an alternative is to scale the deviance (using the command scale = dscale or DEVIANCE in SAS).

2. Another concern is the Pearson chi-square statistic, which is the “squared difference between the observed and predicted values divided by the variance of the predicted value summed over all observations in the model” (UCLA Institute for Digital

Research and Education, 2017a). Related literature suggested that "a low p-value from this test suggests misspecification or other problems with the model" where the test is to compare the reported Pearson chi-square statistic with the appropriate value from the chi-square distribution (which in this case would have 33 degrees of freedom). The *p*-value for that test, i.e., CHIDIST(70.68,13), is significant ($p <$ 0.001). (Although R gives a different Pearson chi-square statistic of 45.50 as indicated in the footnote of the table, the same test also yields a highly significant *p*-value smaller than 0.001.)

A revised model that addresses these two concerns is shown on the left side of Table F14, and for comparison, the after model from Table F13 is shown on the right side. Generally the coefficients do not change; however, because the standard errors are larger, the *p*-values have changed. By addressing the first concern (where the deviance divided by the degrees of freedom now has a value of 1 rather than 1.8 in Table F13), the second concern appears to be resolved: using the scaled Pearson chi-square statistic, the *p*-value is found to be 0.32, where a non-significant value suggests a decent model fit (UCLA Institute for Digital Research and Education, 2017b).

Table F14. Negative Binomial Regression (After Period, Scaled) for Northern Virginia[a]

Item	After Period With Scaling		After Period Without Scaling (From Table F13)	
	Estimate	***p*-value**	**Estimate**	***p*-value**
Intercept	-5.1710	0.04	-5.17	<0.01
Exception request	0.308	0.24	0.308	0.10
Ln (ADT)	0.439	0.05	0.439	0.01
Ln(Distance to the nearest intersection (ft))	0.011	0.96	0.011	0.94
Presence of a median	0.538	0.44	0.538	0.28
Total number of through lanes	0.079	0.39	0.079	0.23
Speed limit ≤ 30 mph	2.881	<0.01	2.881	<0.001
Speed limit 35 to 45 mph	1.376	0.08	1.376	0.02
Traffic control is a signal	0.563	0.23	0.563	0.09
Functional class is principal arterial	-0.568	0.49	-0.568	0.34
Functional class is minor arterial	-1.431	0.05	-1.431	0.01
Functional class is collector	-1.782	0.13	-1.782	0.03
Full access	0.1256	0.78	0.126	0.69
Dispersion parameter	0.0000		0.0000	
Log-likelihood of a null model	-107.37		-107.37	
Log-likelihood of the fitted model	-84.62		-84.62	
Log-likelihood of a perfect model	-52.334		-52.33	
Akaike information criterion (AIC)	197.25		197.25	
Scaled deviance	33.0000		64.5778	
Scaled Pearson chi-square statistic	36.1177		70.6789	

[a] Values are based on execution of SAS.

Development of a Full Model for All 64 Sites

A comment received during the executive review was that the use of additional data might provide different insights than those previously obtained. The research team thus collected additional comparison site data such that full models, with and without scaling, could be developed for all 64 comparison sites—that is, not only those sites in Northern Virginia

(Table F2) but also those in the Fredericksburg, Hampton Roads, and Staunton districts (Table F15).

Table F15. Additional Comparison Site Data From Fredericksburg, Hampton Roads, and Staunton[a]

District	Site	Adjusted - 1 Year		
		Before	After	Difference
Fredericksburg	1	1.667	0.500	-1.167
	2	6.667	2.667	-4.000
	3	10.333	8.000	-2.333
	5	7.000	9.000	2.000
	6	0.000	0.333	0.333
	8	1.333	5.000	3.667
	9	3.667	2.500	-1.167
	11	0.333	0.333	0.000
	12	0.000	0.000	0.000
	13	1.000	0.500	-0.500
	14	1.333	1.000	-0.333
	15	0.333	0.333	0.000
	16	0.000	0.000	0.000
	17	0.000	0.000	0.000
Hampton Roads	1	0.000	1.000	1.000
	2	0.333	0.000	-0.333
	3	1.000	3.000	2.000
	4	0.000	0.667	0.667
	5	0.667	0.500	-0.167
	6	0.000	1.000	1.000
	7	0.333	0.667	0.333
	8	0.000	0.000	0.000
	9	0.667	0.000	-0.667
	10	0.667	0.000	-0.667
	11	0.000	1.000	1.000
	13	0.333	0.000	-0.333
Staunton	1	0.333	0.000	-0.333
	2	0.333	0.000	-0.333
	3	0.000	0.000	0.000
	4	0.000	0.667	0.667
	5	0.000	0.000	0.000
	6	0.333	0.000	-0.333
	7	0.000	0.000	0.000
	8	0.000	0.000	0.000
	9	0.000	0.667	0.667
	13	0.000	0.333	0.333
	15	0.333	0.000	-0.333
	16	1.000	1.000	0.000
	17	0.000	0.000	0.000
	18	0.000	0.000	0.000
	19	0.000	0.000	0.000

[a] These data are comparable to those shown in Table F2 except they are from districts other than the Northern Virginia District.

The results, shown in Tables F16 and F17, generally show that exception requests are significant in the after period—yet they are also significant during the before period. That is, without scaling, exception requests had a *p*-value of 0.04 (before) and 0.02 (after). The ratio of deviance to degrees of freedom is 146.15 / (128 samples – 12 variables plus an intercept) = 1.27, which is closer to a value of 1.0 (the ideal value noted in UCLA Institute for Digital Research and Education [2017a]) than the ratio from Table F13, which was 1.96. This may explain why with scaling, results were similar. Table F17 shows that with scaling, the *p*-values for exception requests were 0.03 (before) and 0.04 (after).

Tables F16 and F17 suggest that there was some type of difference between exception and comparison sites. It is possible that this difference is attributed to some variable not in the model (e.g., some variable besides those named in Table F16 such as traffic control, median presence, speed limit, and ADT). It is also possible that, as discussed in the body of the report, the dependent variable used in Equation F2 is more sensitive to differences between exception and comparison sites than the dependent variable used in Equation F1. However, the difference does not appear to be attributable to the presence of the exception request, since the significance level and the coefficient remained relatively constant prior and following the construction of the site with the exception request. (In fact, the coefficient for exception requests shows a nominal decrease from the before period to the after period.)

Table F16. Negative Binomial Regression Full Model: All 64 Sites, No Scaling[a]

Item	Before Period		After Period	
	Estimate	*p*-value	Estimate	*p*-value
Intercept	-6.816	<0.01	-7.052	<0.01
Exception Request	0.484	0.04	0.467	0.02
Ln (ADT)	0.674	<0.01	0.730	<0.01
Ln(Distance to nearest intersection (ft))	-0.027	0.89	-0.089	0.58
Presence of a median	0.485	0.20	0.209	0.53
Total number of through lanes	0.062	0.50	0.183	0.02
Speed limit ≤ 30 mph	3.028	<0.01	2.359	<0.01
Speed limit 35 to 45 mph	1.905	<0.01	1.246	<0.01
Traffic control is a signal	0.949	0.03	0.410	0.26
Functional class is principal arterial	-1.650	<0.01	-1.560	<0.01
Functional class is minor arterial	-1.938	<0.01	-2.147	<0.01
Functional class is collector	-1.250	0.04	-1.085	0.03
Full access	-0.399	0.23	0.444	0.12
Dispersion parameter[a]	0.511		0.26	
Log-likelihood of a null model	-240.59		-246.66	
Log-likelihood of the fitted model	-193.91		-197.41	
Log-likelihood of the maximum achievable model [a]	-126.57		-124.34	
Akaike information criterion (AIC)	415.83		422.82	
McFadden pseudo R^2 [a]	0.19		0.20	
Deviance	134.68		146.15	
Pearson chi-square statistic	93.36		98.51	

[a] All values calculated from R. However, the inverse of the dispersion parameter from R was reported here in order to make the dispersion parameter consistent with SAS.

Table F17. Negative Binomial Regression Full Model: All 64 Sites With Scaling[a]

Item	Before Period [a]		After Period[a]	
	Estimate	***p*-value**	**Estimate**	***p*-value**
Intercept	-6.8162	<0.01	-7.0519	<0.01
Exception Request	0.4841	0.04	0.4672	0.03
Ln (ADT)	0.6737	<.01	0.7300	<0.01
Ln(Distance to nearest intersection (ft))	-0.0274	0.89	-0.0892	0.61
Presence of a median	0.4849	0.20	0.2087	0.57
Total number of through lanes	0.0621	0.53	0.1831	0.03
Speed limit ≤ 30 mph	3.0280	<.01	2.3590	<0.01
Speed limit 35 to 45 mph	1.9050	<0.01	1.2461	0.01
Traffic control is a signal	0.9492	0.05	0.4097	0.32
Functional class is principal arterial	-1.6502	0.02	-1.5596	0.01
Functional class is minor arterial	-1.9380	<0.01	-2.1472	<0.01
Functional class is collector	-1.2498	0.06	-1.0852	0.06
Full access	-0.3992	0.26	0.4439	0.18
Dispersion parameter[b]	0.5110		0.26	
Akaike information criterion (AIC)	415.8272		422.8158	
Scaled deviance	115.0000		115.0000	
Scaled Pearson chi-square statistic	148.1816		150.0437	

[a] Values obtained from SAS.